Sun. Jul 12, 2020

[E] Oral | U (Union)：Union

9:00 AM - 10:30 AM JST | 12:00 AM - 1:30 AM UTC | Ch.1

[U-11] Planetary Metabolism: The Science of Living Worlds

convener:Anbar Ariel D(Arizona State University), John W Hernlund(Earth-Life Science Institute), Hilairy Ellen Hartnett(Arizona State University), ryuhei nakamura(Tokyo Institute of Technology, Earth-Life Science Institute), Chairperson:Ariel D Anbar(Arizona State University), Hilairy Ellen Hartnett(Arizona State University), John W Hernlund(Earth-Life Science Institute), ryuhei nakamura(Tokyo Institute of Technology, Earth-Life Science Institute)

9:00 AM - 9:15 AM JST | 12:00 AM - 12:15 AM UTC

[U11-01] Syngeosis: Application of the Principles of Symbiosis to Geological Processes

*John W Hernlund[1] (1.Earth-Life Science Institute)

9:15 AM - 9:30 AM JST | 12:15 AM - 12:30 AM UTC

[U11-02] Redox Revolutions on Earth and Beyond

*Ariel D Anbar[1] (1.Arizona State University)

9:30 AM - 9:45 AM JST | 12:30 AM - 12:45 AM UTC

[U11-03] The future life span of Earth's oxygenated biosphere and its controlling factors

★Invited Papers

*Kazumi Ozaki[1], Christopher Reinhard[2] (1.Toho University, 2.Georgia Institute of Technology)

9:45 AM - 10:00 AM JST | 12:45 AM - 1:00 AM UTC

[U11-04] Water worlds may be habitable, but not detectable

*Hilairy Ellen Hartnett[1], ASU NExSS Team (1.Arizona State University)

10:00 AM - 10:15 AM JST | 1:00 AM - 1:15 AM UTC

[U11-05] CHALLENGES TO PREDICTING PLANETARY DIVERSITY

★Invited Papers

*Steven J Desch[1], Hilairy Ellen Hartnett[1], Cayman T Unterborn[1] (1.Arizona State University/CSPO)

10:15 AM - 10:30 AM JST | 1:15 AM - 1:30 AM UTC

[U11-06] Planetary Dyspepsia: Finding Planets that work by understanding the planets that don’t

★Invited Papers

*Cayman T Unterborn[1], Steven J Desch[1] (1.Arizona State University/CSPO)

Mon. Jul 13, 2020

[E] Oral | U (Union)：Union

2:15 PM - 3:45 PM JST | 5:15 AM - 6:45 AM UTC | Ch.2

[U-13] Open Colloquium-NASA/JAXA: Our advance and future load in Heliophysics

convener:Yusuke Iida(Niigata University), Mariko Teramoto(Kyushu Institute of Technology), Chun Ming Mark Cheung(Lockheed Martin Advanced Technology Center), Chairperson:Yusuke Iida(Niigata University), Mariko Teramoto(Kyushu Institute of Technology), Chun Ming Mark Cheung(Lockheed Martin Advanced Technology Center)

2:15 PM - 2:40 PM JST | 5:15 AM - 5:40 AM UTC

[U13-01] Geospace Explorations: Toward cycle 25

★Invited Papers

*Yoshizumi Miyoshi[1] (1.Institute for Space-Earth Environmental Research, Nagoya University)

2:40 PM - 3:05 PM JST | 5:40 AM - 6:05 AM UTC

[U13-02] **The State and Vision for the Future of Heliophysics at NASA**

★Invited Papers

*James F Spann[1] (1.NASA Headquarters)

3:05 PM - 3:30 PM JST | 6:05 AM - 6:30 AM UTC

[U13-03] The Solar-C_EUVST Mission and Solar Observations in 2020s

★Invited Papers

*Toshifumi Shimizu[1] (1.Institute of Space and Astronautical Science, JAXA)

[E] Oral | U (Union)：Union

2:15 PM - 3:45 PM JST | 5:15 AM - 6:45 AM UTC | Ch.3

[U-21] Frontiers of Antarctic Environmental Research

convener:Kenji Kawamura(National Institute of Polar Research, Research Organization of Information and Systems), Carol Finn(USGS), Osamu Seki(Institute of Low Temperature Science, Hokkaido University), Yusuke Suganuma(National institute of Polar Research), Chairperson:Kenji Kawamura(National Institute of Polar Research, Research Organization of Information and Systems), Carol Finn(USGS), Osamu Seki(Institute of Low Temperature Science, Hokkaido University), Yusuke Suganuma(National institute of Polar Research)

2:17 PM - 2:39 PM JST | 5:17 AM - 5:39 AM UTC

[U21-01] Oceanographic and geophysical observation campaign off Sabrina Coast, East Antarctica, in 2019/2020

★Invited Papers

*Shigeru Aoki[1], Takeshi Tamura[2], Yoshihiro Nakayama[1], Kazuya Ono[1], Pat Wongpan[1], Kaihe Yamazaki[1], Takuya Itaki[3], Yuki Tokuda[4], Satoshi Sasaki[5], Daisuke Hirano[1], Yuichi Aoyama[2] (1.Hokkaido University, 2.NIPR, 3.AIST, 4.Tottori University of Environmental Studies, 5.Shimane University)

2:39 PM - 3:01 PM JST | 5:39 AM - 6:01 AM UTC

[U21-02] Hot-water drilling for exploring subglacial environment of the Antarctic ice sheet

★Invited Papers

*Shin Sugiyama[1], Masahiro Minowa[2] (1.Institute of Low Temperature Science, Hokkaido University, 2.Instituto de Ciencias Físicas y Matemáticas, Universidad Austral de Chile)

3:01 PM - 3:23 PM JST | 6:01 AM - 6:23 AM UTC

[U21-03] **Modelling the Stability of Antarctic ice sheet in the past interglacials and its implication on future projection.**

★Invited Papers

*Ayako Abe-Ouchi[1], Takashi Obase[1], Ralf Greve[4], Sam Sheriff-Tadano[1], Fuyuki SAITO[2], Kenji Kawamura[3] (1.Atmosphere and Ocean Research Institute, The University of Tokyo, 2.JAMSTEC, 3.NIPR, 4.Hokkaido University)

3:23 PM - 3:45 PM JST | 6:23 AM - 6:45 AM UTC

[U21-04] **Looking to the Future Collaborative Antarctic Science with Global Impacts**

★Invited Papers

*Robin Elizabeth Bell[1], Terry Wilson[2] (1.Lamont Doherty Earth Observatory, 2.Ohio State University, Columbus ,OH, USA)

[E] Oral | U (Union)：Union

9:00 AM - 10:30 AM JST | 12:00 AM - 1:30 AM UTC | Ch.1

[U-22] Environmental drivers and impacts of the evolving COVID-19 pandemic

convener:Benjamin F Zaitchik(Johns Hopkins University), Teppei J Yasunari(Arctic Research Center, Hokkaido University), Chairperson:Teppei J Yasunari(Arctic Research Center, Hokkaido University), Chairperson:Benjamin F Zaitchik(Johns Hopkins University)

9:00 AM - 9:20 AM JST | 12:00 AM - 12:20 AM UTC

[U22-01] Lessons learned from emission fluctuation of greenhouse gases and air pollutants due to restrictions associated with the COVID-19 pandemic

★Invited Papers

*Toshihiko Takemura[1] (1.Research Institute for Applied Mechanics, Kyushu University)

9:20 AM - 9:40 AM JST | 12:20 AM - 12:40 AM UTC

[U22-02] **Satellite Observations of Aerosols during COVID-19 Pandemic**

★Invited Papers

*Pawan Gupta[1,2], Robert C. Levy[3] (1.Universities Space Research Association Greenbelt, 2.MSFC, 3.GSFC)

9:40 AM - 10:00 AM JST | 12:40 AM - 1:00 AM UTC

[U22-03] Seasonal sensitivity of COVID-19: perspectives from viral-host interactions

★Invited Papers

*Miyu Moriyama[1], Akiko Iwasaki[1] (1.Yale University)

10:00 AM - 10:20 AM JST | 1:00 AM - 1:20 AM UTC

[U22-04] Air pollution, COVID-19, and public health: What we know and don’t know

★Invited Papers

*Susan Anenberg[1] (1.George Washington University)

[E] Oral | U (Union)：Union

10:45 AM - 12:15 PM JST | 1:45 AM - 3:15 AM UTC | Ch.1

[U-23] New challenges to diversity, equality and inclusion under COVID-19

convener:Chiaki T. Oguchi(Institute for Environmental Science and Technology, Graduate School of Science and Engineering, Saitama University), Rie Hori, S.(Department of Earth Science, Faculty of Science, Ehime University), Claudia Jesus-Rydin(European Research Council), Hodaka Kawahata(Atmosphere Ocean Research Institute, the University of Tokyo), Chairperson:Chiaki T. Oguchi(Institute for Environmental Science and Technology, Graduate School of Science and Engineering, Saitama University)

10:45 AM - 11:00 AM JST | 1:45 AM - 2:00 AM UTC

[U23-01] Large-scale survey of work and life in scientific and technological profession in Japan under Emergency Declaration caused due to COVID-19 and requests to Japanese government

★Invited Papers

*Noriko Hirata-Kohno[1], Misa Shimuta[2,3] (1.Nihon University, 2.EPMEWSE, 3.The Jikei University School of Medicine)

11:00 AM - 11:15 AM JST | 2:00 AM - 2:15 AM UTC

[U23-02] The impacts of COVID-19 and how racism is hindering our diversity and inclusion efforts

★Invited Papers

*Robin E Bell[1,2] (1.American Geophysical Union, 2.Lamont-Doherty Earth Observatory)

11:15 AM - 11:30 AM JST | 2:15 AM - 2:30 AM UTC

[U23-03] New challenges and opportunities for equality, diversity and inclusivity under COVID-19 and beyond

★Invited Papers

*Alberto Montanari[1] (1.University of Bologna)

[E] Oral | U (Union)：Union

4:00 PM - 5:30 PM JST | 7:00 AM - 8:30 AM UTC | Ch.1

[U-25] Special session for a Borderless World of Geoscience after COVID-19 (Challenges for the future)

convener:Hodaka Kawahata(Atmosphere Ocean Research Institute, the University of Tokyo), Robin Elizabeth Bell(Lamont Doherty Earth Observatory), Alberto Montanari(University of Bologna), David Laurence Higgitt(Lancaster University College at Beijing Jiaotong University, Weihai, China), Chairperson:Hodaka Kawahata(Atmosphere Ocean Research Institute, the University of Tokyo)

4:03 PM - 4:20 PM JST | 7:03 AM - 7:20 AM UTC

[U25-01] Collaborative, Inclusive, Connected Earth and Space Science for our Future

★Invited Papers

*Robin E Bell[1] (1.American Geophysical Union)

4:20 PM - 4:37 PM JST | 7:20 AM - 7:37 AM UTC

[U25-02] A new mission for the geosciences in an age of pandemics and beyond

★Invited Papers

*Alberto Montanari[1], Helen Glaves[2] (1.University of Bologna, 2.British Geological Survey, Environmental Science Centre)

4:37 PM - 4:54 PM JST | 7:37 AM - 7:54 AM UTC

[U25-03] A Borderless World of Geoscience in Asia after COVID-19… for Asia and the World

★Invited Papers

*David Laurence Higgitt[1] (1.Lancaster University College at Beijing Jiaotong University, Weihai, China)

4:54 PM - 5:09 PM JST | 7:54 AM - 8:09 AM UTC

[U25-04] Borderless World of Geoscience after COVID-19 (Challenges for the future)

★Invited Papers

*Yue-Gau Chen[1] (1.Research Center for Environmental Changes, Academia Sinica)

5:09 PM - 5:24 PM JST | 8:09 AM - 8:24 AM UTC

[U25-05] Contribution by JpGU to the future global development of Earth and Planetary Science – by overcoming COVID-19 -

*Hodaka Kawahata[1] (1.Atmosphere Ocean Research Institute, the University of Tokyo)

Tue. Jul 14, 2020

[E] Oral | U (Union)：Union

10:45 AM - 12:15 PM JST | 1:45 AM - 3:15 AM UTC | Ch.1

[U-02] Assessment and Accountability of Scientific Knowledge Creation

convener:Michiyo SHIMAMURA(Japan Agency for Marine-Earth Science and Technology), Yasuhiro Yamanaka(Faculty of Environmental Earth Science, Hokkaido University), Kiyoshi Suyehiro(Japan Agency for Marine-Earth Science and Technology), Brooks Hanson(American Geophysical Union), Chairperson:Michiyo SHIMAMURA(Japan Agency for Marine-Earth Science and Technology)

10:50 AM - 11:10 AM JST | 1:50 AM - 2:10 AM UTC

[U02-01] Research Evaluation in Japan: Basic and Solution-Oriented Science, Their Perceptions and Realities, and a Future Vision

★Invited Papers

*Tateo Arimoto[1] (1.Japan Science and Technology Agency)

11:10 AM - 11:30 AM JST | 2:10 AM - 2:30 AM UTC

[U02-02] The Critical Importance of Earth and Space Science, Public Perceptions, Global Funding, and What Societies and the Global ESS Community Can Do

★Invited Papers

Robin Elizabeth Bell[2], *Brooks Hanson[1] (1.American Geophysical Union, 2.Lamont-Doherty Earth Observatory of Columbia University)

11:30 AM - 12:15 PM JST | 2:30 AM - 3:15 AM UTC

[U02-03] Panel Discussion of the Session

*Michiyo SHIMAMURA[1], Yasuhiro Yamanaka[2], Kiyoshi Suyehiro[1], Brooks Hanson[3] (1.Japan Agency for Marine-Earth Science and Technology, 2.Hokkaido University, 3.AGU)

[E] Oral | U (Union)：Union

9:00 AM - 10:30 AM JST | 12:00 AM - 1:30 AM UTC | Ch.2

[U-15] Open Colloquium-NASA/JAXA: Earth Science focusing on Climate Change

convener:Yamaji Moeka(Japan Aerospace Exploration Agency), Kosuke Yamamoto(Japan Aerospace Exploration Agency), Paula S Bontempi(NASA Headquarters), Sandra Alba Cauffman(NASA Headquarters), Chairperson:Riko Oki(Japan Aerospace Exploration Agency), Sandra Alba Cauffman(NASA Headquarters), Paula S Bontempi(NASA Headquarters), Yamaji Moeka(Japan Aerospace Exploration Agency), Kosuke Yamamoto(Japan Aerospace Exploration Agency)

9:05 AM - 9:25 AM JST | 12:05 AM - 12:25 AM UTC

[U15-01] Past, Current and Future NASA-JAXA Partnership in Earth System Observations from Space

★Invited Papers

*Arlindo da SIlva[1] (1.NASA Goddard Space Flight Center)

9:25 AM - 9:45 AM JST | 12:25 AM - 12:45 AM UTC

[U15-02] US-Japan collaboration toward accurate flux estimation of greenhouse gases from space: Intercomparison between US OCO and Japanese GOSAT

★Invited Papers

*Akihiko Kuze[1], David Crisp[2], Carol Bruegge[2], Laura Iraci[3], Florian Schwandner[3], Fumie Kataoka[4], Kei Shiomi[1], Nobuhiro Kikuchi[1], Hiroshi Suto[1] (1.Japan Aerospace Exploration Agency, 2.JPL CALTECH, 3.NASA AMES, 4.RESTEC)

9:45 AM - 10:05 AM JST | 12:45 AM - 1:05 AM UTC

[U15-03] JAXA-NASA collaborations toward a better understanding of the global water and energy cycle: From TRMM and GPM to ACCP

★Invited Papers

*Hirohiko Masunaga[1], Riko Oki[2], Moeka Yamaji[2], Kosuke Yamamoto[2] (1.Nagoya University, 2.Japan Aerospace Exploration Agency (JAXA))

10:05 AM - 10:30 AM JST | 1:05 AM - 1:30 AM UTC

[U15-04] Open Discussion

★Invited Papers

*Yamaji Moeka[1] (1.Japan Aerospace Exploration Agency)

[E] Oral | U (Union)：Union

10:45 AM - 12:15 PM JST | 1:45 AM - 3:15 AM UTC | Ch.2

[U-19] A deep dive into planetary habitability as related to subsurface architecture, energy, and water.

convener:Graham Heather Valeah, Vlada Stamenkovic(Jet Propulsion Laboratory), Shino Suzuki(Japan Agency for Marine-Earth Science and Technology), Atsuko Kobayashi(Earth-Life Science Institute), Chairperson: Heather Valeah

10:45 AM - 11:00 AM JST | 1:45 AM - 2:00 AM UTC

[U19-01] Recurring slope lineae on Earth: Implications for hydrological cycles and potential habitability on Mars

★Invited Papers

*Yasuhito Sekine[1], Maya Nakamura[1], Davaasuren Davaadorj[2], Daigo Shoji[1], Koki Morida[3], Keisuke Fukushi[3], Noriko Hasebe[3], Shawn E McGlynn[1] (1.Tokyo Institute of Technology, 2.National University of Mongolia, 3.Kanazawa University)

11:00 AM - 11:15 AM JST | 2:00 AM - 2:15 AM UTC

[U19-02] **Prospects for Subsurface Energy, Water, and Life on Mars**

★Invited Papers

*Joseph Michalski[1,2] (1.Division of Earth and Planetary Science, University of Hong Kong, Hong Kong, 2.CIFAR, Toronto, Canada)

11:15 AM - 11:30 AM JST | 2:15 AM - 2:30 AM UTC

[U19-03] Life on serpentinized setting on the Earth and beyond

★Invited Papers

*Shino Suzuki[1] (1.Japan Agency for Marine-Earth Science and Technology)

11:30 AM - 11:45 AM JST | 2:30 AM - 2:45 AM UTC

[U19-04] Subseafloor biosphere in the ancient Earth: constraint from multiple S isotopes records

★Invited Papers

*Aoyama Shinnosuke[1] (1.Yokohama National University)

11:45 AM - 12:00 PM JST | 2:45 AM - 3:00 AM UTC

[U19-05] **International Center for Deep Life Investigation: A global platform for the entire deep life community**

★Invited Papers

*FengPing Wang[1,2] (1.School of Oceanography, Shanghai Jiao Tong University, Shanghai, China, 2.State Key Laboratory of Microbial Metabolism, School of Life Sciences and Biotechnology, Shanghai JiaoTong University, Shanghai, China)

12:00 PM - 12:15 PM JST | 3:00 AM - 3:15 AM UTC

[U19-06] Opportunities and Exploration: A Panel Discussion on Planetary Subsurface Science

*Heather Valeah Graham[1], Vlada Stamenkovic[2], Shino Suzuki[3], Ken Takai[3], Tomohiro Usui[4] (1.NASA Goddard Space Flight Center, 2.NASA Jet Propulsion Laboratory, 3.Japan Agency for Marine-Earth Science and Technology, 4.Japan Aerospace Exploration Agency)

[E] Oral | U (Union)：Union

2:15 PM - 3:45 PM JST | 5:15 AM - 6:45 AM UTC | Ch.2

[U-20] "Open Colloquium" Exploring the Earth's interior using cutting edge science and technology

convener:Hiroko Watanabe(Research Center for Neutrino Science, Tohoku University), William F McDonough(Department of Earth Science and Research Center for Neutrino Science, Tohoku University, Sendai, Miyagi 980-8578, Japan), Kenta Ueki(Japan Agency for Marine-Earth Science and Technology), Eiichiro Araki(Japan Agency for Marine-Earth Science and Technology), Chairperson:Hiroko Watanabe(Research Center for Neutrino Science, Tohoku University)

2:15 PM - 2:30 PM JST | 5:15 AM - 5:30 AM UTC

[U20-01] Undestanding the Earth's deep interior with geo-neutrino measurements

★Invited Papers

*Hiroko Watanabe[1] (1.Research Center for Neutrino Science, Tohoku University)

2:30 PM - 2:45 PM JST | 5:30 AM - 5:45 AM UTC

[U20-02] Deep seafloor cable observation technologies towards future ocean bottom neutrino detector experiment.

★Invited Papers

*Eiichiro Araki[1], Taichi Sakai[2], Hiroko Watanabe[2], Takashi Yokobiki[1] (1.Japan Agency for Marine-Earth Science and Technology, 2.RCNS, Tohoku Univ.)

2:45 PM - 3:00 PM JST | 5:45 AM - 6:00 AM UTC

[U20-03] Direct sampling and measurement at deep crust through scientific ocean drilling

★Invited Papers

*Shin'ichi Kuramoto[1] (1.Japan Agency for Marine-Earth Science and Technology)

3:00 PM - 3:15 PM JST | 6:00 AM - 6:15 AM UTC

[U20-04] Hadean geodynamo origin and Ediacaran inner core growth preserved Earth’s habitability

★Invited Papers

*John Anthony Tarduno[1,2], Rory D Cottrell[1], Francis Nimmo[3], Hirokuni Oda[4], Axel Hofmann[5] (1.University of Rochester, Department of Earth and Environmental Sciences, Rochester, New York, United States, 2.University of Rochester, Department of Physics and Astronomy, Rochester, New York, United States, 3.University of California – Santa Cruz, Department of Earth and Planetary Sciences, Santa Cruz, California, United States, 4.National Institute of Advanced Science and Technology, Geological Survey of Japan, Tsukuba, Ibaraki, 305-8567, Japan, 5.University of Johannesburg, Department of Geology, Johannesburg, South Africa)

3:15 PM - 3:30 PM JST | 6:15 AM - 6:30 AM UTC

[U20-05] Earth's deep interior revealed by high-pressure experiments

★Invited Papers

*Kei Hirose[1,2] (1.Earth-Life Science Institute, Tokyo Institute of Technology, 2.Dept. Earth and Planetary Science, The University of Tokyo)

3:30 PM - 3:45 PM JST | 6:30 AM - 6:45 AM UTC

[U20-06] **Imaging subducted slabs in the mantle through inversion of seismic waveforms**

★Invited Papers

*Kenji Kawai[1], Anselme F. E. Borgeaud[1,2], Yuki Suzuki[1], Robert J. Geller[1] (1.Department of Earth and Planetary Science, School of Science, University of Tokyo, 2.Academia Sinica)

Wed. Jul 15, 2020

[E] Oral | U (Union)：Union

9:00 AM - 10:30 AM JST | 12:00 AM - 1:30 AM UTC | Ch.1

[U-01] Great Debate: Geoscience and societal leadership in support of planetary stewardship

convener:Fumio Inagaki(Japan Agency for Marine-Earth Science and Technology), William F McDonough(Department of Earth Science and Research Center for Neutrino Science, Tohoku University, Sendai, Miyagi 980-8578, Japan), Susanne Buiter(Geological Survey of Norway), Chairperson:Fumio Inagaki(Japan Agency for Marine-Earth Science and Technology), William F McDonough(Department of Earth Science and Research Center for Neutrino Science, Tohoku University, Sendai, Miyagi 980-8578, Japan)

9:00 AM - 9:30 AM JST | 12:00 AM - 12:30 AM UTC

[U01-01] Challenges of the Anthropocene

*Will Steffen[1] (1.Climate Council of Australia)

9:30 AM - 9:40 AM JST | 12:30 AM - 12:40 AM UTC

[U01-02] Climate change: from security perspectives

*Yasuko Kameyama[1] (1.National Institute for Environmental Studies, Japan)

9:40 AM - 9:50 AM JST | 12:40 AM - 12:50 AM UTC

[U01-03] Multiscale stewardship for water-food-energy nexus

*Makoto Taniguchi[1] (1.Research Institute for Humanity and Nature)

9:50 AM - 10:00 AM JST | 12:50 AM - 1:00 AM UTC

[U01-04] Planetary Stewardship in AGU

*Robin E Bell[1] (1.American Geophysical Union)

10:00 AM - 10:30 AM JST | 1:00 AM - 1:30 AM UTC

[U01-05] Great Debate: Geoscience and societal leadership in support of planetary stewardship

*Fumio Inagaki[1], William F. McDonough[1], Susanne Buiter[2], Guy Brasseur[3], Fumiko Kasuga[4], William Steffen[5], Makoto Taniguchi[6], Yasuko Kameyama[7], Robin E. Belll[8], Alberto Montanari[9], Hodaka Kawahata[10] (1.JpGU-AGU Joint Meeting 2020 Program Committee Chair, 2.EGU General Assembly 2020 Program Committee Chair, 3.AGU Fall Meeting 2020 Program Committee Chair, 4.Future Earth Japan Global Hub, 5.Australian National University, 6.Research Institute for Humanity and Nature, 7.National Institute for Environmental Studies, 8.AGU President, 9.EGU President, 10.JpGU President)

On demand

[E] Oral | U (Union)：Union

[U-03] Sustainable global groundwater management for human security

convener:Yoshihide Wada(International Institute for Applied Systems Analysis), Makoto Taniguchi(Research Institute for Humanity and Nature), Chairperson:Yoshihide Wada(International Institute for Applied Systems Analysis), Chairperson:Makoto Taniguchi(Research Institute for Humanity and Nature)

[U03-01] Groundwater governance for global sustainability

★Invited Papers

*Makoto Taniguchi[1], Sanghyun Lee[1], Naoki Masuhara[1] (1.Research Institute for Humanity and Nature)

[U03-02] **Global Economic Limits of Groundwater used for Irrigation**

★Invited Papers

*Marc FP Bierkens[1,2], Inge E.M de Graaf[3], Scott Jasechko[4], Debra Perrone[4], Rens L.P.H van Beek[1] (1.Utrecht University, 2.Deltares, 3.University of Freiburg, 4.University of California at Santa Barbara)

[U03-03] Net inflow – a key quantity for defining pathways towards sustainability in heavily stressed aquifers

★Invited Papers

*James J Butler[1], Geoffrey C Bohling[1], Donald O Whittemore[1], Blake B Wilson[1] (1.Kansas Geological Survey, University of Kansas, Lawrence, KS USA)

[U03-04] **Human-groundwater interactions in a changing environment: modeling stressed global aquifer systems**

★Invited Papers

*Yadu Pokhrel[1], Farshid Felfelani[1], Sanghoon Shin[1], Tamanna Kabir[1] (1.Michigan State University)

[U03-05] Global salinization risk in irrigated areas

*Sayaka Yoshikawa[1], Kota Higashiyama[1], Shinjiro Kanae[1] (1.Tokyo Institute of Technology)

[U03-06] Gender differences in water insecurity

*Kaoru Kakinuma[1,2], Yoshihide Wada[3] (1.Shanghai University, 2.Tohoku University, 3.International Institute for Applied Systems Analysis)

[E] Oral | U (Union)：Union

[U-03] Sustainable global groundwater management for human security

convener:Yoshihide Wada(International Institute for Applied Systems Analysis), Makoto Taniguchi(Research Institute for Humanity and Nature), Chairperson:Yoshihide Wada(International Institute for Applied Systems Analysis), Chairperson:Makoto Taniguchi(Research Institute for Humanity and Nature)

[U03-07] Development and enhancement of a global hydrological model to better contribute to the sustainable groundwater management and human water security

★Invited Papers

*Naota Hanasaki[1], Julien Eric Boulange[1], Zhipin Ai[1], SARITHA PADIYEDATH GOPALAN[1], Kumiko TAKATA[1] (1.NIES National Institute of Environmental Studies)

[U03-08] **Impacts of Global Groundwater Depletion to Regional Hydroclimatology in 37 Major Aquifers**

★Invited Papers

*Pat J.-F. Yeh[1], Chong Zhang[2], MinHui Lo[3], Yoshihide Wada[4], James S. Famiglietti[5] (1.School of Engineering, Monash University, Malaysia, 2.Beijing Normal University, China, 3.Department of Atmospheric Sciences, National Taiwan University, Taipei, Taiwan, 4.International Institute for Applied Systems Analysis, Laxenburg, Austria, 5.School of Environment and Sustainability and Global Institute for Water Security, University of Saskatchewan, Saskatoon, Canada)

[U03-09] **Divergent effects of climate change on future groundwater availability in key mid-latitude aquifers**

★Invited Papers

*Min-Hui Lo[1], Wen-Ying Wu (1.National Taiwan University)

[U03-10] Uncertainty of global hydrologic simulations: associated with data and physics including groundwater capillary flux

★Invited Papers

*Hyungjun Kim[1], Sujan Koirala[2] (1.The Univ. of Tokyo, 2.Max Planck Institute for Biogeochemistry)

[U03-11] Higher-resolution mapping of regional aquifer storage parameters using a GRACE spherical harmonic inversion method

*Yun Pan[1], Yalin Ma[1], Pat J.-F. Yeh[2], Huili Gong[1] (1.Capital Normal Univ., 2.Monash Univ. Malaysia)

[U03-12] Potential misrepresentation of hydrological extremes using transient climate rather than stabilized climate given identical levels of global warming

*Julien Eric Boulange[1], Naota Hanasaki[1] (1.National Institute for Environmental Studies)

[E] Oral | U (Union)：Union

[U-04] International Efforts Supporting Global Navigation Satellite System-Enhanced Tsunami Early Warning

convener:Rundle John B(University of California Davis), Kazuyoshi Nanjo(University of Shizuoka), Eiichi Fukuyama(Kyoto University / National Research Institute for Earth Science and Disaster Resilience), Chairperson:Kazuyoshi Nanjo(University of Shizuoka), Chairperson:John B Rundle(University of California Davis), Chairperson:Eiichi Fukuyama(Kyoto University / National Research Institute for Earth Science and Disaster Resilience)

[U04-01] Operation of REGARD: Real-Time GNSS analysis system in Japan

*Hiroki MURAMATSU[1], Satoshi ABE[1], Satoshi KAWAMOTO[2], Yusaku Ohta[3] (1.GSI of Japan, 2.Cabinet Office of Japan, 3.Research Center for Prediction of Earthquakes and Volcanic Eruptions, Graduate School of Science, Tohoku University,)

[U04-02] Tsunami early warning system in Japan and plans towards practical uses of GNSS data to tsunami warning operation of the JMA

★Invited Papers

*NISHIMAE Yuji[1], ISHIKAWA Norihiko[2] (1.Japan Meteorological Agency, 2.Geospatial Information Authority of Japan)

[U04-03] **GNSS Tsunami Early Warning: Implementing the Sendai Framework for Disaster Risk Reduction**

★Invited Papers

*John L LaBrecque[1], Diego Arcas[2], Gerald Bawden[3], Allison B. Craddock[4], Lorraine Hwang[5], Shunichi Koshimura[6], Basara Miyahara[7], Yasuku Ohta[8], John Rundle[9] (1.Chair, IUGG Commission on Geophysical Risk and Sustainability (GeoRisk Commission), 2.NOAA Center for Tsunami Research , 3.NASA Headquarters, Natural Hazards Research and GNSS Science Team, 4.Director, Central Bureau IGS & Jet Propulsion Laboratory, 5.Director Computational Infrastructure for Geodynamics, Univ. Califorinia, Davis, 6.International Research Institute of Disaster Science, Tohoku University, 7.President, Global Geodetic Observing System & Director, Space Geodesy Div. , Geospatial Information Authority of Japan , 8.Graduate School of Science, Tohoku University, 9.Professor, Univ. California, Davis)

[U04-04] Coupled Earthquake-Tsunami-TEC Simulator in a Parallel HPC Environment

*John B Rundle[1], David Grzan[1], John Wilson[1], Kasey Schultz[1], Steven Ward[2] (1.University of California Davis, 2.University of California Santa Cruz)

[U04-05] GNSS Total Electronics Contents tsunami measurements and tsunami height inversions.

*Philippe Henri Lognonné[1], Lucie Rolland[2], Giovanni Occhinpinti[1], Elvira Astafeyva[1], Mala Bagiya[3], Khaled Khelfi[4], Virgile Rakoto[4] (1.Université de Paris, Institut de physique du globe de Paris, CNRS, 2.Laboratoire Géoazur - Université de Nice Côte d'Azur Bureau 208 - Bâtiment 4 250 rue Albert Einstein 06560 Valbonne - France, 3.Indian Institute of Geomagnetism, Sector 18, Near Kalamboli Highway New Panvel(W), Navi Mumbai, 410218 India , 4.formerly at Université de Paris, Institut de physique du globe de Paris, CNRS)

[U04-06] GNSS-TEC-based tsunami early warning system: Tsunami ionospheric hole identification, 2D initial tsunami height estimation, and tsunami simulation

★Invited Papers

*Masashi Kamogawa[1], Toshiyasu Nagao[2] (1.Global Center for Asian and Regional Research, University of Shizuoka, 2.Institute of Oceanic Research and Development, Tokai University)

[E] Oral | U (Union)：Union

[U-05] Advanced understanding of Quaternary and Anthropocene hydroclimate changes in East Asia

convener:Chuan-Chou Shen(High-Precision Mass Spectrometry and Environment Change Laboratory, Department of Geosciences, National Taiwan University), Yusuke Yokoyama(Atmosphere and Ocean Research Institute, University of Tokyo), Kaoru Kubota(Graduate School of Human Development and Environment, Kobe University), Li Lo(Department of Geosciences, National Taiwan University), Chairperson:Chuan-Chou Shen(High-Precision Mass Spectrometry and Environment Change Laboratory, Department of Geosciences, National Taiwan University), Chairperson:Yusuke Yokoyama(Atmosphere and Ocean Research Institute, University of Tokyo), Chairperson:Kaoru Kubota(Kochi Institute for Core Sample Research, JAMSTEC), Chairperson:Li Lo(Department of Geosciences, National Taiwan University)

[U05-01] Meaning of stalagmite oxygen isotopes

★Invited Papers

*Akihiro Kano[1] (1.Graduate School of Science, The University of Tokyo)

[U05-02] **Late-Holocene anthropogenic impact on tropical climate**

★Invited Papers

*Yair Rosenthal[1], Samantha Claudia Bova[1], Zhengyu Liu[2], Mi Yan[3] (1.Rutgers University, 2.Ohio State University, 3.Nanjing Normal University)

[U05-03] Evolution of meridional and zonal sea surface temperature gradients in the Pacific Ocean during the Quaternary period

★Invited Papers

*Takuya Sagawa[1], Risako Makino[2], Yukimi Kubota[2], Yoshimi Kubota[3], Yair Rosenthal[4] (1.Institute of Science and Engineering, Kanazawa University, 2.School of Science and Engineering, Kanazawa University, 3.National Museum of Nature and Science, 4.Rutgers University)

[U05-04] How do marine microplankton survive during global warming?

★Invited Papers

*Yurika Ujiie[1], Kyoko Hagino[1], Tatsuhiko Hoshino[2], Jeremy R. Young[3], Ian Probert[4], Richard Jordan[5] (1.CMCR, Kochi University, 2.JAMSTEC, 3.University College London, 4.Roscoff Biological Station, 5.Yamagata University)

[U05-05] Periodical enhancements of multi-decadal hydroclimate variations in central Japan and its implication for the 2600-year East Asian history

★Invited Papers

*Takeshi Nakatsuka[1] (1.Nagoya University)

[U05-06] Benthic biotic response to Quaternary climate changes in the Sea of Japan and other Asian regions

★Invited Papers

*Moriaki Yasuhara[1] (1.University of Hong Kong)

[E] Oral | U (Union)：Union

[U-06] Open Access, Open Data, and FAIR Data in Geosciences

convener:Hirokuni Oda(Institute of Geology and Geoinformation, Geological Survey of Japan, AIST), Hodaka Kawahata(Atmosphere Ocean Research Institute, the University of Tokyo), Brooks Hanson(American Geophysical Union)

[U06-01] Open access and open data: the publisher perspective

★Invited Papers

*Paola Teti[1], Toby Charkin[1], Samuel Winthrop[1] (1.Springer Nature)

[U06-02] Enabling FAIR Data in the Earth, Space, and Environmental Sciences: Encouraging all Researchers to Document, Share, and Cite Scientific Data

★Invited Papers

*Shelley Stall[1] (1.American Geophysical Union)

[U06-03] Preprint is ready, data sharing is still difficult, what scholarly community should do in 2020's?

★Invited Papers

*Kazuhiro Hayashi[1] (1.National Institute of Science and Technology Policy)

[U06-04] An Attempt to Discuss Scientific Outputs including papers and digital data in the Open Science scene

★Invited Papers

*Yasuhiro Murayama[1] (1.Strategic Program Produce Office, National Institute of Information and Communications Technology)

[E] Oral | U (Union)：Union

[U-07] Diversity and equality - Where do we stand on gender equality or equity in the geosciences?

convener:Chiaki T. Oguchi(Institute for Environmental Science and Technology, Graduate School of Science and Engineering, Saitama University), Rie Hori, S.(Department of Earth Science, Faculty of Science, Ehime University), Claudia Jesus-Rydin(European Research Council), Hodaka Kawahata(Atmosphere Ocean Research Institute, the University of Tokyo), Chairperson:Rie Hori, S.(Department of Earth Science, Faculty of Science, Ehime University), Chairperson:Claudia Jesus-Rydin(European Research Council)

[E] Oral | U (Union)：Union

[U-08] Special session for a borderless World of Geoscience (GEOethics)

convener:Hodaka Kawahata(Atmosphere Ocean Research Institute, the University of Tokyo), Brooks Hanson(American Geophysical Union), Takashi Furumura(Earthquake Research Institute The University of Tokyo), Eiichi Tajika(Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo), Chairperson:Hodaka Kawahata(Atmosphere Ocean Research Institute, the University of Tokyo), Chairperson:Takashi Furumura(Earthquake Research Institute The University of Tokyo)

[U08-01] The key role of Scientific Societies

★Invited Papers

*Brooks Hanson[1] (1.American Geophysical Union)

[U08-02] Climate science and social values

★Invited Papers

*Seita Emori[1] (1.National Institute for Environmental Studies)

[U08-03] How can we effectively utilize atmospheric forecasts that include uncertainties?

★Invited Papers

*Hisashi Nakamura[1] (1.Research Center for Advanced Science and Technology, University of Tokyo)

[U08-04] Communicating uncertainty of geoscience for the disaster risk reduction -Geoscience, the ambiguous, and ourselves-

★Invited Papers

*Satoko Oki[1] (1.Faculty of Environment and information Studies)

[U08-05] Transdisciplinary research on geoscience in society

★Invited Papers

*Makoto Taniguchi[1] (1.Research Institute for Humanity and Nature)

[U08-06] Geodiversity and its conservation as a framing guideline for Geoethics in 21st Century

★Invited Papers

*Abhik Chakraborty[1] (1.Wakayama University)

[U08-07] The AGU GeoHealth and Thriving Earth Exchange Programs: Engaging our Geoscience Community for a Sustainable Future

★Invited Papers

Brooks Hanson[1], Janice Lachance[1], *Billy M Williams[1] (1.American Geophysical Union)

[E] Oral | U (Union)：Union

[U-09] Special session For a Borderless World of Geoscience (Challenges for the future)

convener:Hodaka Kawahata(Atmosphere Ocean Research Institute, the University of Tokyo), Robin Elizabeth Bell(Lamont Doherty Earth Observatory), Alberto Montanari(University of Bologna), David Laurence Higgitt(Lancaster University College at Beijing Jiaotong University, Weihai, China), Chairperson:Brooks Hanson(American Geophysical Union), Chairperson:Simon Richard Wallis(The University of Tokyo)

[E] Oral | U (Union)：Union

[U-10] Linking Education and Research Communities in Geosciences: Engaging the Public and Local Communities

convener:Vincent Tong(University College London), Takashi Oguchi(Center for Spatial Information Science, The University of Tokyo), Renee M Clary(Mississippi State University), Keiko Kuge(Department of Geophysics, Graduate School of Science, Kyoto University), Chairperson:Vincent Tong(University College London), Chairperson:Takashi Oguchi(Center for Spatial Information Science, The University of Tokyo), Chairperson:Keiko Kuge(Department of Geophysics, Graduate School of Science, Kyoto University), Chairperson:Renee M Clary(Mississippi State University)

[U10-01] Resilience and public engagement for advancing sustainability policy, research and education

★Invited Papers

*Mika Shimizu[1] (1.Kyoto University)

[U10-02] Japanese Activity in collaboration with the international ocean literacy survey

★Invited Papers

*Hiroshi Ichikawa[1], Noriko Imamiya[2], Akiko Tsuzuki[2], Geraldine Fauville[3], Craig Strang[4] (1.Ocean Literacy and Education Panel, Oceanographic Society of Japan, 2.Marine Learning Center, 3.Stanford University, 4.University of California, Berkeley)

[U10-03] Digital story-telling and video briefs as an approach to enhanced international collaboration and impact

★Invited Papers

*Brendan Francis Dominic Barrett[1] (1.Osaka University)

[U10-04] The International Geography Olympiad and Geography Education in Japan

★Invited Papers

*Yoshiyasu Ida[1] (1.Faculty of Human Sciences,University of Tsukuba)

[U10-05] Open Dialogue in Geoscience-based Policy Process: Linking Stakeholders and Researchers

★Invited Papers

*Hidenroi Nakamura[1] (1.Toyama Prefectural University)

[U10-06] A few points to be considered when we engaging with a local community for research and practice for sustainability

★Invited Papers

*Fumiko Noguchi[1] (1.United Nations University)

[E] Oral | U (Union)：Union

[U-14] Open Colloquium-NASA/JAXA: Planetary science on Mars driving current and future missions

convener:Shunichi Kamata(Faculty of Science, Hokkaido University), Go Murakami(Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency), Mitchell D Schulte(NASA Headquarters), Michael S Kelley(NASA Headquarters), Chairperson:Shunichi Kamata(Faculty of Science, Hokkaido University), Chairperson:Go Murakami(Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency), Chairperson:Mitchell D Schulte(NASA Headquarters), Chairperson:Michael S Kelley(NASA Headquarters)

[U14-01] 50 Years of Mars Exploration: Past and Ongoing NASA Missions Pave the Way for Determining Whether There Was Life on Mars

★Invited Papers

*John A Grant[1] (1.Smithsonian National Air and Space Museum, Center for Earth and Planetary Studies, Washington DC)

[U14-02] MARS SAMPLE RETURN: A MISSION CAMPAIGN OF INTENSE SCIENTIFIC INTEREST

★Invited Papers

*David Beaty[1], Brandi L Carrier[1], Michael A Meyer[2], Elliot Sefton-Nash[3] (1.Jet Propulsion Laboratory/California Institute of Technology, 2.NASA Headquarters, 3.ESA ESTEC)

[U14-03] JAXA's Strategic Mars Exploration Program (JSMEP) for Understanding Origin, Evolution, Inventory of Water on Mars

★Invited Papers

*Tomohiro Usui[1] (1.Japan Aerospace Exploration Agency)

[U14-04] Open discussion

*Go Murakami[1] (1.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency)

[E] Oral | U (Union)：Union

[U-16] OC:Research Advances in Recent Disaster Studies Using Remote Sensing and Computational Methodologies

convener:Jun Matsumoto(Deaprtment of Geography, Tokyo Metropolitan University), Guido Cervone(Pennsylvania State University Main Campus), Chairperson:Jun Matsumoto(Deaprtment of Geography, Tokyo Metropolitan University), Chairperson:Guido Cervone(Pennsylvania State University Main Campus)

[U16-01] Expanded Dimensionality Image Spectroscopy Via Machine Learning

★Invited Papers

*Guido Cervone[1], Mark Salvador, Fangcao Xu[1] (1.Pennsylvania State University Main Campus)

[U16-02] Detection of landslides and vegetation recovery from multitemporal UAV and satellite images

★Invited Papers

*Hitoshi SAITO[1,2], Shoichiro Uchiyama[2], Yuichi S. Hayakawa[3], Hiroyuki Obanawa[4] (1.Kanto Gakuin University, 2.National Research Institute for Earth Science and Disaster Resilience, 3.Hokkaido University, 4.National Agriculture and Food Research Organization)

[U16-03] Next-generation alerting system for natural disasters using ground network and micro-satellites

★Invited Papers

*Yukihiro Takahashi[1,2], Mitsuteru Sato[1,2], Hisayuki Kubota[1,2], Kozo Yamashita[3], Tetsuro Ishida[1,2] (1.Department of Cosmosciences, Graduate School of Science, Hokkaido University, 2.Faculty of Science, Hokkaido University, 3.Faculty of Engineering, Ashikaga University)

[U16-04] The Rise of the Crowd: An Assessment of Crowdsourced Data during Disasters

★Invited Papers

*Carolynne Hultquist[1] (1.Columbia University)

[E] Oral | U (Union)：Union

[U-17] Open Colloquium: What will we expect from Ryugu and Bennu samples?

convener:Satoshi Kasahara(The university of Tokyo), Aki Takigawa(Department of Earth and Planetary Science, The University of Tokyo)

[U17-01] What will we expect from Ryugu and Bennu samples?

*Shogo Tachibana[1,2], Harold C. Connolly Jr.[3] (1.UTokyo Organization for Planetary and Space Science, University of Tokyo , 2.Institute of Space and Astronautical Science, 3.Department of Geology, School of Earth and Environment, Rowan University)

[U17-02] Open discussion: What we expect from Ryugu and Bennu samples

*Satoshi Kasahara[1], Aki Takigawa[2], Shogo Tachibana[1,3], Harold C. Connolly Jr.[4] (1.The university of Tokyo, 2.Kyoto University, 3.Institute of Space and Astronautical Science, 4.Rowan University)

[E] Oral | U (Union)：Union

[U-18] Open Colloquium: Recent advances in atmospheric and hydrospheric sciences

convener:Kazuaki Nishii(Graduate School of Bioresources, Mie University), Hong Liao(Nanjing University of Information Science and Technology), Masahiro Hori(University of Toyama School of Sustainable Design), Kazuhiro Misumi(Environmental Science Research Laboratory, Central Research Institute of Electric Power Industry), Chairperson:Kazuaki Nishii(Graduate School of Bioresources, Mie University)

[U18-01] Seasonally dependent impact of cloud longwave scattering on the polar climate: why it is a necessity in polar climate modeling?

★Invited Papers

*Xianglei Huang[1], Yi-Hsuan Chen[1], Ping Yang[2], Chia-Pang Kuo[3], Xiuhong Chen[1] (1.Univ. Michigan Ann Arbor, 2.Texas A&M Univ., 3.Florida State Univ.)

[U18-04] **Overview of OMIX project “Ocean mixing processes: impact on biogeochemistry, climate and ecosystems”**

★Invited Papers

*Ichiro Yasuda[1] (1.Atmosphere and Ocean Research Institute, The University of Tokyo)

[U18-05] **Typhoon observations using an aircraft from the upper troposphere in the T-PARCII project**

★Invited Papers

*Taro Shinoda[1], Kazuhisa Tsuboki[1], Hiroyuki Yamada[2], Tadayasu Ohigashi[3], Kosuke Ito[2], Munehiko Yamaguchi[4], Tetsuo Nakazawa[4], Hisayuki Kubota[5], Yukihiro Takahashi[5], Norio Nagahama[6], Kensaku Shimizu[6], Nobuhiro Takahashi[1] (1.Institute for Space-Earth Environmental Research, Nagoya University, 2.Faculty of Science, University of the Ryukyus, 3.National Research Institute for Earth Science and Disaster Resilience, 4.Meteorological Research Institute, Japan Meteorological Agency, 5.School of Science, Hokkaido University, 6.Meisei Electric Co. Ltd.)

[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS01] Outer Solar System Exploration Today, and Tomorrow

convener:Jun Kimura(Osaka University), Kunio M. Sayanagi(Hampton University), Fuminori Tsuchiya(Planetary Plasma and Atmospheric Research Center, Graduate School of Science, Tohoku University), Steven Douglas Vance(NASA Jet Propulsion Laboratory, California Institute of Technology)

[PPS01-01] Dynamics in Jupiter's magnetosphere revealed by time variation of plasma densities and temperature in the Io plasma torus coincident with volcanic activations on Io

★Invited Papers

*Reina Hikida[1], Kazuo Yoshioka[1], Fuminori Tsuchiya[2], Masato Kagitani[2], Tomoki Kimura[2], Fran Bagenal[3], Nick Schneider[3], Go Murakami[4], Atsushi Yamazaki[4], Hajime Kita[4], Edward Nerney[3], Seiya Nishimura[1], Hidetaka Kuniyoshi[1], Ichiro Yoshikawa[1] (1.the University of Tokyo, 2.Tohoku University, 3.University of Colorado, 4.JAXA)

[PPS01-02] Identifying the particle responsible for energy supply during the IPT brightening event.

*Seiya Nishimura[1], Fumiharu Suzuki[1], Kazuo Yoshioka[1], Reina Hikida[1], Hidetaka Kuniyoshi[1], Fuminori Tsuchiya[3], Go Murakami[2], Ichiro Yoshikawa[1] (1.The university of tokyo, 2.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 3.Planetary Plasma and Atmospheric Research Center, Graduate School of Science, Tohoku University)

[PPS01-03] **Origin of delayed rotational periodicity in the inner magnetosphere of Jupiter**

*Fuminori Tsuchiya[1], Hiroaki Misawa[1], Masato Kagitani[1], Ryoichi Koga[1], Reina Hikida[2], Kazuo Yoshioka[2], Nick Schneider[5], Peter A Delamere[6], Fran Bagenal[5], Andrew Steffl[4], Tomoki Kimura[1], Yasumasa Kasaba[1], Go Murakami[3], Ichiro Yoshikawa[2], Atsushi Yamazaki[3] (1.Tohoku University, 2.The University of Tokyo, 3.ISAS/JAXA, 4.SwRI, 5.University of Colorado, 6.University of Alaska Fairbanks)

[PPS01-04] Observations of tenuous atmospheres and plumes at the icy Galilean moons: HST and future missions

★Invited Papers

*Lorenz Roth[1] (1.KTH Royal Institute of Technology, Stockholm, Sweden)

[PPS01-05] Performance, Operation and their Feasibilities for Jupiter and Icy Moons: High Frequency Receiver of Radio & Plasma Wave Investigation (RPWI) aboard JUICE

*Yasumasa Kasaba[1], Hiroaki Misawa[1], Fuminori Tsuchiya[1], Tomoki Kimura[1], Hajime Kita[3], Atsushi Kumamoto[1], Yuto Katoh[1], Yoshizumi Miyoshi[4], Yoshiya Kasahara[5], Satoshi Yagitani[4], Hirotsugu Kojima[8], Baptiste Cecconi[2], Lukas Wiśniewski[6], Walter Puccio[7], Jan Bergman[7], Jan-Erik Wahlund[7] (1.Tohoku University, 2.Observatoire de Paris, 3.Japan Aerospace Exploration Agency, 4.Nagoya University, 5.Kanazawa University, 6.Astronika, 7.IRF Uppsala, 8.Kyoto University)

[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS01] Outer Solar System Exploration Today, and Tomorrow

convener:Jun Kimura(Osaka University), Kunio M. Sayanagi(Hampton University), Fuminori Tsuchiya(Planetary Plasma and Atmospheric Research Center, Graduate School of Science, Tohoku University), Steven Douglas Vance(NASA Jet Propulsion Laboratory, California Institute of Technology)

[PPS01-07] Uranus and Neptune are key to understand planets with hydrogen atmospheres

*Tristan Guillot[1,2] (1.Observatoire de la Cote d Azur, 2.JSPS/University of Tokyo)

[PPS01-08] A Possible Formation Scenario of Saturn-Titan System

*Yuri Fujii[1], Masahiro Ogihara[2] (1.Institute for Advanced Research, Nagoya University, 2.Division of Science, National Astronomical Observatory of Japan)

[PPS01-09] Variation in Titan's polar sea distribution due to orbital forcing simulated by a sea balance model

*Tetsuya Tokano[1] (1.University of Cologne)

[PPS01-12] Forced libration of Ganymede: including visco-elastic tidal deformations

*Shinichiro Kojima[1], Jun Kimura[1], Shunichi Kamata[2] (1.Department of Earth and Space Science, Graduate School of Science, Osaka University, 2.Department of Earth and Planetary Science, Faculty of Science, Hokkaido University)

[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS01] Outer Solar System Exploration Today, and Tomorrow

convener:Jun Kimura(Osaka University), Kunio M. Sayanagi(Hampton University), Fuminori Tsuchiya(Planetary Plasma and Atmospheric Research Center, Graduate School of Science, Tohoku University), Steven Douglas Vance(NASA Jet Propulsion Laboratory, California Institute of Technology)

[PPS01-13] **CHARISMA: A space telescope for planetary science**

*Cindy Young[1], Kunio M. Sayanagi[2], Michael Wong[3] (1.NASA Langley Research Center, 2.Hampton University, 3.University of California, Berkeley)

[PPS01-14] Future ultraviolet observation for monitoring Europa and outer planetary systems

*Go Murakami[1], Fuminori Tsuchiya[2], Ryoichi Koga[2], Kazuo Yoshioka[3], Masato Kagitani[2], Tomoki Kimura[4], Atsushi Yamazaki[1], Yudai Suzuki[3], Hajime Kita[1], Masaki Kuwabara[1], Reina Hikida[3], Chihiro Tao[5], Yasumasa Kasaba[2], Ichiro Yoshikawa[3] (1.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 2.Planetary Plasma and Atmospheric Research Center, Graduate School of Science, Tohoku University, 3.Graduate School of Frontier Sciences, The University of Tokyo, 4.Frontier Research Institute for Interdisciplinary Sciences, Tohoku University, 5.National Institute of Information and Communications Technology)

[PPS01-15] **The Europa Clipper Mission: Investigating an Ocean World's Habitability**

*Steven Douglas Vance[1], Robert T Pappalardo[1], David A Senske[1], Haje Korth[2], Kate Craft[2], Sam Howell[1], Rachel L Klima[2], Erin J Leonard[1], Cynthia B Phillips[1], Christina Richey[1] (1.NASA Jet Propulsion Laboratory, California Institute of Technology, 2.The Johns Hopkins University Applied Physics Laboratory)

[PPS01-16] Geophysical and astrobiological perspectives for future spacecraft missions to Jovian icy moons

*Yasuhito Sekine[1], Shunichi Kamata[3], Shuya Tan[1], Shintaro Azuma[1], Ikuo Katayama[6], Yoshifumi Saito[2], Kazushi Asamura[2], Keigo Enya[2], Junichi Haruyama[2], Yasumasa Kasaba[4], YASUKO KASAI[5], Ayako Matsuoka[2] (1.Tokyo Institute of Technology, 2.JAXA, 3.Hokkaido University, 4.Tohoku University, 5.NICT, 6.Hiroshima University)

[PPS01-18] The Io Volcano Observer (IVO): Investigating the Interior of a Tidally Heated World

★Invited Papers

*Christopher W. Hamilton[1], Alfred S. McEwen[1], Xianzhe Jia[2], and the IVO Science Team (1.University of Arizona, 2.University of Michigan)

[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS02] Lunar Science and Exploration

convener:Masaki N Nishino(Japan Aerospace Exploration Agency, Institute of Space and Astronautical Science), Masahiro KAYAMA(Department of General Systems Studies, Graduate School of Arts and Sciences, The University of Tokyo), Hiroshi Nagaoka(Japan Aerospace Exploration Agency), Yusuke Nakauchi(Japan Aerospace Exploration Agency)

[PPS02-01] Energetic Neutral Atom Imaging for Lunar science: Interactions between space plasma, exosphere, and surface

★Invited Papers

*Yoshifumi Futaana[1] (1.Swedish Institute of Space Physics)

[PPS02-02] Development of a detection system for new craters using feature-based image registration

*Emi Morikawa[1], Keisuke Onodera[2,3], Kei Shirai[4], Mitsuo Yamamoto[5], Satoshi Tanaka[5] (1.The University of Tokyo, 2.University of Paris / Institut de Physique du Globe de Paris, 3.The Graduate University for Advanced Studies (SOKENDAI), 4.Kobe University, 5.Institute of Space and Astronautical Science (ISAS) / Japan Aerospace Exploration Agency)

[PPS02-03] Are old continental crusts of the Earth Theia-origin?: Implications for the origin of the Moon

*Masaki Ogawa[1] (1.Division of General Systems Studies, Graduate School of Arts and Sciences, University of Tokyo)

[PPS02-04] **High-pressure and -temperature experiments simulating the lunar KREEP layer and constraint on its water content**

Miki Muranushi[1], *Masahiro KAYAMA[2], Tsuyoshi MIYAMOTO[3], Seiji Kamada[5], Hiroshi Nagaoka[4], Akio Suzuki[1] (1.Department of Earth Science, Graduate School of Science, Tohoku University, 2.Department of General Systems Studies, Graduate School of Arts and Sciences, The University of Tokyo, 3.Center for Northeast Asian Studies, Tohoku University, 4.Japan Aerospace Exploration Agency, 5.Frontier Research Institute for Interdisciplinary Sciences, Tohoku University)

[PPS02-06] SLIM (Smart Lander for Investigating Moon) project for pin-point landing demonstration

★Invited Papers

*Shin-ichiro Sakai[1], Kenichi Kushiki[1], Syujiro Sawai[1], Seisuke Fukuda[1], Tetsuhito Arakawa[1], Hiroo Saito[1], Haruhiko Shimoji[2], Project Team SLIM[1] (1.Japan Aerospace Exploration Agency, 2.Mitsubishi Electric Corporation)

[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS02] Lunar Science and Exploration

convener:Masaki N Nishino(Japan Aerospace Exploration Agency, Institute of Space and Astronautical Science), Masahiro KAYAMA(Department of General Systems Studies, Graduate School of Arts and Sciences, The University of Tokyo), Hiroshi Nagaoka(Japan Aerospace Exploration Agency), Yusuke Nakauchi(Japan Aerospace Exploration Agency)

[PPS02-09] Global emissions of carbon ions from the total lunar surface

*Shoichiro Yokota[1], Kentaro Terada[1], Yoshifumi Saito[2], Kazushi Asamura[2], Masaki N Nishino[2], Hisayoshi Shimizu[3], Futoshi Takahashi[4], Hidetoshi Shibuya[5], Masaki Matsushima[6], Hideo Tsunakawa[2] (1.Osaka University, 2.ISAS/JAXA, 3.Earthquake Research Institute, The University of Tokyo, 4.Kyushu University, 5.Kumamoto University, 6.Tokyo Institute of Technology)

[PPS02-10] **Status on Japanese Lunar Polar Exploration Mission**

★Invited Papers

*Dai ASOH[1], Takeshi HOSHINO[1], Makiko OHTAKE[1], Yuzuru KAROUJI[1] (1.Japan Aerospace Exploration Agency)

[PPS02-11] Examination of water observation procedure in lunar polar exploration

*Yuzuru Karouji[1], Makiko Ohtake[1], Hiroaki Shiraishi[1], Hiroshi Kanamori[1], Inoue Hiroka[1], Takeshi Hoshino[1], Dai Asoh[1], Lunar Polar Exploration Pre-Project Team[1] (1.Japan Aerospace Exploration Agency)

[PPS02-12] The research review on the plasma and dust environment of the moon toward the participation in NASA's Artemis program

*Hideyuki Usui[1], Masaki N Nishino[2], Noriyuki Namiki[3], Yuko Inatomi[2], Makiko Ohtake[2], Tomokatsu Morota[4], Tomohiro Usui[2] (1.Graduate school of system informatics Kobe University, 2.JAXA/ISAS, 3.NAOJ, 4.School of Science The university of Tokyo)

[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS04] Regolith Science

convener:Koji Wada(Planetary Exploration Research Center, Chiba Institute of Technology), Akiko Nakamura(Graduate School of Science, Kobe University), Patrick Michel(Universite Cote D Azur Observatoire De La Cote D Azur CNRS Laboratoire Lagrange), Kevin John Walsh(Southwest Research Institute Boulder)

[PPS04-01] Crater scaling laws in low speed impacts

*Onur Celik[1], Daniel J. Scheeres[2], Yasuhiro Kawakatsu[3] (1.The Graduate University for Advanced Studies (SOKENDAI), 2.University of Colorado Boulder (CU Boulder), 3.Japan Aerospace Exploration Agency (JAXA))

[PPS04-02] Impact experiments for crater scaling laws and impact-induced seismic shaking on rubble-pile asteroids

*Yuya Yamamoto[1], Masahiko Arakawa[1], Minami Yasui[1], Sunao Hasegawa[2], Ryo Sugimura[1], Yusaku Yokota[1], Hatsune Okawa[1] (1.Graduate School of Science, Kobe University, 2.Japan Aerospace Exploration Agency)

[PPS04-03] The size of ejecta particles of the artificial impact crater formed by Hayabusa2 Small Carry-on Impactor

*Koji Wada[1], Ko Ishibashi[1], Hiroshi Kimura[1], Masahiko Arakawa[2], Hirotaka Sawada[3], Kazunori Ogawa[3,2], Kei Shirai[2], Rie Honda[4], Yuichi Iijima[3], Toshihiko Kadono[5], Naoya Sakatani[3], Yuya Mimasu[3], Tomoaki Toda[3], Yuri Shimaki[3], Satoru Nakazawa[3], Hajime Hayakawa[3], Takanao Saiki[3], Yasuhiko Takagi[6], Hiroshi Imamura[3], Chisato Okamoto[2], Masahiko Hayakawa[3], Naru Hirata[7], Hajime Yano[3] (1.Planetary Exploration Research Center, Chiba Institute of Technology, 2.Kobe University, 3.JAXA, 4.Kochi University, 5.University of Occupational and Environmental Health, 6.Aichi Toho University, 7.The University of Aizu)

[PPS04-04] Space impact experiment on Ryugu: Pattern of ejecta curtain and the properties of particles in surface and subsurface layers

★Invited Papers

*Toshihiko Kadono[1], Masahiko Arakawa[2], Rie Honda[3], Ko Ishibashi[4], Kazunori Ogawa[5], Naoya Sakatani[5], Yuri Shimaki[5], Seiji Sugita[6], Koji Wada[4] (1.University of Occupational and Environmental Health, 2.Graduate School of Science, Kobe University, 3.Departiment of Scinece and Technology, System of Natural Science, Kochi University, 4.Planetary Exploration Research Center, Chiba Institute of Technology, 5.Institute of Space and Astronautical Science, 6.Graduate School of Science, The University of Tokyo)

[PPS04-05] Thermophysical property of the artificial impact crater on asteroid Ryugu

*Naoya Sakatani[1], Satoshi Tanaka[1], Tatsuaki Okada[1], Toru Kouyama[2], Akira Miura[1], Naru Hirata[3], Hiroki Senshu[4], Takehiko Arai[5], Yuri Shimaki[1], Hirohide Demura[3], Kentaro Suko[3], Tomohiko Sekiguchi[6], Jun Takita[7], Tetsuya Fukuhara[8], Makoto Taguchi[8], Thomas G. Müller[9], Axel Hagermann[10], Jens Biele[11], Matthias Grott[11], Maximilian Hamm[12,11], Marco Delbo[13], Mizuki Ito[1,19], Naoyuki Hirata[14], Masahiko Arakawa[14], Kazunori Ogawa[15,14], Koji Wada[4], Toshihiko Kadono[16], Rie Honda[17], Kei Shirai[14], Takanao Saiki[1], Hiroshi Imamura[1], Yasuhiko Takagi[18], Hajime Yano[1], Masahiko Hayakawa[1], Chisato Okamoto[14], Hirotaka Sawada[1], Satoru Nakazawa[1], Yu-ichi Iijima[1], Seiji Sugita[19], Tomokatsu Morota[19], Manabu Yamada[4], Shingo Kameda[8], Eri Tatsumi[20], Yasuhiro Yokota[1], Hidehiko Suzuki[21], Chikatoshi Honda[3], Kazuo Yoshioka[19], Moe Matsuoka[1], Yuichiro Cho[19] (1.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 2.National Institute of Advanced Industrial Science and Technology, 3.University of Aizu, 4.Chiba Institute of Technology, 5.Ashikaga University, 6.Hokkaido University of Education, 7.Hokkaido Kitami Hokuto High School, 8.Rikkyo University, 9.Max-Planck Institute for Extraterrestrial Physics, 10.University of Stirling, 11.German Aerospace Center, 12.University of Potsdam, 13.Observatoire de la Côte d'Azur, CNRS, 14.Kobe University, 15.JAXA Space Exploration Center, Japan Aerospace Exploration Agency, 16.University of Occupational and Environmental Health, 17.Kochi University, 18.Aichi Toho University, 19.University of Tokyo, 20.Instituto de Astrofisica de Canarias, 21.Meiji University)

[PPS04-06] Experimental study on the relaxation of slope terrain due to small-scale impact

*Tomomi Omura[1], Shinta Takizawa[1], Hiroaki Katsuragi[1] (1.Department of Earth and Environmental Sciences, Nagoya University)

[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS04] Regolith Science

convener:Koji Wada(Planetary Exploration Research Center, Chiba Institute of Technology), Akiko Nakamura(Graduate School of Science, Kobe University), Patrick Michel(Universite Cote D Azur Observatoire De La Cote D Azur CNRS Laboratoire Lagrange), Kevin John Walsh(Southwest Research Institute Boulder)

[PPS04-07] Investigation into the characteristics of granular materials in low gravitational environment (Introduction of Hourglass mission)

★Invited Papers

*Masatsugu Otsuki[1], Shingo Ozaki[2], Genya Ishigami[3], Takao Maeda[4], Masataku Sutoh[1], Taizo Kobayashi[5], Hideaki Miyamoto[6], Koji Wada[7], Chihiro Kurosawa[1], Yuta Kawai[1], Haruo Kasahara[1], Tetsuya Sakashita[1], Shinobu Doi[1], Hideaki Uchikawa[1], Terumitsu Mano[1] (1.Japan Aerospace Exploration Agency, 2.Yokohama National University, 3.Keio University, 4.Chuo University, 5.Ritsumeikan University, 6.The University of Tokyo, 7.Chiba Institute of Technology)

[PPS04-08] Surface Flow Analysis Based on Spectral Distributions around Larger Boulders on Ryugu

*Naofumi Takaki[1], ERI TATSUMI[1,2], Tomokatsu Morota[1], Yuichiro Cho[1], Kazuo Yoshioka[1], Hirotaka Sawada[3], yokota yasuhiro[3,4], Naoya Sakatani[3], Masahiko Hayakawa[3], Rie Honda[4], Shingo Kameda[5], Moe Matsuoka[3], Manabu Yamada[6], Chikatoshi Honda[7], Toru Kouyama[8], Hidehiko Suzuki[9], Kazunori Ogawa[3,10], Hideaki Miyamoto[1], Naru Hirata[7], Naoyuki Hirata[10], Seiji Sugita[1] (1.The University of Tokyo, 2.Instituto de Astrofísica de Canarias, 3.Japan Aerospace Exploration Agency, 4.Kochi University, 5.Rikkyo University, 6.Planetary Exploration Research Center Chiba Institute of Technology, 7.The University of Aizu, 8.National Institute of Advanced Industrial Science and Technology, 9.Meiji University, 10.Kobe University)

[PPS04-09] Global Geology of Bennu from NASA's OSIRIS-REx Space Mission

*Kevin John Walsh[1], Erica R Jawin[2], Timothy McCoy[2], Harold Connolly[3], Dante S Lauretta[4], Ronald-Louis Ballouz[4], Olivier S Barnouin[5], Chloe Beddingfield[6], Carina Bennet[4], Edward Bierhaus[7], Keara Burke[4], Benton Clark[8], Michael Daly[9], Marco Delbo[10], Daniella DellaGiustina[4], Jason Dworkin[11], Christine Hartzell[12], John Marshall[6], Patrick Michel[10], Jamie Molaro[13], Michael Nolan[4], Maurizio Pajola[14], Michael Perry[5], Bashar Rizk[4], Scott Sandford[15], Daniel Scheeres[16], Steven Schwartz[4], David Trang[17] (1.Southwest Research Institute Boulder, 2.Smithsonian National Institute, 3.Dept. of Geology, Rowan University, 4.Lunar and Planetary Laboratory, University of Arizona, 5.Johns Hopkins University Applied Physics Laboratory, 6.SETI Institute, 7.Lockheed Martin Space, 8.Space Science Institute, 9.York University, 10.Laboratoire Lagrange, Université Côte d'Azur, 11.NASA Goddard Space Flight Center, 12.Department of Aerospace Engineering, University of Maryland, 13.Planetary Science Institute, 14.INAF - Astronomical Observatory of Padova, 15.NASA Ames Research Center, 16.Smead Dept. of Aerospace Engineering Sciences, University of Colorado, 17.HIGP/University of Hawaii at Manoa)

[PPS04-10] Equatorial features on asteroid (101955) Bennu support mass loss by fission

*Alan R Hildebrand[1], Lincoln TJ Hanton[1], Fabio Ciceri[1], Olivier S Barnouin[2], Michael G Daly[3], Jeff A Seabrook[3], Benjamin Rozitis[4], Joshua P Emery[5], Daniella N DellaGiustina[6], Bashar Rizk[6], Michael C Nolan[6], Dante S Lauretta[6], Catherine Johnson[10], Daniel J Scheeres[7], Edward B Bierhaus[8], Paul Sanchez[9] (1.Department of Geoscience, University of Calgary, Calgary, AB, Canada, 2.The Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA, 3.The Centre for Research in Earth and Space Science, York University, Toronto, ON, Canada, 4.The Open University, Milton Keynes, UK, 5.Northern Arizona University, Flagstaff, AZ, USA, 6.Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA, 7.Smead Department of Aerospace Engineering, University of Colorado, Boulder, CO, USA, 8.Lockheed Martin Space, Littleton, CO, USA, 9.Colorado Center for Astrodynamics Research, University of Colorado, Boulder, CO, USA, 10.Department of Earth, Ocean and Atmospheric Sciences, University of British Columbia, Vancouver, BC, Canada)

[PPS04-12] The Morphological, Elastic, and Electric Properties of Dust Aggregates in Comets: A Close Look at COSIMA/Rosetta's Data on Dust in Comet 67P/Churyumov-Gerasimenko

*Hiroshi Kimura[1], Martin Hilchenbach[2], Sihane Merouane[2], John Paquette[2], Oliver Stenzel[2] (1.Planetary Exploration Research Center (PERC), 2.Max Planck Institute for Solar System Research)

[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS05] Planetary Seismic Exploration-From InSight and Apollo to Future Missions-

convener:Taichi Kawamura(Institut de Physique du Globe de Paris), Takeshi Tsuji(Department of Earth Resources Engineering, Kyushu University), Ralph Lorenz(Johns Hopkins University Applied Physics Laboratory), William Bruce Banerdt(Jet Propulsion Laboratory)

[PPS05-01] SEIS-InSight on Mars: results and first constrains on Mars's seismic noise, seismicity and crust/subsurface structure after one year of operation

★Invited Papers

*Philippe Henri Lognonné[1], Domenico Giardini[2], W. Bruce Banerdt[3], W. Tom Pike[4], Maren Böse[5,2], Savas Ceylan[2], Ullrich Christensen[6], John Clinton[2], Martin van Driel[2], Raphael F. Garcia[7], Taichi Kawamura[1], Sharon Kedar[3], Amir Khan[2,8], Brigitte Knapmeyer-Endrun[9], Ludovic Margerin[10], Francis Nimmo[11], Mark Panning[3], Clément Perrin[1], Sue Smrekar[3], Simon Stähler[2], Benoit Tauzin[12], John-Robert Schloz[6], InSight SEIS science team (1.Université de Paris, Institut de physique du globe de Paris, CNRS, 2.Institute of Geophysics, ETH Zurich, Sonneggstr. 5, 8092 Zurich, Switzerland, 3.Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA, 4.Department of Electrical and Electronic Engineering, Imperial College London, South Kensington Campus, London SW7 2AZ, UK, 5.Swiss Seismological Service (SED), ETH Zurich Zurich Switzerland, 6.Max Planck Institute for Solar System Research, Justus-von-Liebig-Weg 3, 37077 Göttingen, Germany, 7.Institut Supérieur de l'Aéronautique et de l'Espace SUPAERO, 10 Avenue Edouard Belin, 31400 Toulouse, France, 8.Institute of Theoretical Physics, University of Zurich Zurich Switzerland, 9.Bensberg Observatory, University of Cologne, Vinzenz-Pallotti-Str. 26, 51429 Bergisch Gladbach, Germany, 10.Institut de Recherche en Astrophysique et Planétologie, Université Toulouse III Paul Sabatier, CNRS, CNES, 14 Av. E. Belin, 31400, Toulouse, France, 11.Dept. of Earth and Planetary Sciences, University of California Santa Cruz, Santa Cruz, CA 95064, USA, 12.Université de Lyon, Université Claude Bernard Lyon 1, ENS, CNRS, Laboratoire de Géologie de Lyon : Terre, Planètes, Environnement, 69622 Villeurbanne, France)

[PPS05-03] "Time-reversal" inversion of InSight seismogram for quake estimation

*Nobuaki Fuji[1], Alice Jacob[1], Clément Perrin[1], Éléonore Stutzmann[1], Philippe Lognonné[1], Mark Panning[3], Bruce Banerdt[3], Simon Stähler[2], Martin van Driel[2], Savas Ceylan[2], Mélanie Drilleau[1], Taichi Kawamura[1] (1.Université de Paris, Institut de physique du globe de Paris, 2.ETH Zürich, 3.NASA Jet Propulsion Laboratory)

[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS05] Planetary Seismic Exploration-From InSight and Apollo to Future Missions-

convener:Taichi Kawamura(Institut de Physique du Globe de Paris), Takeshi Tsuji(Department of Earth Resources Engineering, Kyushu University), Ralph Lorenz(Johns Hopkins University Applied Physics Laboratory), William Bruce Banerdt(Jet Propulsion Laboratory)

[PPS05-06] Seismic investigation of the Moon: Past, Present, and Future

★Invited Papers

*Renee C Weber[1], Clive Neal[2], Bruce Banerdt[3], Sharon Kedar[3], Nicholas Schmerr[4], Mark Panning[3], Philippe Lognonne[5], Taichi Kawamura[5], Ceri Nunn[3], Angela Marusiak[4], Deanna Phillips[9], Yosio Nakamura[7], Caroline Beghein[6], Raphael Garcia[8] (1.NASA Marshall Space Flight Center, 2.Universtiy of Notre Dame, 3.NASA JPL, 4.University of Maryland, 5.IPGP Paris, 6.University of California, Los Angeles, 7.University of Texas, Austin, 8.ISAE SUPAERO, 9.University of Alabama, Huntsville)

[PPS05-07] VBB on the Moon: Expected performances and science return

*Tanguy Nebut[1,2,3], Philippe Lognonne[1,3], Sébastien de Raucourt[1,3], Taichi Kawamura[1,3], Gabriel Pont[4], Taoufik Gabsi[1,2,3], Sylvain Tillier[1,2,3], Olivier Robert[1,2,3], Michel Parise[1,2,3] (1.Institut de Physique du Globe de Paris, 2.CNRS, 3.Université de Paris, 4.CNES)

[PPS05-09] Seismic wave propagation on asteroid Ryugu induced by the impact experiment of the Hayabusa2 mission

*Gaku Nishiyama[1], Taichi Kawamura[2], Noriyuki Namiki[3], Benjamin Fernando[4], Kuangdai Leng[4], Takanao Saiki[5], Hiroshi Imamura[5], Yasuhiko Takagi[6], Kei Shirai[5], Masahiko Hayakawa[5], Chisato Okamoto[7], Hirotaka Sawada[5], Yuichi Tsuda[5], Kazunori Ogawa[5], Masahiko Arakawa[7] (1.University of Tokyo, 2.Institut de Physique du Globe de Paris, 3. RISE Project, National Astronomical Observatory of Japan, 4.University of Oxford, 5.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 6.Aichi Toho University, 7.Kobe University)

[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS06] Science of Venus: Venus Express, Akatsuki, and beyond

convener:Takehiko Satoh(Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency), Kevin McGouldrick(University of Colorado Boulder), Hideo Sagawa(Kyoto Sangyo University), Thomas Widemann(Observatoire De Paris)

[PPS06-01] Next generation Japan's Venus Exploration in 2020s

★Invited Papers

*Masato Nakamura[1], Atsushi Yamazaki[1], Ryoma Yamashiro[2], Nobuaki Ishii[1], Tomoaki Toda[1], Yoshifumi Futaana[4], Sanjay S. Limaye[3], Naoki Terada[5], Hiroki Ando[6], Toru Kouyama[7], Takehiko Satoh[1], Takeshi Imamura[8], Makoto Taguchi[9], Yoshi-Yuki Hayashi[10], Takeshi Horinouchi[11], Yeon Joo Lee[12], Masahiro Takagi[6], Masataka Imai[7], Tetsuya Fukuhara[9], Norihiko Sugimoto[13], Hiroki Kashimura[10], Shigeto Watanabe[14], Takao M. Sato[14], George L. Hashimoto[15], Shin-ya Murakami[1], Kevin McGouldrick[16], Takumi Abe[1], Chikako Hirose[2], Manabu Yamada[17], Kazunori Ogohara[18], Ko-ichiro Sugiyama[19], Shoko Ohtsuki[20], Javier Peralta[1], Seiko Takagi[11], Naomoto Iwagami, Munetaka Ueno[2], Takeshi Sakanoi[5], Shingo Kameda[9], Yasumasa Kasaba[5], Yukihiro Takahashi[11], Mitsuteru Sato[11], Yoshihisa Matsuda[21], Masaru Yamamoto[22] (1.Institute of Space and Astronautical Science of Japan Aerospace Exploration Agency, 2.Japan Aerospace Exploration Agency, 3.Univ. of Wisconsin, 4.IRF, 5.Tohoku Univ., 6.Kyoto Sangyo Univ., 7.AIST, 8.Univ. of Tokyo, 9.Rikkyo Univ., 10.Kobe Univ., 11.Hokkaido Univ., 12.TU Berlin, 13.Keio Univ., 14.Hokkaido Joho Univ., 15.Okayama Univ., 16.Colorado Univ., 17.Chiba Institute of Technology, 18.Univ. of Shiga prefecture, 19.National Institute of Technologuy, Matsue college, 20.Senshu Univ., 21.Tokyo Gakugei Univ., 22.Kyusyu Univ.)

[PPS06-02] EnVision M5 Venus Orbiter Proposal

*Thomas Widemann[1], Colin Wilson[2], Richard Ghail[3], Dmitri Titov[4] (1.Observatoire de Paris, F, 2.Oxford University, UK, 3.Royal Holloway London, UK, 4.ESTEC, NL)

[PPS06-03] Improving Venus gravity field with the Envision candidate mission

★Invited Papers

*Pascal Rosenblatt[1], Caroline Dumoulin[1], Jean-Charles Marty[2], Antonio Genova[3] (1.Laboratory of Planetology and Geodynamics, 2.CNES/GRGS, 3.Sapienza Rome University)

[PPS06-04] Crustal recycling and the history of magmatism in Venus

*Masaki Ogawa[1] (1.Division of General Systems Studies, Graduate School of Arts and Sciences, University of Tokyo)

[PPS06-05] Constraining the Formation of Venus with N-body simulations of Terrestrial Planet Formation

*Patryk Sofia Lykawka[1], Takashi Ito[2] (1.School of Interdisciplinary Social and Human Sciences, Kindai University, 2.National Astronomical Observatory of Japan)

[PPS06-06] VERITAS: Discovering the Secrets of a Lost Habitable World

★Invited Papers

*Suzanne E Smrekar[1] (1.Jet Propulsion Laboratory)

[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS06] Science of Venus: Venus Express, Akatsuki, and beyond

convener:Takehiko Satoh(Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency), Kevin McGouldrick(University of Colorado Boulder), Hideo Sagawa(Kyoto Sangyo University), Thomas Widemann(Observatoire De Paris)

[PPS06-07] Wavelet analysis of gravity wave packets in Venus' atmosphere using radio occultation temperature profiles

Ryota Mori[1], *Takeshi Imamura[1], Hiroki Ando[2], Bernd Hausler[3], Martin Patzold[4], Silvia Tellmann[4] (1.Graduate School of Frontier Sciences, The University of Tokyo, 2.Faculty of Science, Kyoto Sangyo University, 3.Universitat der Bundeswehr Munchen, Germany, 4.Universitat zu Koln, Germany)

[PPS06-08] Cross-link Radio Occultation measurements of Venus Atmosphere by using multiple small satellites

*Hiroki Ando[1], Satoshi Ikari[2], Takeshi Imamura[3], Tomotaka Yamamoto[2], Yosuke Kawabata[2], Shoko Sano[2], Norihiko Sugimoto[4], Masahiro Takagi[1], Hideo Sagawa[1], Yukiko Fujisawa[4], Mutsuko Morimoto[4], Mirai Abe[5], Asako Hosono[6], Ryu Funase[2] (1.Faculty of Science, Kyoto Sangyo University, 2.Department of Aeronautics and Astronautics, The University of Tokyo, 3.Graduate School of Frontier Science, The University of Tokyo, 4.Department of Physics, Keio University, 5.Faculty of Law, Keio University, 6.Toshimagaoka Women High School)

[PPS06-09] Determination of the homopause altitude on Venus from SOIR/VEx observations

★Invited Papers

*Arnaud Mahieux[1,2], Hiromu Nakagawa[3], Nao Yoshida[3], Ann Carine Vandaele[1], Roger Yelle[4], Séverine Robert[1], Shohei Aoki[1,5], Arianna Piccialli[1], Loïc Trompet[1], Yasumasa Kasaba[3] (1.Royal Belgian Institute for Space Aeronomy, Brussels, Belgium, 2.The University of Texas at Austin, Austin, Texas, 3.Tohoku University, Sendai, Japan, 4.University of Arizona, Tucson, Arizona, 5.Université de Liège, Liège, Belgium)

[PPS06-10] Long term monitoring of planetary scale temperature variations at the cloud top level of Venus by Akatsuki/LIR observations

★Invited Papers

*Toru Kouyama[1], Masataka Imai[1], Takeshi Horinouchi[2], Takeshi Imamura[3], Makoto Taguchi[4], Tetsuya Fukuhara[4] (1.National Institute of Advanced Industrial Science and Technology, 2.Hokkaido University, 3.University of Tokyo, 4.Rikkyo University)

[PPS06-11] Dayside cloud top structure of Venus retrieved from Akatsuki IR2 observations

*Takao M. Sato[1], Takehiko Satoh[2], Hideo Sagawa[3], Naohiro Manago[4], Yeon Joo Lee[5], Shin-ya Murakami[2], Kazunori Ogohara[6], George HASHIMOTO[7], Yasumasa Kasaba[8], Atsushi Yamazaki[2], Manabu Yamada[9], Shigeto Watanabe[1], Takeshi Imamura[10], Masato Nakamura[2] (1.Hokkaido Information University, 2.ISAS/JAXA, 3.Kyoto Sangyo University, 4.Chiba University, 5.Technische Universität Berlin, 6.The University of Shiga Prefecture, 7.Okayama Unviersity, 8.Tohoku University, 9.Chiba Institute of Technology, 10.The University of Tokyo)

[PPS06-12] Variability of UV albedo and its relation to the wind field revealed by Akatsuki UVI

*Tatsuro Iwanaka[1], Takeshi Imamura[1], Yeon Joo Lee[2], Takeshi Horinouchi[3] (1.The Univesity of Tokyo, 2.Technical University of Berlin, 3.Hokkaido University)

[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS06] Science of Venus: Venus Express, Akatsuki, and beyond

convener:Takehiko Satoh(Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency), Kevin McGouldrick(University of Colorado Boulder), Hideo Sagawa(Kyoto Sangyo University), Thomas Widemann(Observatoire De Paris)

[PPS06-13] Topographic waves in the Venus atmosphere

*Anna Suzuki[1], Masahiro Takagi[1], Yasumitsu Maejima[2], Hiroki Ando[1], Norihiko Sugimoto[3], Yoshihisa Matsuda[4] (1.Kyoto Sangyo University, 2.RIKEN Center for Computational Science, 3.Keio University, 4.Tokyo Gakugei University)

[PPS06-14] Akatsuki IR2 camera data restoration towards revealing Venus's middle cloud properties

★Invited Papers

*Choon Wei Vun[1], Takehiko Satoh[2,1], Takao M. Sato[3], Takeshi Horinouchi[4] (1.SOKENDAI, 2.ISAS/JAXA, 3.Hokkaido Information University, 4.Hokakido University)

[PPS06-15] Variations of Venus night clouds as observed by Akatsuki/IR2

*Takehiko Satoh[1,2], Choon Wei Vun[2], Takeshi Horinouchi[3], Takao M. Sato[4] (1.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 2.Department of Space and Astronautical Science, The Graduate University for Advanced Studies, SOKENDAI, 3.Faculty of Environmental Earth Science, Hokkaido University, 4.Space Information Center, Hokkaido Information University)

[PPS06-16] Effect of Insoluble Sulfur on the Microphysics of the Sulfuric Acid Clouds of Venus

*Kevin McGouldrick[1] (1.University of Colorado Boulder)

[PPS06-17] Status of lightning search in Venus

*Yukihiro Takahashi[1,2], Masataka Imai[3], Mitsuteru Sato[1,2], Ralph Lorenz[4], Tatsuharu Ono[1] (1.Department of Cosmosciences, Graduate School of Science, Hokkaido University, 2.Faculty of Science, Hokkaido University, 3.AIST, 4.Applied Physics Laboratory, Johns Hopkins University)

[PPS06-18] Searching minor species on Venus atmosphere using the high-dispersion spectra taken by IRTF/iSHELL

*Hideo Sagawa[1], Takao M. Sato[2], Hajime Kita[3] (1.Faculty of Science, Kyoto Sangyo University, 2.Hokkaido Information University, 3.Japan Aerospace Exploration Agency)

[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS07] Solar System Small Bodies: Explorations of Ryugu, Bennu, and the Solar System at Large

convener:Taishi Nakamoto(Tokyo Institute of Technology), Tatsuaki Okada(Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency), Dante S Lauretta(University of Arizona), Masateru Ishiguro(Department of Physics and Astronomy, Seoul National University)

[PPS07-01] Technological challenges and achievements in Hayabusa2 mission

*Makoto Yoshikawa[1], Yuichi Tsuda[1], Satoru Nakazawa[1], Fuyuto Terui[1], Takanao Saiki[1] (1.Japan Aerospace Exploration Agency)

[PPS07-02] Surface evolution of carbonaceous asteroid Ryugu revealed from touchdown operation of Hayabusa2

★Invited Papers

*Tomokatsu Morota[1], Seiji Sugita[1], Yuichiro Cho[1], Masanori Kanamaru[2], ERI TATSUMI[3], Naoya Sakatani[4], Rie Honda[5], Naoyuki Hirata[6], Hiroshi Kikuchi[4], Manabu Yamada[7], yokota yasuhiro[4], Shingo Kameda[8], Moe Matsuoka[4], Hirotaka Sawada[4], Chikatoshi Honda[9], Toru Kouyama[10], Kazunori Ogawa[4], Hidehiko Suzuki[11], Kazuo Yoshioka[1], Masahiko Hayakawa[4], Naru Hirata[9], Masatoshi Hirabayashi[12], Hideaki Miyamoto[1], Tatsuhiro Michikami[13], Takahiro Hiroi[14], Carolyn M. Ernst[15], Olivier S. Barnouin[15], Sei-ichiro WATANABE[16] (1.The University of Tokyo, 2.Osaka University, 3.Universidad de La Laguna, 4.JAXA, 5.Kochi University, 6.Kobe University, 7.Chiba Institute of Technology, 8.Rikkyo University, 9.The University of Aizu, 10.AIST, 11.Meiji University, 12.Auburn University, 13.Kindai University, 14.Brown University, 15.APL/JHU, 16.Nagoya University)

[PPS07-03] Thermal evolution of Ryugu inffered from spectral characterization of experimentally-heated CI carbonaceous chondrite

*Kana Amano[1], Tomoki Nakamura[1], Fumihiko Usui[2], Satoshi Okumura[1], Michael E. Zolensky[3] (1.Tohoku University, 2.Kobe University, 3.NASA Johnson Space Center)

[PPS07-04] Morphological and spectral trends among boulders on asteroid 162173 Ryugu: implication for parent body processes

*Koki Yumoto[1], Yuichiro Cho[1], Tomokatsu Morota[1], Eri Tatsumi[1,10], Yokota Yasuhiro[2,3], Naoya Sakatani[2], Kazuo Yoshioka[1], Hirotaka Sawada[2], Rie Honda[3], Shingo Kameda[4], Manabu Yamada[5], Chikatoshi Honda[6], Toru Kouyama[7], Moe Matsuoka[2], Hidehiko Suzuki[8], Kazunori Ogawa[9,11], Masahiko Hayakawa[2], Hideaki Miyamoto[1], Chiho Sugimoto[1], Seiji Sugita[1] (1.Univ. of Tokyo, 2.JAXA, 3.Kochi Univ., 4.Rikkyo Univ., 5.PERC, Chiba Institute of Technology, 6.Univ. of Aizu, 7.AIST, 8.Meiji Univ., 9.JSEC, JAXA, 10.Instituto de Astrofisica de Canarias, 11.Kobe Univ.)

[PPS07-05] Time-dependent spectroscopic and mineralogical changes by heating of Murray CM chondrite

*Yuri Fujioka[1], Tomoki Nakamura[1], Kana Amano[1], Shiho Kobayashi[1], Aki Takigawa[2] (1.Department of Earth Science, Graduate School of Science, Tohoku University, 2.Division of Earth and Planetary Science, Kyoto University)

[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS07] Solar System Small Bodies: Explorations of Ryugu, Bennu, and the Solar System at Large

convener:Taishi Nakamoto(Tokyo Institute of Technology), Tatsuaki Okada(Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency), Dante S Lauretta(University of Arizona), Masateru Ishiguro(Department of Physics and Astronomy, Seoul National University)

[PPS07-06] Artificial impact crater formed by Small Carry-on Impactor on the asteroid 162173 Ryugu in the gravity-dominated regime

★Invited Papers

*Masahiko Arakawa[1], Takanao Saiki[2], Toshihiko Kadono[3], Yasuhiko Takagi[4], Koji Wada[5], Yu-ichi Iijima[2], Hiroshi Imamura[2], Chisato Okamoto[1], Yuri Shimaki[2], Kei Shiai[1], Satoru Nakazawa[2], Masahiko Hayakawa[2], Naru Hirata[6], Hajime Yano[2], Hirotaka Sawada[2], Kazunori Ogawa[2], Rie Honda[7], Ko Ishibashi[5], Naoya Sakatani[2], Tomoaki Toda[2], Hajime Hayakawa[2], Seiji Sugita[8], Tomokatsu Morota[8], Shingo Kameda[9], ERI TATSUMI[13], Chikatoshi Honda[6], yokota yasuhiro[2], Toru Kouyama[10], Manabu Yamada[5], Hidehiko Suzuki[11], Kazuo Yoshioka[8], Yuichiro Cho[8], Moe Matsuoka[2], Patrick Michel[12] (1.Kobe University, 2.Japan Aerospace Exploration Agency, 3.University of Occupational and Environmental Health, 4.Aichi Toho University, 5.Chiba Institute of Technology, 6.University of Aizu, 7.Kochi University, 8.The University of Tokyo, 9.Rikkyo University, 10.National Institute of Advanced Industrial Science and Technology, 11.Meiji University, 12.Observatoire de la Côte d'Azur, 13.Instituto de Astrofisica de Canarias)

[PPS07-07] Assessing the Small carry-on Impactor debris operated by the Hayabusa2 mission: an evaluation by FT-IR, micro-Raman, STXM and NanoSIMS.

*Motoo Ito[1], Yoshinori Takano[2], Takuji Ohigashi[3], Hayato Yuzawa[3], Yoko Kebukawa[4], Kento Kiryu[4], Masayuki Uesugi[5], Naotaka Tomioka[1], Yu Kodama[7], Hiroshi Naraoka[6], Toru Yada[8], Masanao Abe[8] (1.Kochi Institute for Core Sample Research, JAMSTEC, 2.Biogeochemistry Program, JAMSTEC, 3.UVSOR, Institute for Molecular Science, 4.Yokohama National University, 5.JASRI, 6.Kyushu University, 7.Marine Works Japan, 8.JAXA)

[PPS07-08] Subsurface structure inferred from the relation between craters and their surrounding boulders on asteroid Ryugu

*Sei-ichiro WATANABE[1,2], Hiroki Akahane[1], Tomokatsu Morota[3,1], Tatsuhiro Michikami[4], Naru Hirata[5], Naoyuki Hirata[6], Yuri Shimaki[2], Rina Noguchi[2], Rie Honda[7], Shingo Kameda[8], Manabu Yamada[9], Naoya Sakatani[2], Kazunori Ogawa[2], ERI TATSUMI[10], Toru Kouyama[11], yokota yasuhiro[2,7], Yuichiro Cho[3], Hidehiko Suzuki[12], Masahiko Hayakawa[2], Moe Matsuoka[2], Chikatoshi Honda[5], Kazuo Yoshioka[3], Hirotaka Sawada[2], Seiji Sugita[3], Masahiko Arakawa[6], Hayabusa2 Science Team[13] (1.Nagoya University, 2.JAXA, 3.University of Tokyo, 4.Kindai University, 5.University of Aizu, 6.Kobe University, 7.Kochi University, 8.Rikyo University, 9.Chiba Institute of Technology, 10.University of La Laguna, 11.National Institute of Advanced Industrial Science and Technology, 12.Meiji University, 13.Hayabusa2 Project)

[PPS07-09] Highly Porous Asteroid 162173 Ryugu Derived from Lowest Temperatures in a Day

*Tatsuaki Okada[1,2], Tetsuya Fukuhara[3], Satoshi Tanaka[1], Takehiko Arai[4], Naoya Sakatani[1], Yuri Shimaki[1], Hiroki Senshu[5], Hirohide Demura[6], Kentaro Suko[6], Tomohiko Sekiguchi[7], Toru Kouyama[8], Ayumu Ohsugi[1,2] (1.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 2.University of Tokyo, 3.Rikkyo University, 4.Ashikaga University, 5.Chiba Institute of Technology, 6.University of Aizu, 7.Hokkaido University of Education, 8.National Institute of Advanced Industrial Science and Technology)

[PPS07-10] Thermophysical Properties of Ryugu Estimated from a Box-A Observation

*Yuri Shimaki[1], Hiroki Senshu[2], Naoya Sakatani[1], Tatsuaki Okada[1,3], Tetsuya Fukuhara[4], Satoshi Tanaka[1,5], Makoto Taguchi[4], Takehiko Arai[6], Hirohide Demura[7], Kentaro Suko[7], Tomohiko Sekiguchi[8], Toru Kouyama[9], Jun Takita[10], Sunao Hasegawa[1] (1.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 2.Chiba Institute of Technology, 3.University of Tokyo, 4.Rikkyo University, 5.The Graduate University for Advanced Studies, SOKENDAI, 6.Ashikaga University, 7.University of Aizu, 8.Hokkaido University of Education, 9.National Institute of Advanced Industrial Science and Technology (AIST), 10.Hokkaido Kitami Hokuto High School)

[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS07] Solar System Small Bodies: Explorations of Ryugu, Bennu, and the Solar System at Large

convener:Taishi Nakamoto(Tokyo Institute of Technology), Tatsuaki Okada(Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency), Dante S Lauretta(University of Arizona), Masateru Ishiguro(Department of Physics and Astronomy, Seoul National University)

[PPS07-11] Spectral heterogeneities at the surface of Ryugu as seen by the NIRS3 spectrometer

*Lucie Riu[1], NIRS3 Team, Hayabusa2 Science Team (1.Institut of Space and Astronautical Science (ISAS/JAXA))

[PPS07-12] The ESA Hera mission: rendezvous with a binary asteroid and planetary defense

★Invited Papers

*Patrick Michel[1], Tatsuaki Okada[2], Michael Kueppers[3], Ian Carnelli[4], Paolo Martino[5], Adriano Campo Bagatin[6], Benoit Carry[1], Sebastien Charnoz[7], Julia de Leon[8], Alan Fitzsimmons[9], Simon Green[10], Carsten Guettler[11], Alain Herique[12], Martin Jutzi[13], Ozgur Karatekin[14], Naomi Murdoch[15], Petr Pravec[16], Holger Sierks[11], Colin Snodgrass[17], Paolo Tortora[18], Kleomenis Tsiganis[19], Stephan Ulamec[20], Jean-Baptiste Vincent[20], Kai Wuennemann[21], Andy Cheng[22], Andy Rivkin[22], Nancy Chabot[22], Olivier S Barnouin[22], Carolyn Ernst[22], Derek C Richardson[23], Angela Stickle[22], Masahiko Arakawa[24], Akiko Nakamura[24], Hideaki Miyamoto[25], Seiji Sugita[25], Makoto Yoshikawa[2] (1.Universite Cote D Azur Observatoire De La Cote D Azur CNRS Laboratoire Lagrange, 2.ISAS JAXA, 3.ESA ESAC, 4.ESA HQ, 5.ESA ESTEC, 6.University of Alicante, 7.IPGP, 8.Instituto de Astrofisica de Canarias, 9.Queen's University, 10.The Open University, 11.Max Planck Institute, 12.IPAG, 13.University of Bern, 14.Royal Observatory of Belgium, 15.ISAE-Supaero, 16.Czech Academy of Sciences, 17.The University of Edinburgh, 18.University of Bologna, 19.University of Thessaloniki, 20.DLR, 21.Natural History Museum Berlin, 22.APL JHU, 23.University of Maryland, 24.Kobe University, 25.The University of Tokyo)

[PPS07-13] Science of DESTINY+ mission

*Tomoko Arai[1], Masanori Kobayashi[1], Ko Ishibashi[1], Fumi Yoshida[1], Hiroshi Kimura[1], Takayuki Hirai[1], Peng Hong[1], Ralf Srama[2], Harald Kruger[3], Naoya Okazaki[4], Takayuki Yamamoto[4], Hiroyuki Toyota[4], Kazutaka Nishiyama[4], Takeshi Takashima[4], DESTINY+ Science team (1.Planetary Exploration Research Center, Chiba Institute of Technology, 2.University of Stuttgart, 3.Max Planck Institute, 4.JAXA)

[PPS07-14] Multiple Asteroid Flyby Tour Design Utilizing Low-Thrust and Gravity-Assist for DESTINY+ Mission

*Ozaki Naoya[1], Takayuki Yamamoto[1], Nishanth Pushparaj[2], Diogene Alessandro Dei Tos[1], Onur Celik[2], Ferran Gonzalez-Franquesa[2], Roger Gutierrez Ramon[2], Kanako Machii[4], Takuya Chikazawa[5], Tomoko Arai[3], Yasuhiro Kawakatsu[1], Kazutaka Nishiyama[1], Takeshi Takashima[1] (1.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 2.SOKENDAI, the Graduate University for Advanced Studies, 3.Planetary Exploration Research Center, Chiba Institute of Technology, 4.University of Electro-Communications, 5.University of Tokyo)

[PPS07-15] Twinkle: a visible and near-infrared space-based observatory for exoplanet and solar system spectroscopy

*Billy Nelson Edwards[1,2], Giovanna Tinetti[1,2], Marcell Tessenyi[2,1], Giorgio Savini[1,2], Jonathan Tennyson[1,2], Richard Archer[2], Ian Stotesbury[2], Max Joshua[2], Benjamin Wilcock[2] (1.University College London , 2.Blue Skies Space Ltd.)

[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS07] Solar System Small Bodies: Explorations of Ryugu, Bennu, and the Solar System at Large

convener:Taishi Nakamoto(Tokyo Institute of Technology), Tatsuaki Okada(Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency), Dante S Lauretta(University of Arizona), Masateru Ishiguro(Department of Physics and Astronomy, Seoul National University)

[PPS07-16] OSIRIS-REx: Prospects for the Return of Pristine Carbonaceous Regolith from Asteroid (101955) Bennu

*Dante S Lauretta[1], Hannah H Kaplan[2], Humberto Campins[3], Harold C Connolly[4], Daniella N DellaGiustina[1], Jason P Dworkin[5], Heather L Enos[1], Daniel P Glavin[5], Timothy D Glotch[6], Dathon R Golish[1], Victoria E Hamilton[2], Romy D Hanna[7], Erica R Jawin[8], Timothy J McCoy[8], Amy A Simon[5], Nicholas Porter[1], Dennis Reuter[5] (1.University of Arizona, Tucson, AZ, USA, 2.Southwest Research Institute, Boulder, CO, USA , 3.University of Central Florida, Orlando, FL, USA, 4.Rowan University, Glassboro, NJ, USA, 5.NASA Goddard Space Flight Center, Greenbelt, MD, USA, 6.Stony Brook University, Stony Brook, NY, USA, 7.University of Texas, Austin, TX, USA, 8.Smithsonian Institution National Museum of Natural History, Washington, DC, USA)

[PPS07-17] **Overcoming the Challenges of Sample Collection at Nightingale**

★Invited Papers

*Michael C Moreau[1], Dante Lauretta[2] (1.NASA Goddard Space Flight Center, 2.University of Arizona)

[PPS07-18] **The Measured Gravity and Global Geophysical Properties of (101955) Bennu**

*Daniel Jay Scheeres[1], J W McMahon[1], A S French[1], A B Davis[1], D N Brack[1], S Chesley[2], D Farnocchia[2], Y Takahashi[2], R S Park[2], J Leonard[3], P Antreasian[3], K Getzandanner[4], A Liounis[4], D E Highsmith[4], D Rowlands[4], E Mazarico[4], M Moreau[4], P Tricarico[5], O S Barnouin[6], M G Daly[7], R W Gaskell[5], E E Palmer[5], J Weirich[5], C L Johnson[8], M M Al Asad[8], J A Seabrook[7], J Roberts[7], C W Hergenrother[9], M C Nolan[9], D S Lauretta[9] (1.University of Colorado Boulder, 2.Jet Propulsion Laboratory, 3.KinetX, 4.Goddard Space Flight Center, 5.Planetary Sciences Institute, 6.Applied Physics Laboratory, 7.York University, 8.University of British Colombia, 9.Lunar and Planetary Laboratory, University of Arizona)

[PPS07-19] Apparently Layered Boulders with Multiple Textures on Bennu's Surface

*Kana Ishimaru[1], Dathon R Golish[1], Nicholas Porter[1], Manar M Al Asad[3], Ronald Ballouz[1], Daniellla N DellaGuistina[1], Bashar Lizk[1], Kevin John Walsh[2], Dante S Lauretta[1] (1.Lunar and Planetary Laboratory, University of Arizona, 2.Southwest Research Institute, 3.Department of Earth, Oceans, and Atmospheric Sciences, The University of British Columbia)

[PPS07-20] The Phenomenon of Particle Ejections from Asteroid Bennu

*Coralie Dominique Adam[1], Dante S Loretta[2], Carl W Hergenrother[2], Steven R Chesley[3] (1.KinetX Inc., Space Navigation and Flight Dynamics Practice, Simi Valley, CA, USA, 2.Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA, 3.Jet Propulsion Laboratory, Pasadena, CA, USA)

[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS07] Solar System Small Bodies: Explorations of Ryugu, Bennu, and the Solar System at Large

convener:Taishi Nakamoto(Tokyo Institute of Technology), Tatsuaki Okada(Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency), Dante S Lauretta(University of Arizona), Masateru Ishiguro(Department of Physics and Astronomy, Seoul National University)

[PPS07-21] Evolution of thermally metamorphosed C-complex asteroids inferred from a heated CM chondrite Jbilet Winselwan

★Invited Papers

*Wataru Fujiya[1], Hisato Higashi[1], Yuki Hibiya[2], Shingo Sugawara[1], Akira Yamaguchi[3], Makoto Kimura[3], Ko Hashizume[1] (1.Ibaraki University, College of Science, 2.Japan Agency for Marine-Earth Science and Technology, 3.National Institute of Polar Research)

[PPS07-22] Aggregate structure of comet 67P/Churyumov-Gerasimenko

*Sota ARAKAWA[1,2], Kazumasa Ohno[3,2] (1.NAOJ, 2. Tokyo Tech, 3.UCSC)

[PPS07-23] Numerical Simulations of Spinup of Asteroids and the Formation of Top-Shaped Asteroids

*Keisuke Sugiura[1], Hiroshi Kobayashi[2], Sei-ichiro WATANABE[3], Hidenori Genda[1], Ryuki Hyodo[4], Shu-ichiro Inutsuka[2] (1.Tokyo Institute of Technology, Earth Life Science Institute, 2.Nagoya University, Department of Physics, 3.Nagoya University, Department of Earth and Environmental Sciences, 4.JAXA, ISAS, Department of Solar System Sciences)

[PPS07-24] YORP Effect on Asteroid Ryugu

*Masanori Kanamaru[1], Sho Sasaki[1], Tomokatsu Morota[2], Yuichiro Cho[2], Naru Hirata[3], Naoyuki Hirata[4], Hiroki Senshu[5], Yuri Shimaki[6], Satoshi Tanaka[6], Tatsuaki Okada[6], Tomohiro Usui[6], Seiji Sugita[2], Sei-ichiro WATANABE[7] (1.Osaka University, 2.The University of Tokyo, 3.The University of Aizu, 4.Kobe University, 5.Chiba Institute of Technology, 6.ISAS/JAXA, 7.Nagoya University)

[PPS07-25] Likelihood for rubble-pile near-Earth asteroids to be 1st or Nth generation: focus on Bennu and Ryugu

*Kevin John Walsh[1], Ronald Ballouz[2], William F Bottke[1], Chrysa Avdellidou[3], Harold C Connolly Jr.[4], Marco Delbo[3], Daniella N DellaGiustina[2], Erica R Jawin[5], Timothy McCoy[5], Patrick Michel[3], Tomokatsu Morota[6], Michael C Nolan[2], Steven R Schwartz[2], Seiji Sugita[6], Dante S Lauretta[2] (1.Southwest Research Institute Boulder, 2.Lunar and Planetary Laboratory, University of Arizona, 3.Laboratoire Lagrange, Université Côte d'Azur, 4.Dept. of Geology, Rowan University, 5.Smithsonian Institution National Museum of Natural History, 6.University of Tokyo)

[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS08] Mars and Mars system: results from a broad spectrum of Mars studies and aspects for future missions

convener:Hideaki Miyamoto(University of Tokyo), Tomohiro Usui(Japan Aerospace Exploration Agency), Yuki Harada(Kyoto University), Sushil K Atreya(University of Michigan Ann Arbor)

[PPS08-01] On possibility of visualization of Martian space environment with diffuse aurora: Relations between magnetic field structure and solar energetic electron penetration into the upper atmosphere observed by MAVEN

*Kanako Seki[1], Takuya Hara[2], Dave A Brain[3], Rob J. Lillis[2], Naoki Terada[4], Hiromu Nakagawa[4], Darvin E. Larson[2], Dave L. Mitchell[2], Gina A. Dibraccio[5], Nicholas McCord Schneider[3], Sonal K. Jain[3], Janet G. Luhmann[2], Bruce M. Jakosky[3] (1.Graduate School of Science, University of Tokyo, 2.Space Sciences Laboratory, University of California, Berkeley, 3.LASP, University of Colorado, Boulder, 4.Graduate School of Science, Tohoku University, 5.Goddard Space Flight Center, NASA)

[PPS08-02] Low electron temperatures observed at Mars by MAVEN on dayside crustal magnetic field lines

★Invited Papers

*Shotaro Sakai[1,2], Thomas E. Cravens[3], Laila Andersson[4], Christopher M. Fowler[5], David L. Mitchell[5], Christian Mazelle[6], Edward M. B. Thiemann[4], David A. Brain[4], Kanako Seki[1] (1.Graduate School of Science, University of Tokyo, 2.Graduate School of Science, Tohoku University, 3.Department of Physics and Astronomy, University of Kansas, 4.Laboratory for Atmospheric and Space Physics, University of Colorado Boulder, 5.Space Science Laboratory, University of California, Berkeley, 6.IRAP, Université de Toulouse, CNRS, CNES, UPS-OMP)

[PPS08-03] A warm layer in the nightside mesosphere of Mars

*Hiromu Nakagawa[1], Sonal K Jain[2], Nicholas M Schneider[2], Franck Montmessin[3], Roger V Yelle[4], Fayu Jiang[4], Loic Verdier[3], Takeshi Kuroda[1], Nao Yoshida[1], Hitoshi Fujiwara[5], Takeshi Imamura[6], Kaori Terada[1], Naoki Terada[1], Kanako Seki[7], Hannes Groller[4], Justin I Deighan[2] (1.Planetary Atmosphere Physics Laboratory, Department of Geophysics, Graduate School of Science, Tohoku University, 2.Laboratory for Atmospheric and Space Physics, University of Colorado, 3.Laboratoire Atmosphères, Milieux, Observations Spatiales, 4.Lunar and Planetary Laboratory, University of Arizona, 5.Faculty of Science and Technology, Seikei University, 6.Graduate School of Frontier Sciences, The University of Toky, 7.Graduate School of Science, The University of Tokyo)

[PPS08-04] Studying martian dust storms, clouds, and associated meteorology using observations from Indian and foreign satellite missions

*JAGABANDHU PANDA [1], Bijay Kumar Guha[1] (1.National Institute of Technology Rourkela)

[PPS08-05] Greeley et al. (2006) revisited: the size distribution and frequency of dust devils at the Gale crater

*Kazunori Ogohara[1] (1.School of Engineering, University of Shiga Prefecture)

[PPS08-06] Observations of the Martian atmosphere by NOMAD on ExoMars Trace Gas Orbiter

★Invited Papers

*Ann Carine Vandaele[1], Frank Daerden[1], Ian R. Thomas[1], Shohei Aoki[1,2], Cédric Depiesse[1], Justin T. Erwin[1], Lori Neary[1], Bojan Ristic[1], Yannick Willame[1], Jean-Claude Gérard[2], Giuliano Liuzzi[3], Geronimo Villanueva[3], Jon Mason[4], Manish R. Patel[4], Francesca Altieri[5], Giancarlo Bellucci[5], Miguel Lopez-Valverde[6], Jose-Juan Lopez-Moreno[6] (1.Royal Belgian Institute for Space Aeronomy, Brussels, Belgium, 2.Laboratory for Planetary and Atmospheric Physics, University Liège, Belgium, 3.NASA Goddard Space Flight Center, Greenbelt, MD, USA, 4.School of Physical Sciences, The Open University, Milton Keynes, UK, 5.Istituto di Astrofisica e Planetologia Spaziali (IAPS/INAF), Rome, Italy, 6.Instituto de Astrofisica de Andalucia (IAA/CSIC), Granada, Spain)

[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS08] Mars and Mars system: results from a broad spectrum of Mars studies and aspects for future missions

convener:Hideaki Miyamoto(University of Tokyo), Tomohiro Usui(Japan Aerospace Exploration Agency), Yuki Harada(Kyoto University), Sushil K Atreya(University of Michigan Ann Arbor)

[PPS08-07] Strong seasonal and diurnal variability of water D/H on Mars as revealed with ExoMars/NOMAD

★Invited Papers

*Geronimo Luis Villanueva[1], Giuliano Liuzzi[1,2], Matteo James Crismani[1], Shohei Aoki[3], Ann-Carine Vandaele[3], Michael Jon Mumma[1], Michael D Smith[1], Frank Daerden[3], Ian R Thomas[3], Miguel Angel Lopez-Valverde[4], Bojan Ristic[3], Manish R Patel[5], Giancarlo Bellucci[6], Jose Juan Lopez-Moreno[4] (1.NASA Goddard Space Flight Center, 2.Department of Physics, American University, USA, 3.Royal Belgian Institute for Space Aeronomy, Belgium, 4.Instituto de Astrofísica de Andalucía, Spain, 5.Open University, UK, 6.Istituto di Astrofisica e Planetologia, Italy)

[PPS08-08] Retrievals of ice clouds, dust and ozone from NOMAD/UVIS on board Exomars TGO

*Yannick Willame[1], Ann C. Vandaele[1], Arianna Piccialli[1], Cédric Depiesse[1], Frank Daerden[1], Ian R. Thomas[1], Bojan Ristic[1], Jon Mason[2], Manish R. Patel[2], Giancarlo Bellucci[3], Jose-Juan Lopez-Moreno[4], NOMAD Team (1.Royal Belgian Institute for Space Aeronomy (IASB-BIRA), av. Circulaire 3, 1180 Brussels, Belgium, 2.School of Physical Sciences, The Open University, Milton Keynes, UK, 3.Istituto di Astrofisica e Planetologia Spaziali (IAPS/INAF), Via del Fosso del Cavaliere, 00133 Rome, Italy, 4.Instituto de Astrofisica de Andalucia (IAA/CSIC), Granada, Spain)

[PPS08-09] Evolution of hydrological and glaciological activities on early Mars before late Tharsis formation

*Arihiro Kamada[1], Takeshi Kuroda[1], Yasumasa Kasaba[1], Naoki Terada[1], Hiromu Nakagawa[1], Katsushige Toriumi[1] (1.Graduate School of Science, Tohoku University)

[PPS08-10] Permittivity of subsurface on Mars and its importance for electromagnetic wave reflection method such as radar sounder and ground penetrating radar

*Makito Kobayashi[1], Takafumi Niihara[1], Hideaki Miyamoto[1], Atsushi Kumamoto[2], Toshiyuki Nishibori[3] (1.University of Tokyo, 2.Tohoku University, 3.Japan Aerospace eXploration Agency)

[PPS08-11] TIMINGS OF MARTIAN WRINKLE RIDES, A GLOBAL INVESTIGATION

*Trishit Ruj[1], KENJI KAWAI[1] (1.Department of Earth and Planetary Science, School of Science, The University of Tokyo)

[PPS08-12] Displacement-Length Ratios and Contractional Strains of Wrinkle Ridges in Thaumasia Minor and Solis Planum, Mars

DIPAYAN DASGUPTA[1], *ABHIK KUNDU[1] (1.Asutosh College, Kolkata, India)

[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS08] Mars and Mars system: results from a broad spectrum of Mars studies and aspects for future missions

convener:Hideaki Miyamoto(University of Tokyo), Tomohiro Usui(Japan Aerospace Exploration Agency), Yuki Harada(Kyoto University), Sushil K Atreya(University of Michigan Ann Arbor)

[PPS08-13] **The Giant Sinkholes of Mars: Furthering our Understanding of the Red Planet's Hydrosphere**

★Invited Papers

*Alexis Palmero Rodriguez[1], Hideaki Miyamoto[2], Victor Baker[3] (1.Planetary Science Institute, 2.University of Tokyo, 3.University of Arizona)

[PPS08-15] Constraining the Formation of Mars with N-body simulations of Terrestrial Planet Formation

*Patryk Sofia Lykawka[1], Takashi Ito[2] (1.School of Interdisciplinary Social and Human Sciences, Kindai University, 2.National Astronomical Observatory of Japan)

[PPS08-16] Extensive delivery of Martian ejecta to its moons: The gateway to a time-resolved history of Mars

*Hidenori Genda[1], Ryuki Hyodo[2], Kosuke Kurosawa[3], Tomohiro Usui[2], Kazuhisa Fujita[2] (1.Earth-Life Science Institute, Tokyo Institute of Technology, 2.JAXA ISAS, 3.Planetary Exploration Research Center, Chiba Institute of Technology)

[PPS08-17] Morphological characteristics of small craters of Phobos

*Ryodo Hemmi[1], Hideaki Miyamoto[1] (1.The University of Tokyo)

[PPS08-18] The MMX Rover: objectives, science goals, and contributions to the MMX mission

*Hideaki Miyamoto[1], Patrick Mitchel[2], Stephan Ulamec[3], Ute Böttger[3], Matthias Grott[3], Naomi Murdoch[4], Pierre Vernazza[5], MMX Rover team (1.University of Tokyo, 2.Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, 3.Deutsches Zentrum für Luft- und Raumfahrt e.V. , 4.Institut Supérieur de l'Aéronautique et de l'Espace, 5.Laboratoire d'Astrophysique de Marseille)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM11] Heliosphere and Interplanetary Space

convener:Kazumasa Iwai(Institute for Space–Earth Environmental Research (ISEE), Nagoya University), Yasuhiro Nariyuki(Faculty of Education, University of Toyama), Ken Tsubouchi(University of Electro-Communications), Masaki N(Japan Aerospace Exploration Agency, Institute of Space and Astronautical Science)

[PEM11-01] Stream Interaction Regions in the Inner Heliosphere: Insights from the First Four Orbits of Parker Solar Probe

★Invited Papers

*Robert Colby Allen[1], George Ho[1], Lan K Jian[2], David Lario[2], Dusan Odstrcil[2], Charles Nick Arge[2], Sam T Badman[4,5], Steward D Bale[4,5,7,8], John W Bonnell[5], Anthony W Case[9], Eric R Christian[2], Christina M. S. Cohen[3], Thierry Dundok de Wit[10], Keith Goetz[11], Peter R Harvey[5], Carl J Henney[12], Matt E Hill[1], Shaela I Jones[2,6], Justin C Kasper[13,9], Kelly E Korreck[9], Davin Larson[5], Roberto Livi[5], Robert J MacDowall[2], David M Malaspina[14], Glenn M Mason[1], M Leila Mays[2], David J McComas[15], Ralph McNutt Jr.[1], Don G Mitchell[1], Marc Pulupa[5], Nour Raouafi[1], Nathon Schwadron[16], Michael L Stevens[9], Sarah K Vines[1], Phyllis L Whittlesey[5], Mark Wiedenbeck[17] (1.Johns Hopkins University Applied Physics Laboratory, 2.NASA/Goddard Space Flight Center, 3.California Institute of Technology, 4.Physics Department, University of California Berkeley, 5.Space Sciences Laboratory, University of California Berkeley, 6.Catholic University of America, 7.The Blackett Laboratory, Imperial College London, 8.School of Physics and Astronomy, Queen Mary University of London, 9.Smithsonian Astrophysical Observatory, 10.LPC2E, CNRS, 11.School of Physics and Astronomy, University of Minnesota, 12.Air Force Research Laboratory, Space Vehicles Directorate, 13.Climate and Space Sciences and Engineering, University of Michigan, 14.Laboratory for Atmospheric and Space Physics, University of Colorado Boulder, 15.Princeton University, Department of Astrophysical Sciences, 16.University of New Hampshire, Space Science Center, 17.Jet Propulsion Laboratory)

[PEM11-02] Hinode Observation of Sun's Polar Regions over a solar cycle

*Daikou Shiota[1], Masumi Shimojo[2] (1.National Institute of Information and Communications Technology (NICT), 2.National Astronomical Observatory of Japan)

[PEM11-03] Coronal radio sounding using Akatuski spacecraft: variation in the solar cycle

*Shota Chiba[1], Takeshi Imamura[1], Munetoshi Tokumaru[2], Ayumi Asai[3], Hiroaki Isobe[4], Daikou Shiota[5], Takuma Matsumoto[6], Hiroki Ando[7] (1.Graduate School of Frontier Sciences, The University of Tokyo, 2.Institute for Space-Earth Environmental Research, Nagoya University, 3.Astronomical Observatory, Kyoto University, 4.Faculty of Fine Arts, Kyoto City University of Arts, 5.National Institute of Information and Communications Technology (NICT), 6.Nagoya University, Ta Lab, 7.Kyoto Sangyo University)

[PEM11-04] Global distribution of the solar wind speed during Cycle 22-24

*Munetoshi Tokumaru[1], Ken'ichi Fujiki[1], Kazumasa Iwai[1], Nobuhiko Nishimura[1], Ryuya Maeda[1] (1.Institute for Space-Earth Environmental Research, Nagoya University)

[PEM11-05] Next generation interplanetary scintillation observation telescope using 2D phased array system

*Kazumasa Iwai[1], Munetoshi Tokumaru[1], Ken'ichi Fujiki[1] (1.Institute for Space–Earth Environmental Research (ISEE), Nagoya University)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM11] Heliosphere and Interplanetary Space

convener:Kazumasa Iwai(Institute for Space–Earth Environmental Research (ISEE), Nagoya University), Yasuhiro Nariyuki(Faculty of Education, University of Toyama), Ken Tsubouchi(University of Electro-Communications), Masaki N(Japan Aerospace Exploration Agency, Institute of Space and Astronautical Science)

[PEM11-07] **Ion scale waves and kinetic instabilities in the inner heliosphere**

*Jungjoon Seough[1], Yasuhiro Nariyuki[2], Peter Yoon[1,3,4], Kyung-Suk Cho[1] (1.KASI, 2.UT, 3.UMD, 4.KHU)

[PEM11-08] Effects of initial density fluctuations on linear and nonlinear evolution of parametric decay instabilities of circularly polarized Alfven waves

*Yasuhiro Nariyuki[1] (1.Faculty of Education, University of Toyama)

[PEM11-09] **Search of energy source of 1-16Hz Whistler Mode Waves Detected by Kaguya in the Lunar Polar Orbit**

*Tomoko Nakagawa[1], Futoshi Takahashi[2], Hisayoshi Shimizu[3], Yoshifumi Saito[4] (1.Information and Communication Engineering, Tohoku Institute of Technology, 2.Department of Earth and Planetary Sciences, Faculty of Science, Kyushu University, 3.Earthquake Research Institute, University of Tokyo, 4.Solar System Science Division, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency)

[PEM11-10] Relationship between the inner heliosheath thickness and the pickup ion density

*Ken Tsubouchi[1] (1.University of Electro-Communications)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM12] Coupling Processes in the Atmosphere-Ionosphere System

convener:Huixin Liu(Earth and Planetary Science Division, Kyushu University SERC, Kyushu University), Yuichi Otsuka(Institute for Space-Earth Environmental Research, Nagoya University), Yue Deng(University of Texas at Arlington), Loren Chang(Institute of Space Science, National Central University)

[PEM12-01] Inter-hemispheric Coupling During Sudden Stratospheric Warming Events

Kristina Shizuka Yamase Skarvang[2], *Patrick J Espy[1], Robert E. Hibbins[1], Willem E. van Caspel[1] (1.Norwegian Univ. of Science and Technology, Birkeland Centre for Space Science, 2.Norwegian Univ. of Science and Technology)

[PEM12-02] Dynamical characteristics of the middle atmosphere associated with the Antarctic sudden stratospheric warming in 2019.

★Invited Papers

*Kaoru Sato[1], Yoshihiro Tomikawa[2], Dai Koshin[1] (1.Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, 2.National Institute of Polar Research)

[PEM12-03] WACCMX Simulations of the 2002 and 2019 Southern Hemisphere Sudden Stratospheric Warmings

★Invited Papers

*Nicholas M Pedatella[1] (1.National Center for Atmospheric Research)

[PEM12-04] Characteristics of small-scale gravity waves in the Arctic winter mesosphere

*JING LI[1], TAO LI[2,3], QIAN WU[4], YIHUAN TANG[2], ZHAOPENG WU[1,3], JUN CUI[1] (1.Planetary Environmental and Astrobiological Research Laboratory (PEARL), School of Atmospheric Sciences, Sun Yat-sen University, Zhuhai, Guangdong, China, 2.CAS Key Laboratory of Geospace Environment, School of Earth and Space Sciences, University of Science and Technology of China, Hefei, Anhui, China, 3.CAS Center for Excellence in Comparative Planetology, Hefei, Anhui, China, 4.High Altitude Observatory, National Center for Atmospheric Research, Boulder, CO, USA)

[PEM12-05] Studying atmospheric and ionospheric variabilities in the mesopause and ionospheric F2-region during winter sudden stratospheric warmings of various types

*Irina Medvedeva[1,2], Konstantin Ratovsky[1], Alla Suvorova[3] (1.Institute of Solar-Terrestrial Physics SB RAS, Irkutsk, Russia , 2.Obukhov Institute of Atmospheric Physics RAS, Moscow, Russia , 3.GPSARC National Central University, Taoyuan, Taiwan)

[PEM12-06] Influences of migrating semidiurnal tide variabilities on the low latitude ionosphere

*Jia-Ting Lin[1], Charles Lin[1], Loren Chang[2,3], Hanli Liu[4], Nicholas M Pedatella[4,5] (1.Department of Earth Sciences, National Cheng Kung University, Taiwan, 2.Center for Astronautical Physics and Engineering, National Central University, Taoyuan, Taiwan, 3.Graduate Institute of Space Science, National Central University, Taoyuan, Taiwan, 4.High Altitude Observatory, National Center for Atmospheric Research, Boulder, CO, USA, 5.COSMIC Program Office, University Corporation for Atmospheric Research, Boulder, CO, USA)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM12] Coupling Processes in the Atmosphere-Ionosphere System

convener:Huixin Liu(Earth and Planetary Science Division, Kyushu University SERC, Kyushu University), Yuichi Otsuka(Institute for Space-Earth Environmental Research, Nagoya University), Yue Deng(University of Texas at Arlington), Loren Chang(Institute of Space Science, National Central University)

[PEM12-07] A model-data comparative study of large-scale ionospheric disturbances during the 17 March 2015 storm

★Invited Papers

*Gang Lu[1], Irina Zakharenkova[2], Iurii Cherniak[2], Tong Dang[3] (1.National Center for Atmospheric Research, 2.COSMIC Program Office, University Corporation for Atmospheric Research, 3.University of Science and Technology of China)

[PEM12-08] Evolution of mid-latitude density irregularities and scintillation during storms

★Invited Papers

*Toshi Nishimura[1], Sebastijan Mrak[1], Josh Semeter[1] (1.Boston University)

[PEM12-09] Growin: Modeling Ionospheric Instability Growth Rates and Giving Away the Code

*Jonathon Smith[1,2] (1.Catholic University of America, 2.NASA Goddard Space Flight Center)

[PEM12-10] Spatial and temporal relation among magnetic ripples, wavy structure of electron density fluctuation and GPS TEC variations

*Toshihiko Iyemori[1], Tadashi Aoyama[1], Yoshihiro Yokoyama[1], Akiyasu Yamada[1] (1.Kyoto University)

[PEM12-11] Temporal and spatial variations of the total electron content enhancement from the mid-latitude to the equator associated with a geomagnetic storm

*Atsuki Shinbori[1], Yuichi Otsuka[1], Sori Takuya[1], Takuya Tsugawa[2], Michi Nishioka[2] (1.Institute for Space-Earth Environment Research (ISEE), Nagoya University, 2.National Institute of Information and Communications Technology)

[PEM12-12] Atmospheric influence on relationship between solar and ionospheric 27-day variations

*Konstantin Ratovsky[1], Maxim Klimenko [2], Vladimir Klimenko[2], Alexei Dmitriev[3], Loren Chang[3] (1.Institute of Solar-Terrestrial Physics SB RAS, 2.West Department of Pushkov IZMIRAN, RAS, 3.National Central University)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM12] Coupling Processes in the Atmosphere-Ionosphere System

convener:Huixin Liu(Earth and Planetary Science Division, Kyushu University SERC, Kyushu University), Yuichi Otsuka(Institute for Space-Earth Environmental Research, Nagoya University), Yue Deng(University of Texas at Arlington), Loren Chang(Institute of Space Science, National Central University)

[PEM12-13] Observations of Atmospheric Waves in the Thermosphere from New Earth-Orbiting Spacecraft

★Invited Papers

*Scott England[1] (1.Virginia Tech)

[PEM12-14] Observations of the Thermosphere-Ionosphere System by the Global-scale Observations of the Limb and Disk (GOLD) Mission

★Invited Papers

*Richard Eastes[1] (1.Laboratory for Atmospheric and Space Physics/University of Colorado)

[PEM12-15] Initial result on aurora and airglow observations with the all sky 630nm imager on Shirase

*Takeshi Sakanoi[1], Naoshi Yagi[1], Yuta Hozumi[2], Takuo T. Tsuda[2], Takeshi Aoki[2], Akinori Saito[3], Takahiro Naoi[5], Takanori Nishiyama[4], Mitsumu K. Ejiri[4] (1.Planetary Plasma and Atmospheric Research Center, Graduate School of Science, Tohoku University, 2.Graduate School of Informatics and Engineering, The University of Electro-Communications, 3.Graduate School of Science, Kyoto University, 4.National Institute of Polar Research, 5.National Institute of Information and Communications Technology)

[PEM12-16] **Comparison between migrating atmospheric tides in TIMED/SABER observations and free running WACCM-X simulations**

*Yi Chung Chiu[1], Loren Chang[1], Cornelius Csar Jude Salinas[1], Qian Liying [2] (1.Graduate Institute of Space Science and Engineering, National Central University, Taiwan, 2.High Altitude Observatory, National Center for Atmospheric Research, Boulder, Colorado, USA)

[PEM12-17] Interannual Variation of Diurnal Tide Components in Tropical Lower Thermospheric Temperatures

*Cornelius Csar Jude Salinas[1], Huixin Liu[2], Loren Chang[1], Jia Yue[3], James Russell[4], Martin G Mlynczak[5] (1.National Central University, 2.Kyushu University, 3.NASA Goddard Space Flight Center, 4.Hampton University, 5.NASA Langley Research Center)

[PEM12-18] Dynamical response in the upper atmosphere: GAIA simulation with doubled CO2

*Huixin Liu[1], Chihiro Tao[2], H. Jin[2] (1.Earth and Planetary Science Division, Kyushu University SERC, Kyushu University, 2.NICT)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM12] Coupling Processes in the Atmosphere-Ionosphere System

convener:Huixin Liu(Earth and Planetary Science Division, Kyushu University SERC, Kyushu University), Yuichi Otsuka(Institute for Space-Earth Environmental Research, Nagoya University), Yue Deng(University of Texas at Arlington), Loren Chang(Institute of Space Science, National Central University)

[PEM12-19] **Energy Flux and Conductance from Meso-Scale Auroral Features**

★Invited Papers

*Christine Gabrielse[1], Toshi Nishimura[2], Margaret Chen[1], James Hecht[1], Larry Lyons[3], Yue Deng[4] (1.The Aerospace Corporation, 2.Boston University, 3.UCLA, 4.University of Texas, Arlington)

[PEM12-20] Study of latitudinal and longitudinal differences of mesospheric and ionospheric waves based on 3-dimentional FFT analysis of long-term multi-point airglow images

★Invited Papers

*Kazuo Shiokawa[1], Yuichi Otsuka[1], Takuji Nakamura[2] (1.Institute for Space-Earth Environmental Research, Nagoya University, 2.National Institute of Polar Research)

[PEM12-22] Global distribution of the mesoscale disturbances at 95km altitude detected by a space-borne airglow observation

*Akinori Saito[1], Ryota Okada[1], Takeshi Sakanoi[2], Yuta Hozumi[3] (1.Department of Geophysics, Graduate School of Science, Kyoto University, 2.Planetary Plasma and Atmospheric Research Center, Graduate School of Science, Tohoku University, 3.University of Electro-Communications)

[PEM12-23] **Recurrent high-speed solar wind co-rotating interaction region imprint on the ionosphere and atmosphere: GPS TEC variations and atmospheric gravity waves**

*Paul Prikryl[1,2], James M. Weygand[3], Reza Ghoddousi-Fard[4], Lidia Nikitina[2], Bharat S. R. Kunduri[5] (1.Physics Department University of New Brunswick, Canada , 2.Geomagnetic Laboratory Natural Resources Canada, 3.Earth Planetary and Space Sciences, University of California, USA, 4.Canadian Geodetic Survey Natural Resources Canada , 5.Bradley Dept. of Electrical and Computer Engineering, Virginia Tech, USA)

[PEM12-24] Observation of secondary gravity waves over the Southern Andes during an intense mountain wave event.

*Masaru Kogure[1], Jia Yue[2,3], Takuji Nakamura[1,4], Lars Hoffmann[5], Sharon Vadas[6], Yoshihiro Tomikawa[1,4], Mitsumu K. Ejiri[1,4], Diego Janches[2,3] (1.National Institute of Polar Research, 2.NASA Goddard Space Flight Center, 3.Catholic University of America, 4.SOKENDAI (The Graduate University for Advanced Studies), 5.Forschungszentrum Jülich, 6.NorthWest Research Associates)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM12] Coupling Processes in the Atmosphere-Ionosphere System

convener:Huixin Liu(Earth and Planetary Science Division, Kyushu University SERC, Kyushu University), Yuichi Otsuka(Institute for Space-Earth Environmental Research, Nagoya University), Yue Deng(University of Texas at Arlington), Loren Chang(Institute of Space Science, National Central University)

[PEM12-25] Importance of Realistic Auroral Precipitation, Electrical Field Variability, and Model Resolution in Resolving the Storm-Time Neutral Temperature and Density

★Invited Papers

*Xian Lu[1], Haonan Wu[1], Gang Lu[2], Xinzhao Chu[3,4], Wenbin Wang[2], Delores Delores[2,4], Yukitoshi Nishimura[5] (1.Department of Physics and Astronomy, Clemson University, Clemson, SC, USA, 2.High Altitude Observatory, National Center for Atmospheric Research, Boulder, CO, USA, 3.Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, CO, USA, 4.Department of Aerospace Engineering Sciences, University of Colorado, Boulder, CO, USA, 5.College of Electrical and Computer Engineering, Boston University, Boston, MA, USA)

[PEM12-26] Driver and Response Characteristics for Improved Physics-Based Simulation of the Thermosphere

★Invited Papers

*Eric K Sutton[1], Marcin Pilinski[2], Greg Lucas[2], Jeffrey P Thayer[1], Thomas E Berger[1] (1.Space Weather Technology, Research & Education Center, University of Colorado at Boulder, 2.Laboratory for Atmospheric and Space Physics, University of Colorado at Boulder)

[PEM12-27] Longitudinal Variation and Peak Time of Equatorial Electrojet Current from Ground and Satellite Measurements

*Nurul Shazana Abdul Hamid[1], Wan Nur Izzaty Ismail[1], Mardina Abdullah[1], Akimasa Yoshikawa[2], Teiji Uozumi[2], Zahira Mohd Razi[3] (1.Universiti Kebangsaan Malaysia, 2.Kyushu University, 3.Malaysia Space Agency)

[PEM12-28] Thermospheric wind acceleration in the ionospheric trough for Kp = 0+

*Shin-ichiro Oyama[1,2,3], Anita Aikio[2], Heikki Vanhamaki[2], Atsuki Shinbori[1], Mike Rietveld[5], Yasunobu Ogawa[3], Mirjam Kellinsalmi[4], Tero Raita[2], Kazuo Shiokawa[1], Ilkka Virtanen[2], Lei Cai[6], Abiyot Workayehu[2], Marcus Pedersen[2], Kirsti Kauristie[4], Boris Kozelov[7], Andrei Demekhov[7] (1.Institute for Space-Earth Environmental Research, Nagoya University, 2.Space Physics and Astronomy Research Unit, University of Oulu, Finland, 3.National Institute of Polar Research, Japan, 4.Finnish Meteorological Institute, Finland, 5.EISCAT, Norway, 6.KTH Royal Institute of Technology, Sweden, 7.Polar Geophysical Institute, Russia)

[PEM12-29] Day-to-day variation of pre-reversal enhancement in the equatorial ionosphere based on GAIA model

Priyanka Ghosh[1], *Yuichi Otsuka[1], Sivakandan Mani[1], Hiroyuki Shinagawa[2] (1.Institute for Space-Earth Environmental Research, Nagoya University, 2.National Institute of Information and Communications Technology)

[PEM12-30] Enhanced Electric Field Before Large Earthquakes

*Koichiro Oyama[1,2,3], Yoshihiro Kakinami[4], Chia-Hung Chen[5], Teiji Uozumi[2] (1.ISAPS,National Cheng Kung Univ., 2.ICSWE, Kyushu University, 3.ASERC Coltd, 4.Hokkaido Information Univ., 5.Depart. of Earth Science, National Cheng Kung Univ.)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM12] Coupling Processes in the Atmosphere-Ionosphere System

convener:Huixin Liu(Earth and Planetary Science Division, Kyushu University SERC, Kyushu University), Yuichi Otsuka(Institute for Space-Earth Environmental Research, Nagoya University), Yue Deng(University of Texas at Arlington), Loren Chang(Institute of Space Science, National Central University)

[PEM12-31] Chemical releases from the sounding rockets - old but new technique to observe thermosphere and ionosphere

*Yoshihiro Kakinami[1], Shigeto Watanabe[1], Masa-yuki Yamamoto[2], Takumi Abe[3], Hiroto Habu[3], Taro Watanabe[2], Mark Conde[4], Miguel Larsen[5] (1.Hokkaido Information University, 2.Kochi University of Technology, 3.ISAS/JAXA, 4.University of Alaska Fairbanks, 5.Clemson University)

[PEM12-32] IDEASSat: A 3U CubeSat Mission for Ionospheric Science and Expanded in-Situ Observations

*Loren Chang[1], Chi-Kuang Chao[1], Yi Duann[1], Yi-Chung Chiu[1], Rong Tsai-Lin[1], Tzu-Ya Tai[1], Wei-Hao Luo[1], Chi-Ting Liao[1], Hsin-Tzu Liu[1], Amal Chandran[2], Cheng-Ling Kuo[1], Jann-Yenq Liu[1] (1.Department of Space Science and Engineering, National Central University, 2.Satellite Research Centre, Nanyang Technological University, Singapore)

[PEM12-33] Development of new receiver for HF Doppler sounding utilized by Software-Defined Radio device

*Hiroyuki Nakata[1], Yuhei Oki[2], Kenro Nozaki[3], Keisuke Hosokawa[3], Ichiro Tomizawa[3], Ryo Matsushima[3], Kumiko K. Hashimoto[4], Toshiaki Takano[1], Hiroyo Ohya[1] (1.Graduate School of Engineering, Chiba University, 2. Department of Electrical and Electronics Engineering, Faculty of Engineering, Chiba University, 3.The University of Electro-Communications, 4.Kibi International University)

[PEM12-34] GPS radio occultation measurement for SMILES-2

*Makoto Suzuki[1], Philippe Baron[2], Satoshi Ochiai[2], Naohiro Manago[3], Josaphat Tetuko Sri Sumantyo[3], JANN-YENQ Liu[4], Akinori Saito[5], Huixin Liu[6], Masato Shiotani[7] (1.Institute for Space and Astronautical Sciences, Japan Aerospace Exploration Agency, 2.National Institute of Information and Communications Technology, 3.Center for Environmental Remote Sensing, Chiba University, 4.Center for Astronautical Space and Engineering, National Central University , 5.Kyoto University, 6.Dept. of Earth and Planetary Science Faculty of Science Kyushu University, 7.RISH, Kyoto University)

[PEM12-35] SCIntillation and IONosphere – eXtended (SCION-X) – A Small Satellite for Ionospheric and Atmospheric Science

*Pin-An Lin[1], Kai-Lun Cheng[1], Tsai-Ju Yu[1], Ruo-Yu Wang[1], Yueh-Chun Hsieh[1], Glenn Franco Gacal[1], Hsin-I Tu[1], Sittinat Denduonghatai[1], Guan-Po Ciou[1], Loren C. Chang[1], Jann-Yenq Liu[1], Cheng-Ling Kuo[1], Tang-Huang Lin[2], Amal Chandran[3] (1.Graduate Institute of Space Science and Engineering, National Central University, Taoyuan City, Taiwan, 2.Center for Space and Remote Sensing Research, National Central University, Taoyuan City, Taiwan, 3.Satellite Research Centre, Nanyang Technological University, Nanyang Avenue, Singapore)

[PEM12-36] The development and validation of a photochemical model for atomic oxygen ion retrieval from ground-based airglow observations

*YI DUANN[1,2], Loren C. Chang[1,2], Yi-Chung Chiu[1,2], Cornelius Csar Jude H. Salinas[1,2], Alexei V. Dmitriev[1], Konstantin G. Ratovsky[3], Irina V. Medvedeva[3], Roman Vasilyev[3], Alexander V. Mikhalev[3], Jann-Yenq Liu[1,2], Charles Lin[4] (1.Institute of Space Science, National Central University, Taoyuan City, Taiwan, 2.Center for Astronautical Physics and Engineering, National Central University, Taoyuan City, Taiwan, 3.Institute of Solar-Terrestrial Physics, Siberian Branch, Russian Academy of Sciences, Irkutsk, Russia, 4.Department of Earth Science, National Cheng Kung University, Tainan, Taiwan)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM13] Dynamics of Magnetosphere and Ionosphere

convener:Aoi Nakamizo(Applied Electromagnetic Research Institute, National Institute of Information and Communications Technology), Mitsunori Ozaki(Faculty of Electrical and Computer Engineering, Institute of Science and Engineering, Kanazawa University), Akiko Fujimoto(Kyushu Institute of Technology), Yuka Sato(Nippon Institute of Technology)

[PEM13-01] Effect of solar wind high-speed streams on the high-latitude ionosphere

★Invited Papers

*Anita Aikio[1], Nada Ellahouny[1], Ilkka Virtanen[1], Heikki Vanhamäki[1], Marcus Pedersen[1], Johannes Norberg[2], Kirsti Kauristie[2], Maxime Grandin[3], Alexander Kozlovsky[4], Tero Raita[4], Aurelie Marchaudon[5], Pierre-Louis Blelly[5], Shin-ichiro Oyama[6] (1.Space Physics and Astronomy Research Unit, University of Oulu, Finland, 2.Finnish Meteorological Institute, Helsinki, Finland, 3.CoE in Sustainable Space, University of Helsinki, Finland, 4.Sodankylä Geophysical Observatory, Finland, 5.IRAP, University of Toulouse, France, 6.ISEE, Nagoya University, Japan)

[PEM13-02] The relationship between F-region disappearance in the polar cap region and field-aligned currents at geosynchronous orbit during the 11 May 2019 magnetic storm

*Hyuck Jin Kwon[1], Khan-Hyuk Kim[1], Geonhwa Jee[2,3], Jongho Seon[1], Jeong-Han Kim[2], Changsup Lee[2], Young-Bae Ham[2,3], Terence Bullett[4,5], Uli Auster[6], Werner Magnes[7], Stefan Kraft[8] (1.Kyung Hee Univ., 2.Korea Polar Research Institute, 3.University of Science and Technology, 4.University of Colorado, 5.NOAA, 6.TUBS, 7.OeAW, 8.ESA)

[PEM13-03] High ion temperature events at F region altitudes in the cusp: Spatial relations to the moving electron precipitation regions

*Satoshi Taguchi[1], Yunosuke Nagafusa[1], Yasunobu Ogawa[2], Keisuke Hosokawa[3], Tomokazu Oigawa[1], Morio Tanaka[1], Hiroyuki Shinagawa[4] (1.Department of Geophysics, Graduate School of Science, Kyoto University, 2.National Institute of Polar Research, 3.Department of Communication Engineering and Informatics, University of Electro-Commnunications, 4.National Institute of Information and Communication Technology)

[PEM13-04] Ionization of the mesosphere during substorm growth phase

*Kiyoka Murase[1], Ryuho Kataoka[2], Takanori Nishiyama[2], Koji Nishimura[2], Taishi Hashimoto[2], Yoshimasa Tanaka[2], Akira Kadokura[2], Yoshihiro Tomikawa[2], Masaki Tsutsumi[2], Kaoru Sato[3], Satoshi Kasahara[3], Takefumi Mitani[4], Shoichiro Yokota[9], Tomoaki Hori[7], Kunihiro Keika[3], Nana Higashio[5], Takeshi Takashima[4], Yoshiya Kasahara[6], Shoya Matsuda[4], Masafumi Shoji[7], Ayako Matsuoka[4], Iku Shinohara[4], Yoshizumi Miyoshi[7], Tatsuhiko Sato[8] (1.The Graduate University for Advanced Studies, 2.National Institute of Polar Research, 3.University of Tokyo, 4.Japan Aerospace Exploration Agency, Institute of Space and Astronautical Science, 5.Japan Aerospace Exploration Agency, 6.Kanazawa University, 7.Nagoya University, 8.Japan Atomic Energy Agency, 9.Osaka University)

[PEM13-05] Characteristics of ion upflows from the low-altitude ionosphere observed by EISCAT

*Masayoshi Takada[1], Kanako Seki[1], Yasunobu Ogawa[2], Kunihiro Keika[1], Satoshi Kasahara[1], Shoichiro Yokota[3], Tomoaki Hori[4], Kazushi Asamura[5], Yoshizumi Miyoshi[4], Iku Shinohara[5] (1.Tokyo University, 2.National Institute of Polar Research, Japan, 3.Graduate School of Science, Osaka University, 4.Institute for Space-Earth Environmental Research, Nagoya University, 5.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency)

[PEM13-06] The Formation of Substorm Aurora in the Solar Wind-Magnetosphere- Ionosphere Coupling System

*Yan Song[1], Robert L Lysak[1] (1.University of Minnesota)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM13] Dynamics of Magnetosphere and Ionosphere

convener:Aoi Nakamizo(Applied Electromagnetic Research Institute, National Institute of Information and Communications Technology), Mitsunori Ozaki(Faculty of Electrical and Computer Engineering, Institute of Science and Engineering, Kanazawa University), Akiko Fujimoto(Kyushu Institute of Technology), Yuka Sato(Nippon Institute of Technology)

[PEM13-07] The Known and Unknown of Equatorial Plasma Bubbles

★Invited Papers

*Shasha Zou[1], Ercha Aa[1,2] (1.University of Michigan Ann Arbor, 2.MIT Haystack Observatory)

[PEM13-08] **Causality for formation of electromagnetic channel from Polar to Equatorial Ionosphere**

*Akimasa Yoshikawa[1], Aoi Nakamizo[2], Shinichi Ohtani[3] (1.Department of Earth and Planetary Sciences, Kyushu University, 2.National Institute of Information and Commiunications Technology , 3.APL/JHU)

[PEM13-09] **Automatic scaling of echo traces on ionogram for elucidation of a global current system**

*Moe Hayashi[1], Akimasa Yoshikawa[4], Akiko Fujimoto[3], Shinichi Ohtani[2] (1.Kyushu University, 2.The Johns Hopkins University Applied Physics Laboratory, 3.Kyushu Institute of Technology, 4.Department of Earth and Planetary Sciencse, Kyushu University)

[PEM13-10] Ion-neutral collision frequencies for calculating ionospheric conductivity

*Akimasa Ieda[1] (1.Institute for Space-Earth Environmental Research, Nagoya University)

[PEM13-11] Properties of Auroral Electron Backscatter

*John P Dombeck[1], Joshua Magnus[1], Robert Lysak[1], Cynthia Cattell[1] (1.University of Minnesota)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM13] Dynamics of Magnetosphere and Ionosphere

convener:Aoi Nakamizo(Applied Electromagnetic Research Institute, National Institute of Information and Communications Technology), Mitsunori Ozaki(Faculty of Electrical and Computer Engineering, Institute of Science and Engineering, Kanazawa University), Akiko Fujimoto(Kyushu Institute of Technology), Yuka Sato(Nippon Institute of Technology)

[PEM13-13] What is the role of repeatable meso-scale processes in the Magnetosphere-Ionosphere system?

★Invited Papers

*Jesper W Gjerloev[1], Shinichi Ohtani[1] (1.Johns Hopkins University Applied Physics Laboratory)

[PEM13-14] 3D current system of auroral vortices in the discrete arc estimated by auroral tomography and local KRM methods

*Yoshimasa Tanaka[1,2,3], Yasunobu Ogawa[1,3], Akira Kadokura[1,2,3], Takanori Nishiyama[1,3], Akimasa Yoshikawa[4], Bjorn Gustavsson[5], Kirsti Kauristie[6], Carl-fredrik Enell[7], Urban Brandstrom[8], Tima Sergienko[8], Alexander Kozlovsky[9], Tero Raita[9], Heikki Vanhamaki[10] (1.National Institute of Polar Research, 2.Polar Environment Data Science Center, 3.The Graduate University for Advanced Studies, 4.Department of Earth and Planetary Sciences, Kyushu University, 5.The Arctic University of Norway, 6.Finnish Meteorological Institute, 7.EISCAT Scientific Association, 8.Swedish Institute of Space Physics, 9.Sodankyla Geophysical Observatory, 10.University of Oulu)

[PEM13-15] Simulation on 3D structure of auroral electrojet

*Yuto Yano[1], Yusuke Ebihara[1] (1.Research Institute for Sustainable Humanosphere, Kyoto University)

[PEM13-16] Statistical characteristics of the duskside mesoscale field-aligned currents without accompanying the large-scale Region 1 current

*Yoshihiro Yokoyama[1], Satoshi Taguchi[1], Toshihiko Iyemori[2], Keisuke Hosokawa[3] (1.Department of Geophysics, Graduate School of Science, Kyoto University, 2.Kyoto University, 3. Department of Communication Engineering and Informatics, University of Electro-Communications)

[PEM13-17] Ionospheric plasma sheet isolation during northward interplanetary magnetic field periods reproduced by numerical magnetohydrodynamic modeling

*Masakazu Watanabe[1,2], Takashi Tanaka[2], Shigeru Fujita[3] (1.Graduate School of Science, Kyushu University, 2.International Center for Space Weather Science and Education, Kyushu University, 3.Meteorological College)

[PEM13-18] Impact of foreshock transients on the Earth's nightside magnetosphere and ionosphere

*Chih-Ping Wang[1], Xueyi Wang[2], Terry Z. Liu[3], Yu Lin[2], Sixue Xu[1] (1.University of California Los Angeles, 2.Auburn University, 3.University of Alaska, Fairbanks)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM13] Dynamics of Magnetosphere and Ionosphere

convener:Aoi Nakamizo(Applied Electromagnetic Research Institute, National Institute of Information and Communications Technology), Mitsunori Ozaki(Faculty of Electrical and Computer Engineering, Institute of Science and Engineering, Kanazawa University), Akiko Fujimoto(Kyushu Institute of Technology), Yuka Sato(Nippon Institute of Technology)

[PEM13-19] The main observational properties of throat aurora and their implicaitons on dayside S-M-I coupling

*Han Desheng[1] (1.School of Ocean and Earth Science, Tongji University)

[PEM13-20] A Possible Formation Scenario of the Transpolar Arcs with the Nightside End Distortions: Role of Field-Aligned Currents

*Motoharu Nowada[1], Qiu-Gang Zong[2], Benoît Hubert[3], Quan-Qi Shi[1], Yong-Fu Wang[2], Jun Yang[1], Adrian Grocott[4], Alexander William Degeling[1], An-Min Tian[1], Xu-Zhi Zhou[2], Chao Yue[2] (1.Shandong Provincial Key Laboratory of Optical Astronomy and Solar-Terrestrial Environment, Institute of Space Sciences, Shandong University, Weihai, 2.Institute of Space Physics and Applied Technology, School of Earth and Space Sciences, Peking University, 3.Space science, Technologies and Astrophysics Research (STAR) Institute, Université de Liège, Belgium, 4.Space and Planetary Physics Group, Department of Physics, Lancaster University, Lancaster, United Kingdom)

[PEM13-21] **Fade of transpolar arc and its relation to the intensification of the nightside oval**

*Takahiro Obara[1] (1.Planetary Plasma and Atmospheric Research Center,Tohoku University)

[PEM13-22] Feedback instability theory extended to the magnetosphere-ionosphere coupling with field-aligned inhomogeneity

*Tomo-Hiko Watanabe[1], Junya Hiwatari[1], Shinya Maeyama[1] (1.Graduate School of Science, Nagoya University)

[PEM13-23] Antarctic large area network observation of auroral phenomena using unmanned system: Current status of project as of early 2020

*Akira Kadokura[1], Yasunobu Ogawa[1], Yoshimasa Tanaka[1], Hisao Yamagishi[1], Masaki Okada[1], Ryuho Kataoka[1], Herbert Akihito Uchida[2], Yuichi Otsuka[3], Motoba Tetsuo[4], Natsuo Sato[1] (1.National Institute of Polar Research, 2.SOKENDAI, 3.Nagoya University, 4.Johns Hopkins University, Applied Physics Laboratory)

[PEM13-24] **Short review for recent studies of pulsating aurora in Japan during Arase era**

★Invited Papers

*Keisuke Hosokawa[1], Yoshizumi Miyoshi[2], Mitsunori Ozaki[3], Shin-ichiro Oyama[2], Yasunobu Ogawa[4], Satoshi Kurita[2], Yoshiya Kasahara[3], Yasumasa Kasaba[5], Satoshi Yagitani[3], Shoya Matsuda[7], Fuminori Tsuchiya[5], Atsushi Kumamoto[5], Ryuho Kataoka[4], Kazuo Shiokawa[2], Hiroshi Miyaoka[4], Yoshimasa Tanaka[4], Satonori Nozawa[2], Mariko Teramoto[6], Takeshi Takashima[7], Iku Shinohara[7], Ryoichi Fujii[8] (1.Univ. of Electro-Communications, 2.ISEE, Nagoya Univ., 3.Kanazawa Univ., 4.National Institute of Polar Research, 5.Tohoku Univ., 6.Kyushu Institute of Technology, 7.ISAS/JAXA, 8.Research Organization of Information and Systems)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM13] Dynamics of Magnetosphere and Ionosphere

convener:Aoi Nakamizo(Applied Electromagnetic Research Institute, National Institute of Information and Communications Technology), Mitsunori Ozaki(Faculty of Electrical and Computer Engineering, Institute of Science and Engineering, Kanazawa University), Akiko Fujimoto(Kyushu Institute of Technology), Yuka Sato(Nippon Institute of Technology)

[PEM13-25] Utilizing the Heliophysics/Geospace System Observatory to Understand Particle Injections: Their Scale Sizes and Propagation Directions

*Christine Gabrielse[1], Emma Spanswick[2], Anton Artemyev[3], Toshi Nishimura[4], Andrei Runov[3], Larry Lyons[3], Vassilis Angelopoulos[3], Drew L. Turner[5], Geoffrey D. Reeves[6], Eric Donovan[2] (1.The Aerospace Corporation, 2.Univ. of Calgary, 3.UCLA, 4.Boston University, 5.John Hopkins Applied Physics Lab., 6.LANL)

[PEM13-26] **Flux decrease of outer radiation belt electrons associated with solar wind pressure pulse: A Code coupling simulation of GEMSIS-RB and GEMSIS-GM**

*Ito Hiroki[1], Yoshizumi Miyoshi[1], Shinji Saito[2], Yosuke Matsumoto[3], Takanobu Amano[4] (1.Institute for Space-Earth Environmental Research, Nagoya University, 2.National Institute of Information and Communications Technology, 3.Gradual School of Science, Chiba University, 4.Department of Earth and Planetary Science, University of Tokyo)

[PEM13-27] Seasonal Variation in Mass and Electron Densities of the Plasmasphere in the New Zealand Meridian

*Yuki Obana[1], Akiko Fujimoto[2], Satoko Saita[3], János Lichtenberger[4,5], Tanja Petersen[6] (1.Department of Engineering Science, Faculty of Engineering, Osaka Electro-Communication University, 2.Graduate School of Computer Science and Systems Engineering, Kyushu Institute of Technology, 3.National Institute of Technology, Kitakyushu College, 4.Eötvös Loránd University, 5.Research Center for Astronomy and Earth Sciences, 6.GNS Science)

[PEM13-28] Differences in Near-Earth Magnetotail Evolution Between Pseudosubstorms and Substorms

*Yukinaga Miyashita[1], Kento Fukui[2], Shinobu Machida[2], Yoshizumi Miyoshi[2], Akimasa Ieda[2], Toshi Nishimura[3], Vassilis Angelopoulos[4] (1.Korea Astronomy and Space Science Institute, 2.Institute for Space-Earth Environmental Research, Nagoya University, 3.Boston University, 4.University of California, Los Angeles)

[PEM13-29] Geomagnetic field and energetic particle oscillations observed at geosynchronous orbit during the growth and expansion phases of a substorm

*Khan-Hyuk Kim[1], Hyuck-Jin Kwon[1], Jongho Seon[1], Uli Auster[2], Werner Magnes[3], Stefan Kraft[4] (1.School of Space Research, Kyung Hee University, Korea, 2.IGeP, TUBS, Mendelssohnstrasse, Braunschweig, Germany, 3.Space Research Institute, OeAW, Graz, Austria, 4.ESOC-ESA, Robert-Bosch-Strasse, Darmstadt, Germany)

[PEM13-30] Longitudinal propagation of thin auroral arcs

Fei Zhang[1], *Jian Yang[1], Wenrui Wang[1,2] (1.Southern University of Science and Technology, 2. Sun Yat-sen University)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM14] Frontiers in solar physics

convener:Shinsuke Imada(Institute for Space-Earth Environmental Research, Nagoya University), Alphonse Sterling(NASA/MSFC), Takaaki Yokoyama(School of Science, University of Tokyo), Toshifumi Shimizu(Institute of Space and Astronautical Science, JAXA)

[PEM14-01] Alfvenic fluctuations in the near-Sun solar wind: Measurements from Parker Solar Probe

★Invited Papers

*Stuart D Bale[1] (1.University of California Berkeley)

[PEM14-02] Contribution of the BepiColombo mission to inner heliospheric science

★Invited Papers

*Go Murakami[1], Yoshizumi Miyoshi[2], Kazumasa Iwai[2], Daikou Shiota[3], Takeshi Imamura[4], Iku Shinohara[1], Shinsuke Imada[2], Toshifumi Shimizu[1] (1.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 2.Institute for Space-Earth Environmental Research, Nagoya University, 3.National Institute of Information and Communications Technology, 4.Graduate School of Frontier Sciences, The University of Tokyo)

[PEM14-03] Instrumental design of the Solar-C_EUVST telescope

*Yoshinori Suematsu[1], Toshifumi Shimizu[2], Hirohisa Hara[1], Tomoko Kawate[2], Yukio Katsukawa[1], Kiyoshi Ichimoto[3], Shinsuke Imada[4] (1.NAOJ National Astronomical Observatory of Japan, 2.ISAS/JAXA, 3.Kyoto University, 4.Nagoya University)

[PEM14-04] Analysis of Small-scale Flares using Genetic Algorithm

*Toshiki Kawai[1], Shinsuke Imada[1] (1.Institute for Space-Earth Environmental Research, Nagoya University)

[PEM14-05] Magnetic Flux Cancellation and Associated Plasma Heating in the Upper Solar Atmosphere

*Sung-Hong Park[1], KD Leka[1,2], Kanya Kusano[1] (1.Institute for Space-Earth Environmental Research of Nagoya University, 2.NorthWest Research Associates)

[PEM14-06] Nonlinear force-free modeling of the flare-productive magnetic fields observed in the solar active region 12673

*Daiki Yamasaki[1], Satoshi Inoue[2], Shin'ichi Nagata[3], Kiyoshi Ichimoto[3] (1.Department of Astronomy, Kyoto University, 2.Institute for Space-Earth Environmental Research, Nagoya University, 3.Astronomical Observatory, Kyoto University)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM14] Frontiers in solar physics

convener:Shinsuke Imada(Institute for Space-Earth Environmental Research, Nagoya University), Alphonse Sterling(NASA/MSFC), Takaaki Yokoyama(School of Science, University of Tokyo), Toshifumi Shimizu(Institute of Space and Astronautical Science, JAXA)

[PEM14-07] The Chromospheric Layer SpectroPolarimeter (CLASP2) Mission: Introduction

★Invited Papers

*David E. McKenzie[1], Ryohko Ishikawa[2], Ryouhei Kano[2], Joten Okamoto[2], Laurel Rachmeler[1], Javier Trujillo Bueno[3], Frederic Auchere[4], Ken Kobayashi[1], Donguk Song[2], Masaki Yoshida[2] (1.NASA Marshall Space Flight Center, 2.National Astronomical Observatory of Japan, 3.Instituto Astrofísica de Canarias, 4.Institut d'Astrophysique Spatiale)

[PEM14-08] Initial results from CLASP2 rocket experiment to measure magnetic fields in the solar chromosphere

★Invited Papers

*Joten Okamoto[1], Ryoko Ishikawa[1], David McKenzie[2], Javier Trujillo Bueno[3], Frederic Auchere[4], Laurel Rachmeler[2], Ryohei Kano[1], Donguk Song[1], Christian Bethge[5], Ken Kobayashi[2], Masaki Yoshida[1], Tanausu del Pino Aleman[3], CLASP2 team (1.National Astronomical Observatory of Japan, 2.NASA Marshall Space Flight Center, 3.Instituto Astrofisica de Canarias, 4.Institut d'Astrophysique Spatiale, 5.Universities Space Research Association)

[PEM14-09] Mathematical modelling of effect of flows in magnetic flux tubes

*Samuel Joseph Skirvin[1], Viktor fedun[1], Gary Verth[1] (1.University of Sheffield)

[PEM14-10] Numerical study of fast and slow wave heating of the magnetic chromosphere

*WANG YIKANG[1], Takaaki Yokoyama[1], Haruhisa Iijima[2] (1.The University of Tokyo, 2.Nagoya University)

[PEM14-11] Solar photospheric jet-like structures formed by slow shock

*Yuji Kotani[1], Kazunari Shibata[2] (1.Department of Astronomy, Kyoto University, 2.Kwasan and Hida Observatories, Kyoto University)

[PEM14-12] Chromospheric magnetic field: A comparison of He I 10830 Å observation with nonlinear force-free field extrapolation

*Yusuke Kawabata[1], Andrés Asensio Ramos[2], Satoshi Inoue[3], Toshifumi Shimizu[4] (1.National Astronomical Observatory of Japan, 2.Instituto de Astrofísica de Canarias, 3.Institute for Space-Earth Environmental Research, Nagoya University, 4.Institute of Space and Astronautical Science, JAXA)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM15] Plasma Theory and Simulation

convener:Seiji Zenitani(Kobe University), Fan Guo(Los Alamos National Laboratory), Takayuki Umeda(Institute for Space-Earth Environmental Research, Nagoya University), Takanobu Amano(Department of Earth and Planetary Science, University of Tokyo), Yasuhiro Nariyuki(Faculty of Education, University of Toyama)

[PEM15-01] An adaptive load balancing method for particle-in-cell simulations

*Yosuke Matsumoto[1] (1.Graduate School of Science, Chiba University)

[PEM15-02] Relation between Alfven-ion-cyclotron and Weibel instabilities in the collisionless perpendicular shock transition region: Upstream plasma parameter dependence

*Takuro Nishigai[1], Takanobu Amano[1] (1.Department of Earth and Planetary Science, University of Tokyo)

[PEM15-03] Full PIC simulations of the surface charging on the night side of Phobos

*Masaki Tanabe[1], Naoki Terada[1], Yohei Miyake[2], Hideyuki Usui[2] (1.Graduate school of science, Tohoku University, 2.Graduate school of system informatics Kobe University)

[PEM15-04] An Analysis of Slow-Shock and Slow Shock-Like Structures Observed in the 2D Hybrid Magnetic Reconnection Simulations

*Nehpreet Kaur Walia[1], Kanako Seki[1], Takanobu Amano[1] (1. Department of Earth & Planetary Science, Graduate School of Science, University of Tokyo)

[PEM15-05] Outstanding issues in plasma Riemann problem

*Tohru Hada[1] (1.Interdisciplinary Graduate School of Engineering Sciences, Kyushu University)

[PEM15-06] A simple stochastic model of electron diffusion by whistler waves in a non-uniform magnetic field

*Yasuhiro Nariyuki[1] (1.Faculty of Education, University of Toyama)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM15] Plasma Theory and Simulation

convener:Seiji Zenitani(Kobe University), Fan Guo(Los Alamos National Laboratory), Takayuki Umeda(Institute for Space-Earth Environmental Research, Nagoya University), Takanobu Amano(Department of Earth and Planetary Science, University of Tokyo), Yasuhiro Nariyuki(Faculty of Education, University of Toyama)

[PEM15-07] Nonlinear Interaction of Radiation Belt Electrons with Obliquely Propagating Whistler-mode Chorus Emissions

*Yoshiharu Omura[1], Yi-Kai Hsieh[1] (1.Reserach Institute for Sustainable Humanosphere, Kyoto University)

[PEM15-08] Energy-consistent finite difference method for compressible magnetohydrodynamic simulations

*Haruhisa Iijima[1] (1.Institute for Space-Earth Environmental Research, Nagoya University)

[PEM15-09] **Implementing neural network's inference into the magnetohydrodynamic simulation code**

*Yuki Sawamura[1], Yosuke Matsumoto[1] (1.Chiba University)

[PEM15-10] Visualizing Magnetospheric Topology in Global 3D MHD Simulations

*DongSheng CAI[1] (1.University of Tsukuba)

[PEM15-12] Plasma State inside of the Super Massive Kerr Black Hole and Problem of the Gravitational Wave Source

*Hiroshi Oya[1] (1.Department of Geophysics Graduate School for Science Tohoku University)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM16] Magnetospheric Multi Scale (MMS) mission: Accomplishments and Future Plans

convener:Yoshifumi Saito(Solar System Science Division, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency), James L Burch(Southwest Research Institute), Barbara L Giles(NASA Goddard Space Flight Center), Hiroshi Hasegawa(Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency)

[PEM16-01] Advances in Reconnection, Acceleration and Turbulence with MMS

★Invited Papers

*James L Burch[1] (1.Southwest Research Inst.)

[PEM16-02] Observations of multi-scale wave coupling and plasma mixing in the magnetotail separatrix

★Invited Papers

*Justin C. Holmes[1], Rumi Nakamura[1], Daniel Schmid[1], Owen Wyn Roberts[1], Takuma Nakamura[1], Zoltan Vörös[1] (1.Space Research Institute)

[PEM16-03] Direct measurements of energy transfer from hot protons to EMIC waves in ULF waves at the outer magnetosphere

*Naritoshi Kitamura[1], Masafumi Shoji[2], Masahiro Kitahara[3], Takanobu Amano[1], Yoshiharu Omura[4], Satoko Nakamura[2], Yoshizumi Miyoshi[2], Hiroshi Hasegawa[5], Yuto Katoh[3], Yoshifumi Saito[5], Mariko Teramoto[7], Reiko Nomura[6], Shoichiro Yokota[8], Daniel J Gershman[9], Adolfo F Vinas[9,10], Barbara L Giles[9], Scott A Boardsen[9,11], Craig J Pollock[12], Christopher T Russell[13], Robert J Strangeway[13], Narges Ahmadi[14], Per-Arne Lindqvist[15], Robert E Ergun[14], James L Burch[16] (1.Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, 2.Institute for Space-Earth Environmental Research, Nagoya University, 3.Department of Geophysics, Graduate school of Science, Tohoku University, 4.Research Institute for Sustainable Humanosphere, Kyoto University, 5.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 6.National Astronomical Observatory of Japan, 7.Kyushu Institute of Technology, 8.Department of Earth and Space Science, Graduate School of Science, Osaka University, 9.NASA Goddard Space Flight Center, 10.Department of Physics, American University, 11.University of Maryland, 12.Denali Scientific, 13.Institute of Geophysics and Planetary Physics, University of California, Los Angeles, 14.Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, 15.Royal Institute of Technology, 16.Southwest Research Institute)

[PEM16-04] Electron Scattering and Acceleration by Whistler Waves at Collisionless Shocks

★Invited Papers

*Mitsuo Oka[1], Fumiko Otsuka[2], Shuichi Matsukiyo[2], Tai Phan[1], The MMS team (1.University of California Berkeley, 2.Kyushu University)

[PEM16-05] The relation between high-frequency whistler waves and energetic electrons in the quasi-perpendicular bow shock

Chika Umegaki[1], *Takanobu Amano[1], Naritoshi Kitamura[1], Olivier Le Contel[2], Narges Ahmadi[3], Barbara L Giles[4] (1.Department of Earth and Planetary Science, University of Tokyo, 2.Laboratoire de Physique des Plasmas, CNRS/Ecole Polytechnique/Sorbonne Université/Univ. Paris-Sud/Obs. de Paris, 3.Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, 4.NASA Goddard Space Flight Center)

[PEM16-06] Future Plans of the Magnetospheric Multiscale Mission

★Invited Papers

*Steven M Petrinec[1], James L Burch[2], Stephen A Fuselier[2,3], Michael Hesse[4], Roy Torbert[2,5], Tai D Phan[6], Barbara L Giles[7] (1.Lockheed Martin Advanced Technology Center, Palo Alto, CA USA, 2.Southwest Research Institute, San Antonio, TX, USA, 3.University of Texas at San Antonio, TX, USA, 4.University of Bergen, Bergen, Norway, 5.University of New Hampshire, Durham, NH, USA, 6.University of California, Berkeley, CA, USA, 7.NASA Goddard Space Flight Center, Greenbelt, MD, USA)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM17] Space Weather and Space Climate

convener:Ryuho Kataoka(National Institute of Polar Research), Antti A Pulkkinen(NASA Goddard Space Flight Center), Kanya Kusano(Institute for Space-Earth Environmental Research, Nagoya University), Kaori Sakaguchi(National Institute of Information and Communications Technology)

[PEM17-01] Thailand-Japan collaboration on the first VHF radar for plasma bubbles monitoring

★Invited Papers

*Kornyanat Hozumi[1], Takuya Tsugawa[1], Pornchai Supnithi[2], Punyawi Jamjareegulgarn[3], Yuichi Otsuka[4], Susumu Saito[5], Shinichi Hama[1], Udomsit Tangtrakunphaisan[3], Mamoru Ishii[1] (1.National Institute of Information and Communications Technology (NICT),Tokyo, Japan, 2.King Mongkut's Institute of Technology Ladkrabang, Bangkok (KMITL), Thailand, 3.King Mongkut's Institute of Technology Ladkrabang, Prince of Chumphon Campus, Chumphon, Thailand, 4.Institute for Space-Earth Environmental Research (ISEE), Nagoya University, Nagoya 464-8601, Japan, 5.National Institute of Maritime, Port and Aviation Technology, Electronic Navigation Research Institute (ENRI), Tokyo, Japan)

[PEM17-02] COSPAR/URSI International Reference Ionosphere 2020

*Dieter Bilitza[1,2] (1.George Mason University Fairfax, 2.SPDF NASA GSFC Greenbelt)

[PEM17-03] Full-scale spatial characteristics of pulsating aurora derived from color digital camera images from the International Space Station

*Sota Nanjo[1], Yuta Hozumi[1], Keisuke Hosokawa[1], Ryuho Kataoka[2,3], Yoshizumi Miyoshi[4], Shin-ichiro Oyama[2,4,5], Mitsunori Ozaki[6], Kazuo Shiokawa[4], Satoshi Kurita[4] (1.The University of Electro-Communications, 2.National Institute of Polar Research, 3.Department of Polar Science, School of Multidisciplinary Science, SOKENDAI, The Graduate University for Advanced Studies, 4.Institute for Space-Earth Environmental Research, Nagoya University, 5.Ionospheric Physics Research Unit, University of Oulu, 6.Kanazawa University)

[PEM17-04] The longterm trend of temperature in mesopause region between 1990 and 2020

*Tao Yuan[1] (1.Utah State University)

[PEM17-05] Statistical analysis of ionospheric total electron content (TEC): Estimation of extreme values in a hundred years in Japan

*Michi Nishioka[1], Susumu Saito[2], Chihiro Tao[1], Daikou Shiota[1], Takuya Tsugawa[1] (1.National Institute of Information and Communications Technology, 2.Electronic Navigation Research Institute)

[PEM17-06] Drastic time variations of transfer function of geomagnetically induced current (GIC)

*Satoko Nakamura[1,2], Yusuke Ebihara[2], Shigeru Fujita[3], Tada-nori Goto[4], Shinichi Watari[5] (1.Institute for Space-Earth Environmental Research (ISEE), Nagoya University, 2.Research Institute for Sustainable Humanosphere, Kyoto University, 3.Meteorological College, Japan Meteorological Agency/ Nationa Institute of Polar Research, 4.Graduate School of Life Science, University of Hyogo, 5.National Institute of Information and Communications Technology)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM17] Space Weather and Space Climate

convener:Ryuho Kataoka(National Institute of Polar Research), Antti A Pulkkinen(NASA Goddard Space Flight Center), Kanya Kusano(Institute for Space-Earth Environmental Research, Nagoya University), Kaori Sakaguchi(National Institute of Information and Communications Technology)

[PEM17-07] The Heliophysics Space Weather Science Application Program

★Invited Papers

*James F Spann[1], Nicola J Fox[1], James E Favors[1] (1.NASA Headquarters)

[PEM17-08] Space Weather Research Support at the National Science Foundation

★Invited Papers

*Lisa M Winter[1] (1.National Science Foundation Office of Polar Programs)

[PEM17-09] Toward cycle 25: Future perspective on space radiation environment in the inner heliopshere

★Invited Papers

*Yoshizumi Miyoshi[1], Shinsuke Imada[1], Ryuho Kataoka[2], Kanako Seki[3], Hiroko Miyahara[4], Aiko Nagamatsu[5], Daikou Shiota[6], Tatsuhiko Sato[7] (1.Institute for Space-Earth Environmental Research, Nagoya University, 2.National Institute for Polar Research, 3.The University of Tokyo, 4.Musashino Art University, 5.JAXA, 6.NICT, 7.JAEA)

[PEM17-10] Development of real-time prediction system of CME arrival and magnetic field with ensemble SUSANOO-CME simulation

*Daikou Shiota[1,4], Seiji Yashiro[2], Ryuho Kataoka[3], Kazumasa Iwai[4], Yusuke Ebihara[5] (1.National Institute of Information and Communications Technology (NICT), 2.Catholic University of America, 3.National Institute of Polar Research, 4.Institute for Space-Earth Environmental Research, Nagoya University, 5.Research Institute for Sustainable Humanosphere, Kyoto University)

[PEM17-11] A dynamical model of the heliosphere with adaptive mesh refinement

*Tomoaki Matsumoto[1], Daikou Shiota[2], Ryuho Kataoka[3], Hiroko Miyahara[4], Shoko Miyake[5] (1.Hosei University, 2.NICT, 3.National Institute of Polar Research, 4.Musashino Art University, 5.National Institute of Technology, Ibaraki College)

[PEM17-12] Validation and operation of a coronal mass ejection arrival time forecasting system using interplanetary scintillation observations

*Kazumasa Iwai[1], Daikou Shiota[2], Munetoshi Tokumaru[1], Ken'ichi Fujiki[1], Mitsue Den[2], Yuki Kubo[2] (1.Institute for Space–Earth Environmental Research (ISEE), Nagoya University, 2.National Institute of Information and Communications Technology)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM17] Space Weather and Space Climate

convener:Ryuho Kataoka(National Institute of Polar Research), Antti A Pulkkinen(NASA Goddard Space Flight Center), Kanya Kusano(Institute for Space-Earth Environmental Research, Nagoya University), Kaori Sakaguchi(National Institute of Information and Communications Technology)

[PEM17-13] ^{14}C during the ~660 BCE solar proton event from Japanese tree rings

★Invited Papers

*Hirohisa Sakurai[1], Fusa Miyake[2], Fuyuki Tokanai[1], Kazuho Horiuchi[3], Hiroko Miyahara[4], Kimiaki Masuda[2], Motonari Ooyama[5], Minoru Sakamoto[6], Takumi Mitsutani[7], Toru Moriya[1] (1.Faculty of Science, Yamagata University, 2.ISEE, Nagoya University,, 3.Hirosaki University, 4.Graduate School of Science and Technology, Hirosaki University, 5.Botanical Gardens, Tohoku University, 6.National Museum of Japanese History, 7.National Institutes for Cultural Heritage, Nara National Research Institute for Cultural Properties)

[PEM17-14] Variability of High Energy particle Environment associated with Solar Activities

★Invited Papers

*Shinsuke Imada[1], Daikou Shiota[2], Kazumasa Iwai[1], Takashi Minoshima[3], Haruhisa Iijima[1], Yoshizumi Miyoshi[1] (1.Institute for Space-Earth Environmental Research, Nagoya University, 2.NICT, 3.JAMSTEC)

[PEM17-15] MHD-SDE Hybrid Simulation of the Cosmic Ray Modulation

*Shoko Miyake[1], Tomoaki Matsumoto[2], Ryuho Kataoka[3,9], Tatsuhiko Sato[4], Daikou Shiota[5], Hiroko Miyahara[6], Shinsuke Imada[7], Haruka Ueno[8] (1.National Institute of Technology, Ibaraki College, 2.Hosei University, 3.National Institute of Polar Research, 4.Japan Atomic Energy Agency, 5.National Institute of Information and Communications Technology, 6.Musashino Art University, 7.Nagoya University, 8.Japan Aerospace Exploration Agency, 9.SOKENDAI)

[PEM17-16] Geosynchronous Energetic Particle Variations based on FY-2 Series Satellites Observations

*chunqin wang[1], guohong shen[1], shenyi zhang[1], huanxin zhang[1] (1.national space sciend center,CAS)

[PEM17-17] 10 years observation of charged pariticle flux with MAXI/RBM on the International Space Station

*Satoshi NAKAHIRA[1], Ryuho Kataoka[2], Haruka Ueno[1] (1.Japan Aerospace Exploration Agency, 2.National Institute of Polar Research)

[PEM17-18] Statistical Analysis of the Relation between Coronal Mass Ejections and Solar Energetic Particles

*Kosuke Kihara[1], Yuwei Huang[2], Nobuhiko Nishimura[3], Nariaki Nitta[4], Seiji Yashiro[5], Kiyoshi Ichimoto[2], Ayumi Asai[2] (1.Department of Astronomy, Kyoto University, 2.Astronomical Observatory, Kyoto University, 3.Institute for Space Earth Environmental Research, 4.Lockheed Martin Advanced Technology Center, 5.The Catholic University of America)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM17] Space Weather and Space Climate

convener:Ryuho Kataoka(National Institute of Polar Research), Antti A Pulkkinen(NASA Goddard Space Flight Center), Kanya Kusano(Institute for Space-Earth Environmental Research, Nagoya University), Kaori Sakaguchi(National Institute of Information and Communications Technology)

[PEM17-19] A New Parameter of Photospheric Magnetic Field to Determine Eruptive-Flare Producing Solar Active Regions

*Pei Hsuan Lin[1], Kanya Kusano[1], Daikou Shiota[2], Satoshi Inoue[1], K. D. Leka[3] (1.Institute for Space-Earth Environmental Research, Nagoya University, 2.National Institute of Information and Communications Technology (NICT), 3.NorthWest Research Associates)

[PEM17-20] Realistic MHD Modeling of delta-sunspots: How to Generate Most Violent Active Regions of the Sun

*Shin Toriumi[1], Hideyuki Hotta[2] (1.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 2.Graduate School of Science, Chiba University)

[PEM17-22] Deep Flare Net Extended to 4-Class Solar Flare Prediction

*Naoto Nishizuka[1], Komei Sugiura[1], Yuki Kubo[1], Mitsue Den[1], Mamoru Ishii[1] (1.National Institute of Information and Communications Technology)

[PEM17-23] Investigation of statistical relationships between loop structures in X-ray coronal image and CME using automatic recognition of coronal loops

*Yusuke Iida[1], Yusuke Kawabata[2], Toshifumi Shimizu[3] (1.Niigata University, 2.NAOJ, 3.JAXA/ISAS)

[PEM17-24] Determination of 3D velocity fields of disappearing and erupting solar filaments using SMART/SDDI at Hida observatory

*Nami Kimura[1], Kenichi Otsuji[1], Ayumi Asai[1], Yosuke Alexandre Yamashiki[1] (1.Kyoto University)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM18] Study of coupling processes in solar-terrestrial system

convener:Mamoru Yamamoto(Research Institute for Sustainable Humanosphere, Kyoto University), Yasunobu Ogawa(National Institute of Polar Research), Satonori Nozawa(Institute for Space-Earth Environmental Research, Nagoya University), Akimasa Yoshikawa(Department of Earth and Planetary Sciences, Kyushu University)

[PEM18-01] Study of coupling processes in the solar-terrestrial system = Current status in 2020 =

*Mamoru Yamamoto[1], Hiroyuki Hashiguchi[1], Tatsuhiro Yokoyama[1], Hiroshi Miyaoka[2], Yasunobu Ogawa[2], Kazuo Shiokawa[3], Satonori Nozawa[3], Akimasa Yoshikawa[4], Toshitaka Tsuda[1] (1.Research Institute for Sustainable Humanosphere, Kyoto University, 2.National Institute of Polar Research, 3.Institute for Space-Earth Environmental Research, 4.Graduate School of Science, Kyushu University)

[PEM18-02] Status of Equatorial MU Radar project in 2020

*Mamoru Yamamoto[1], Hiroyuki Hashiguchi[1], Tatsuhiro Yokoyama[1], Toshitaka Tsuda[1] (1.Research Institute for Sustainable Humanosphere, Kyoto University)

[PEM18-03] Current Status of the EISCAT_3D project and the Japan's contribution

*Hiroshi Miyaoka[1], Yasunobu Ogawa[1], Satonori Nozawa[2], Koji Nishimura[1], Taishi Hashimoto[1], Shin-ichiro Oyama[2], Takuji Nakamura[1], Ryoichi Fujii[2], Craig James Heinselman[3] (1.National Institute of Polar Research, 2.Institute for Space-Earth Environmental Research, Nagoya University, 3.European Incoherent Scatter Scientific Association)

[PEM18-04] Current status of the ground-based multi-point network by the PWING Project and the Optical Mesosphere Thermosphere Imagers (OMTIs)

*Kazuo Shiokawa[1], Yuichi Otsuka[1] (1.Institute for Space-Earth Environmental Research, Nagoya University)

[PEM18-05] IUGONET data analysis system for a study of coupling processes in the solar-terrestrial system

*Atsuki Shinbori[1], Yoshimasa Tanaka[2], Norio Umemura[1], Shuji Abe[3], Satoru UeNo[4] (1.Institute for Space-Earth Environment Research (ISEE), Nagoya University, 2.National Institute of Polar Research, 3.International Center for Space Weather Science and Education (ICSWSE), Kyushu University, 4.Kwasan and Hida Observatories, Graduate School of Science, Kyoto University)

[PEM18-06] Statistical study of Sporadic Sodium Layers (SSLs) above Tromsø (2)

*Satonori Nozawa[1], Takuo T. Tsuda[2], Norihito Saito[3], Takuya Kawahara[4], Satoshi Wada[3], Yasunobu Ogawa[5], Hitoshi Fujiwara[6], Toru Takahashi[7], Tetsuya Kawabata[1], Chris Hall[8], Asgeir Brekke[8] (1.Institute for Space-Earth Environmental Research, Nagoya University, 2.The University of Electro-Communications, 3.RIKEN Center for Advanced Photonics, 4.Faculty of Engineering, Shinshu University, 5.National Institute of Polar Research, 6.Faculty of Science and Technology, Seikei University, 7.Department Physics, University of Oslo, 8.UiT The Arctic University of Norway)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM18] Study of coupling processes in solar-terrestrial system

convener:Mamoru Yamamoto(Research Institute for Sustainable Humanosphere, Kyoto University), Yasunobu Ogawa(National Institute of Polar Research), Satonori Nozawa(Institute for Space-Earth Environmental Research, Nagoya University), Akimasa Yoshikawa(Department of Earth and Planetary Sciences, Kyushu University)

[PEM18-07] A journey of energy from solar wind to polar ionosphere as viewed from global MHD simulation

★Invited Papers

*Yusuke Ebihara[1], Takashi Tanaka[2] (1.Research Institute for Sustainable Humanosphere, Kyoto University, 2.International Center for Space Weather Science and Education, Kyushu University)

[PEM18-08] Review of the mid-latitude SuperDARN and the future of the SuperDARN

*Nozomu Nishitani[1] (1.Institute for Space-Earth Environmental Research, Nagoya University)

[PEM18-09] Investigation of global electromagnetic coupling from polar to equatorial ionosphere

*Akimasa Yoshikawa[1], Hideaki Kawano[1], Shuji Abe[2], Teiji Uozumi[2], Akiko Fujimoto[4], Akihiro Ikeda[5], Taisei Kabasawa[3], Satoshi Kuroki[3], Moe Hayashi[3], Takayama Kumi[3], Aoi Nakamizo[6], Shinichi Ohtani[7] (1.Department of Earth and Planetary Sciences, Kyushu University, 2.International Center for Space Weather Science and Education, Kyushu University, 3.Graduate school of Earth and Planetary Sciences, Kyushu University, 4.Faculty of Computer Science and Systems Engineering, Kyushu Institute of Technology , 5.National Institute of Technology Kagoshima College, 6.National Institute of Information and Communications Technology, 7.APL/JHU)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM18] Study of coupling processes in solar-terrestrial system

convener:Mamoru Yamamoto(Research Institute for Sustainable Humanosphere, Kyoto University), Yasunobu Ogawa(National Institute of Polar Research), Satonori Nozawa(Institute for Space-Earth Environmental Research, Nagoya University), Akimasa Yoshikawa(Department of Earth and Planetary Sciences, Kyushu University)

[PEM18-11] Comparison of FM-CW Ionosonde and MAGDAS observations with S4 index in Peru during 15-18 March 2019

*Akiko Fujimoto[1], Akimasa Yoshikawa[2], Akihiro Ikeda[3], Shuji Abe[2], Moe Hayashi[2] (1.Kyushu Institute of Technology, 2.Kyushu University, 3.National Institute of Technology, Kagoshima College)

[PEM18-12] **Complimenting regional GPS-TEC computerized ionospheric tomography (CIT) with ionosonde data assimilation**

*Nicholas Ssessanga[1], Mamoru Yamamoto [1], Susumu Saito[2], Akinori Saito[3], Michi Nishioka[4] (1.RISH , 2.ENRI, 3.Kyoto Univ., 4.NICT)

[PEM18-13] A study of equatorial plasma bubble structure using VHF radar and GNSS scintillations over the low-latitude region

*Acharaporn Bumrungkit[1], Susumu Saito[2], Pornchai Supnithi[1] (1.King Mongkut's Institute of Technology Ladkrabang (KMITL), 2.Electronic Navigation Research Institute (ENRI), National Institute of Maritime, Port, and Aviation Technology (MPAT))

[PEM18-14] **Evolution of a Mesospheric Bore in a Duct Observed by Ground-Based Double-Layer Imagers and Satellite Observations Over the Tibetan Plateau Region**

*Qinzeng Li[1], Jiyao Xu[1], Jia Yue[2], Xiao Liu[3], Wei Yuan[1] (1.State Key Laboratory of Space Weather, National Space Science Center, Chinese Academy of Sciences, Beijing, China, 2.Department of Atmospheric and Planetary Sciences, Hampton University, Hampton, Virginia, USA, 3.School of Mathematics and Information Science, Henan Normal University, Xinxiang, China)

[PEM18-15] Discussion 1

*Mamoru Yamamoto[1] (1.Research Institute for Sustainable Humanosphere, Kyoto University)

[PEM18-16] Discussion 2

*Mamoru Yamamoto[1] (1.Research Institute for Sustainable Humanosphere, Kyoto University)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM19] Dynamics of the Inner Magnetospheric System

convener:Kunihiro Keika(Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo), Aleksandr Y Ukhorskiy(Johns Hopkins University Applied Physics Laboratory), Yoshizumi Miyoshi(Institute for Space-Earth Environmental Research, Nagoya University), Lynn M Kistler(University of New Hampshire Main Campus)

[PEM19-01] Solar wind as a Source of Magnetospheric Plasma

★Invited Papers

*Robert Colby Allen[1], Sarah K Vines[1], Stefano A Livi[2], Don G Mitchell[1], Chris P Paranicas[1], Kareem Sorathia[1], Sam Bingham[1] (1.Johns Hopkins University Applied Physics Laboratory, 2.Southwest Research Institute)

[PEM19-02] Magnetic field dipolarization and low-energy O^+ ion flux variations in the inner magnetosphere observed by Arase

*Masahito Nose[1], Ayako Matsuoka[2], Yoshizumi Miyoshi[1], Kazushi Asamura[2], Mariko Teramoto[3], Tomoaki Hori[1], Iku Shinohara[2] (1.Institute for Space-Earth Environmental Research, Nagoya University, 2.Research Division for Space Plasma, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 3.Kyushu Institute of Technology)

[PEM19-03] Jupiter's plasma circulation and particle precipitation associated with the inner magnetosphere probed with the Hisaki satellite

★Invited Papers

*Tomoki Kimura[1], Fuminori Tsuchiya[1], Chihiro Tao[2], Kazuo Yoshioka[3], Hajime Kita[4], Go Murakami[4], Atsushi Yamazaki[4], Reina Hikida[3], Fumiharu Suzuki[3], Ryoichi Koga[1], George Clark[5], Zhonghua Yao[6], Yasutaka Hiraki[7], Fran Bagenal[8], Peter Delamere[9], Keiichiro Fukazawa[10], Ichiro Yoshikawa[3], Masaki Fujimoto[4], Hisaki Science team (1.Tohoku University, 2.NICT, 3.University of Tokyo, 4.JAXA/ISAS, 5.Johns Hopkins University / Applied Physics Laboratory, 6.Liege University , 7.Advanced Knowledge Laboratory, Inc., 8.University of Colorado Boulder, 9.University of Alaska Fairbanks, 10.Kyoto University)

[PEM19-04] Cold ions perpendicularly heated by fast magnetosonic waves in the inner magnetosphere observed by Arase (ERG) satellite

*Kazushi Asamura[1], Masafumi Shoji[2], Yoshizumi Miyoshi[2], Ryosuke Fujii[2], Atsushi Miyazaki[2], Yasumasa Kasaba[3], Yoshiya Kasahara[4], Ayako Matsuoka[1], Vania Koleva Jordanova[5] (1.ISAS/JAXA, 2.Nagoya U., 3.Tohoku U., 4.Kanazawa U., 5.LANL)

[PEM19-05] Magnetosonic waves driven by proton ring distributions in the Martian magnetosphere

★Invited Papers

*Yuki Harada[1], Suranga Ruhunusiri[2], Jasper S Halekas[2], Jared R Espley[3], Gina A DiBraccio[3], James P McFadden[4], David L Mitchell[4], Christian Mazelle[5], Glyn Collinson[3], David A Brain[6], Takuya Hara[4], Masahito Nose[7], Oimatsu Satoshi[1], Kazuhiro Yamamoto[1], Bruce M Jakosky[6] (1.Graduate School of Science, Kyoto University, 2.Department of Physics and Astronomy, University of Iowa, 3.NASA Goddard Space Flight Center, 4.Space Sciences Laboratory, University of California, Berkeley, 5.IRAP, University of Toulouse, CNRS, UPS, CNES, 6.LASP, University of Colorado at Boulder, 7.ISEE, Nagoya Univ)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM19] Dynamics of the Inner Magnetospheric System

convener:Kunihiro Keika(Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo), Aleksandr Y Ukhorskiy(Johns Hopkins University Applied Physics Laboratory), Yoshizumi Miyoshi(Institute for Space-Earth Environmental Research, Nagoya University), Lynn M Kistler(University of New Hampshire Main Campus)

[PEM19-06] **Formation of Energy-Dispersed Narrow band structure in the Plasmaspheric Region**

*Junhyun Lee[1], Ensang Lee[1], Khan-huk Kim[1] (1.Kyung Hee University)

[PEM19-07] Statistical characteristics and forming mechanisms of trunk structure of ring current ions: Arase ion observations

*Ryosuke Fujii[1], Yoshizumi Miyoshi[1], Masafumi Shoji[1], Kazushi Asamura[2], Lynn M Kistler[1,3], Vania Jordanova[4], Tomoaki Hori[1], Shoichiro Yokota[5], Satoshi Kasahara[6], Kunihiro Keika[6], Ayako Matsuoka[2], Iku Shinohara[2] (1.Nagoya University, 2.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 3.University of New Hampshire, 4.Los Alamos National Laboratory, 5.Osaka University, 6.The university of Tokyo)

[PEM19-08] Excitation of poloidal Pc 5 waves associated with the substorm nose structure: Arase observation

*Kazuhiro Yamamoto[1], Masahito Nose[2], Ayako Matsuoka[3], Mariko Teramoto[4], Reiko Nomura[5], Satoshi Kasahara[6], Shoichiro Yokota[7], Kunihiro Keika[6], Kazushi Asamura[3], Yoshiya Kasahara[8], Atsushi Kumamoto[9], Fuminori Tsuchiya[9], Masafumi Shoji[2], Yoshizumi Miyoshi[2] (1.Graduate School of Science, Kyoto University, 2.Institute for Space-Earth Environmental Research, Nagoya University, 3.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 4.Kyushu Institute of Technology, 5.National Astronomical Observatory of Japan, 6.Graduate School of Science, The University of Tokyo, 7.Graduate School of Science, Osaka University, 8.Graduate School of Natural Science and Technology, Kanazawa University, 9.Graduate School of Science, Tohoku University)

[PEM19-09] Study of the excitation mechanism of storm-time Pc5 ULF waves by ring current ions based on the drift-kinetic simulation

*Tomotsugu Yamakawa[1], Kanako Seki[1], Takanobu Amano[1], Naoko Takahashi[1], Yoshizumi Miyoshi[2] (1.Department of Earth and Planetary Science, School of Science, The University of Tokyo, 2.ISEE, Nagoya University)

[PEM19-10] Recent Progress in ULF Wave's Interaction with Cold Electrons and Ions in the Earth's Inner Magnetosphere

★Invited Papers

*Jie Ren[1], Qiugang Zong[1], Xuzhi Zhou[1], Chao Yue[1], Robert Rankin[2] (1.Peking University, 2.University of Alaska)

[PEM19-11] Nonlinear drift resonance between electrons and ULF waves under the convection electric field

*Li Li[1,2], Yoshiharu Omura[2], Xuzhi Zhou[1] (1.Peking Univ., 2.Kyoto Univ.)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM19] Dynamics of the Inner Magnetospheric System

convener:Kunihiro Keika(Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo), Aleksandr Y Ukhorskiy(Johns Hopkins University Applied Physics Laboratory), Yoshizumi Miyoshi(Institute for Space-Earth Environmental Research, Nagoya University), Lynn M Kistler(University of New Hampshire Main Campus)

[PEM19-12] **An Empirical Model of Electron Flux from the Seven-Year Van Allen Probe Mission**

★Invited Papers

*Christine Gabrielse[1], James Roeder[1], Justin Lee[1], Seth Claudepierre[1,2], Drew L. Turner[3], T. Paul O'Brien[1], Joseph Fennell[1], J. Bernard Blake[1] (1.The Aerospace Corporation, 2.UCLA, 3.John Hopkins Applied Physics Lab.)

[PEM19-13] **Comparison of storm-time electron dynamics observed by Arase/ERG and POES missions**

*ALEXEI DMITRIEV[1,2], Shoichiro Yokota[3], Kunihiro Keika[4], Tomoaki Hori[5], Yoshizumi Miyoshi[5] (1.Institute of Space Science and Engineering, National Central University, Jungli City, Taiwan, 2.Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia, 3.Univesity Osaka, Japan, 4.Univesity Tokyo, Japan, 5.Univesity Nagoya, Japan)

[PEM19-14] Comprehensive Observations of Substorm-Enhanced Plasmaspheric Hiss Generation, Propagation, and Dissipation

*Nigang Liu[1], Zhenpeng Su[1], Zhonglei Gao[2], Huinan Zheng[1], Yuming Wang[1], Shui Wang[1], Yoshizumi Miyoshi[3], Iku Shinohara[4], Yoshiya Kasahara[5], Fuminori Tsuchiya[6], Atsushi Kumamoto[6], Shoya Matsuda[4], Masafumi Shoji[3], Takefumi Mitani[4], Takeshi Takashima[4], Yoichi Kazama[7], Bo-Jhou Wang[7], Shiang-Yu Wang[7], Chae-Woo Jun[3], Tzu-Fang Chang[8], Sunny W. Y. Tam[8], Satoshi Kasahara[9], Shoichiro Yokota[10], Kunihiro Keika[9], Tomoaki Hori[3], Ayako Matsuoka[4] (1.University of Science and Technology of China, Hefei, China, 2.Harbin Institute of Technology, Shenzhen, China, 3.Nagoya University, Nagoya, Japan, 4.Japan Aerospace Exploration Agency, Kanagawa, Japan, 5.Kanazawa University, Kanazawa, Japan, 6.Tohoku University, Sendai, Japan, 7.Academia Sinica Institute of Astronomy and Astrophysics, Taiwan, 8.National Cheng Kung University, Taiwan, 9.University of Tokyo, Tokyo, Japan, 10.Osaka University, Osaka, Japan)

[PEM19-15] Propagation characteristics of whistler-mode chorus waves in the outer radiation belt deduced from the Arase PWE observation

*Satoshi Kurita[1], Yoshizumi Miyoshi[1], Yoshiya Kasahara[2], Hirotsugu Kojima[3], Shoya Matsuda[4], Ayako Matsuoka[4], Iku Shinohara[4] (1.Institute for Space-Earth Environmental Research, Nagoya University, 2.Information Media Center, Kanazawa University, 3.Research Institute for Sustainable Humanosphere, Kyoto University, 4.ISAS/JAXA)

[PEM19-16] **EMIC (ElectroMagnetic Ion Cyclotron) waves during the Van Allen Probes and ERG era: EMIC wave properties depending on geomagnetic conditions**

*Chae-Woo Jun[1], Yoshizumi Miyoshi[1], Chao Yue[2], Jacob Bortnik[3], Larry Lyons[3], Toshi Nishimura[5], Craig Kletzing[4], Satoshi Kasahara[6], Yasumasa Kasaba[7], Shoya Matsuda[8], Masafumi Shoji[1], Fuminori Tsuchiya[6], Atsushi Kumamoto[6], Ayako Matsuoka[8], Iku Shinohara[8] (1.Institute for Space-Earth Environmental Research, Nagoya University, Nagoya, Japan, 2.Department of Earth and Space Science, Peking University, Beijing, China, 3.Atmospheric and Oceanic Sciences, University of California Los Angeles, Los Angeles, USA, 4.Department of Physics and Astronomy, University of Iowa, Iowa City, USA, 5.Boston University, Boston, USA, 6.Kanazawa University, Kakuma, Japan., 7.Tohoku University, Sendai, Japan. , 8.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Sagamihara, Japan.)

[PEM19-17] Statistical error estimation of the WPIA method and its application for nonlinear EMIC-proton interactions

*Masafumi Shoji[1], Yoshizumi Miyoshi[1], Kazushi Asamura[2], Atsushi Miyazaki[1], Yasumasa Kasaba[3], Yoshiya Kasahara[4], Shoya Matsuda[2], Ayako Matsuoka[2], Lynn M Kistler[5,1] (1.Institute for Space-Earth Environmental Research, Nagoya University, 2.ISAS, 3.Tohoku University, 4.Kanazawa University, 5.The University of New Hampshire)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM19] Dynamics of the Inner Magnetospheric System

convener:Kunihiro Keika(Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo), Aleksandr Y Ukhorskiy(Johns Hopkins University Applied Physics Laboratory), Yoshizumi Miyoshi(Institute for Space-Earth Environmental Research, Nagoya University), Lynn M Kistler(University of New Hampshire Main Campus)

[PEM19-18] Comprehensive Study of the Response of Outer Radiation Belt and Inner Magnetosphere to Sheath Regions of Coronal Mass Ejections

*Milla Kalliokoski[1], Emilia Kilpua[1], Drew Turner[2], Allison Jaynes[3], Adnane Osmane[1], Lucile Turc[1], Harriet George[1], Minna Palmroth[1,4] (1.University of Helsinki, 2.Johns Hopkins University Applied Physics Laboratory, 3.University of Iowa, 4.Finnish Meteorological Institute)

[PEM19-19] Electron fluxes interacting with localized oblique whistler mode waves in the Earth's outer radiation belt

*Yikai Hsieh[1], Yuko Kubota[1], Yoshiharu Omura[1] (1.Reserach Institute for Sustainable Humanosphere, Kyoto University)

[PEM19-20] Deformation of electron pitch angle distributions by Upper Band Chorus: Numerical verification for Arase observations

*Shinji Saito[1], Satoshi Kurita[2], Yoshizumi Miyoshi[2] (1.National Institute of Information and Communications Technology, 2.ISEE, Nagoya Univ.)

[PEM19-21] Relative contribution of ULF and whistler-mode chorus waves to the radiation belt variation

*Naoko Takahashi[1], Kanako Seki[1], Mei-Ching Fok[2], Yihua Zheng[2], Yoshizumi Miyoshi[3], Satoshi Kasahara[1], Kunihiro Keika[1], David Hartley[4], Yoshiya Kasahara[5], Yasumasa Kasaba[6], Nana Higashio[1], Ayako Matsuoka[7], Shoichiro Yokota[8], Tomoaki Hori[3], Iku Shinohara[7] (1.Graduate School of Science, The University of Tokyo, 2.NASA Goddard Space Flight Center, 3.Institute for Space-Earth Environmental Research, Nagoya University, 4.The University of Iowa, 5.Information Media Center, Kanazawa University, 6.Planetary Plasma and Atmospheric Research Center, Tohoku University, 7.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 8.Graduate School of Science, Osaka University)

[PEM19-22] Energetic electron variations during magnetic storms: Comparative study between Arase observations and code coupling simulations

*Yoshizumi Miyoshi[1], Vania Jordanova[2], Yuto Katoh[3], Shinji Saito[4], Satoshi Kurita[5], Sandeep Kumar[1], Yoshiya Kasahara[6], Shoya Matsuda[7], Masafumi Shoji[1], Fuminori Tsuchiya[3], Atsushi Kumamoto[3], Ayako Matsuoka[5], Satoshi Kasahara[8], Shoichiro Yokota[9], Tomoaki Hori[1], Kunihiro Keika[8], Yoichi Kazama[10], Shiang-Yu Wang[10], Chae-Woo Jun[1], Takefumi Mitani[7], Takeshi Takashima[7], Nana Higashio[7], Iku Shinohara[7] (1.Institute for Space-Earth Environmental Research, Nagoya University, 2.Los Alamos National Laboratory, 3.Tohoku University, 4.NICT, 5.Kyoto University, 6.Kanazawa University, 7.JAXA, 8.The University of Tokyo, 9.Osaka University, 10.ASIAA)

[PEM19-23] Electric Field Effect on Proton Flux Response in South Atlantic Anomaly during Geomagnetic Storms

*Kirolosse Mina GIRGIS[1,2], Tohru Hada[3,4], Shuichi Matsukiyo[3,4] (1.Department of Earth System Science and Technology (ESST), Interdisciplinary Graduate School of Engineering Sciences (IGSES), Kyushu University, Japan , 2.Aerospace Engineering Department, Faculty of Engineering, Cairo University, Egypt, 3.Department of Advanced Environmental Science and Engineering, Faculty of Engineering Sciences, Kyushu University, Japan, 4.International Center for Space Weather Science and Education (ICSWSE), Kyushu University, Japan)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM20] Recent Advances in Ionosphere Observation and Modeling through New Observation Opportunities

convener:CHIYEN LIN(Center for Astronautical Physics and Engineering, National Central University, TAIWAN), Yen-Jung Wu(Space Sciences Laboratory, University of California, Berkeley), Yang-Yi Sun(China University of Geosciences), Charles Lin(Department of Earth Sciences, National Cheng Kung University)

[PEM20-01] Ionospheric Variability during the September 2019 Southern Hemisphere Sudden Stratospheric Warming

★Invited Papers

*Yosuke Yamazaki[1], Vivien Matthias[2], Yasunobu Miyoshi[3], Claudia Stolle[1,4], Tarique Siddiqui[1], Guram Kervalishvili[1], Jan Laštovička[5], Michal Kozubek[5], William Ward[6], David Themens[6], Samuel Kristoffersen[6], Patrick Alken[7,8] (1.GFZ Potsdam, 2.PIK Potsdam, 3.Kyushu Univ., 4.Univ. of Potsdam, 5.CAS Prague, 6.Univ. of New Brunswick, 7.Colorado Univ., 8.NOAA)

[PEM20-02] Recent Insights into the Thermosphere-Ionosphere Response to External Forcing from the Global-scale Observations of the Limb and Disk (GOLD) Mission

★Invited Papers

*Richard Eastes[1] (1.Laboratory for Atmospheric and Space Physics)

[PEM20-03] Comparing Equatorial Plasma Irregularities across Scale Sizes with GOLD and COSMIC

*Jeffrey Klenzing[1], Alexa Jean Halford[1], Jonathon Smith[1,2], Carlos Martinis[3] (1.NASA Goddard Space Flight Center, 2.Catholic University of America, 3.Boston University)

[PEM20-04] Multi-scale Ion Composition and Plasma Density Irregularities: Swarm-E Observations in the Topside Ionosphere

*Andrew W Yau[1] (1.University of Calgary)

[PEM20-05] The variation of the ionospheric electron density associated with active lightning

Yu-Cheng Lin[1], *Alfred Bing-Chih Chen[1], Chiawen Chuang[1] (1.National Cheng Kung University)

[PEM20-06] Global distribution of persistence of total electron content anomaly

*Yang-Yi Sun[1], Chieh-Hung Chen[1], JANN-YENQ Liu[2] (1.China University of Geosciences (Wuhan), 2.National Central University)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM20] Recent Advances in Ionosphere Observation and Modeling through New Observation Opportunities

convener:CHIYEN LIN(Center for Astronautical Physics and Engineering, National Central University, TAIWAN), Yen-Jung Wu(Space Sciences Laboratory, University of California, Berkeley), Yang-Yi Sun(China University of Geosciences), Charles Lin(Department of Earth Sciences, National Cheng Kung University)

[PEM20-07] Assimilation of Ground- and Space-Based Ionosphere Observations in WACCMX+DART

★Invited Papers

*Nicholas M Pedatella[1], Jeffrey Anderson[1], Chia-Hung Chen[2], Charles Lin[2], Jing Liu[1], Hanli Liu[1], Kevin Raeder[1] (1.National Center for Atmospheric Research, 2.National Cheng Kung University)

[PEM20-08] COSMIC 2 Observation of Topside Ionosphere and Plasmasphere During A Substorm Event

*Qian Wu[1], William Schreiner[2], John Braun[2], Iurii Cherniak[2], Irina Zakharenkova[2], Nick Pedatella[1,2], Min-yang Chou[2] (1.National Center for Atmospheric Research, 2.COSMIC Program/UCP)

[PEM20-09] **Extreme Ionospheric Response to a Minor Magnetic Storm in Deep Solar Minimum Revealed by Data Assimilation Results of FORMOSAT-7/COSMIC-2 and GNSS Total Electron Content**

*Charles Lin[1], P. K. Rajesh[1], CHIYEN LIN[2], JANN-YENQ Liu[3], Chia-Hung Chen[1] (1.Department of Earth Sciences, National Cheng Kung University, 2.Center for Astronautical Physics and Engineering, National Central University, 3.Graduate Institute of Space Science and Engineering, National Central University)

[PEM20-10] Near real-time plasma irregularity monitoring by FORMOSAT-7/COSMIC-2

*Shih-Ping Chen[1], Charles Lin[1], Rajesh Panthalingal Krishnanunni[1], Richard Eastes[2], Jong-Min Choi[1] (1.Department of Earth Sciences, National Cheng-Kung University, 2.Laboratory for Atmospheric and Space Physics, University of Colorado)

[PEM20-11] **Behavior of the low-latitude ionospheric plasma observed by FORMOSAT-7/COSMIC-2**

*FU-YUAN CHANG[1,2], JANN-YENQ Liu[1,2,3], CHI-YEN LIN[1,2], Charles Lin[4] (1.Center for Astronautical Physics and Engineering, National Central University, Taoyuan City, Taiwan, 2.Institute of Space Science, National Central University, Taoyuan City, Taiwan, 3.Center for Space and Remote Sensing Research, National Central University, Taoyuan City, Taiwan, 4.Department of Earth Sciences, National Cheng Kung University, Tainan City, Taiwan)

[PEM20-12] Space Weather Products of FORMOSAT-7/COSMIC-2: Global Ionospheric Specification and Aided Abel Electron Density Profile

*CHIYEN LIN[1,2], Charles Lin[3], JANN-YENQ Liu[1,2], P. K. Rajesh[3], MINYANG CHOU[4], Ho-Fang Tsai[3] (1.Center for Astronautical Physics and Engineering, National Central University, 2.Institute of Space Science and Engineering, National Central University, 3.Department of Earth Sciences, National Cheng Kung University, 4.University Corporation for Atmospheric Research)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM20] Recent Advances in Ionosphere Observation and Modeling through New Observation Opportunities

convener:CHIYEN LIN(Center for Astronautical Physics and Engineering, National Central University, TAIWAN), Yen-Jung Wu(Space Sciences Laboratory, University of California, Berkeley), Yang-Yi Sun(China University of Geosciences), Charles Lin(Department of Earth Sciences, National Cheng Kung University)

[PEM20-13] First Results from the NASA Ionospheric Connection Explorer Mission

★Invited Papers

*Thomas J Immel[1], Scott L. England[4], Roderick A. Heelis[3], Christoph R. Englert[2], Stephen B. Mende[1], Jerry E. Edelstein[1] (1.University of California Berkeley, 2.U.S. Naval Research Laboratory, 3.University of Texas at Dallas, 4.Virginia Institute of Technology)

[PEM20-14] First results from the ICON Far-Ultra-Violet (FUV) Instrument

*Harald U Frey[1], Stephen B Mende[1], Scott L England[5], Robert R Meier[2], Andrew W Stephan[3], Farzad Kamalabadi[4], Ulas Kamaci[4], Thomas J Immel[1] (1.University of California Berkeley, 2.George Mason University, 3.Naval Research Laboratory, 4.University of Illionois, 5.Virgina Technical University)

[PEM20-15] Spatial-structure of mid-latitude sporadic-E episodes revealed by L-band ALOS/PALSAR InSAR observations

*Masato Furuya[1], Natsu Takaki (1.Department of Earth and Planetary Sciences Hokkaido University)

[PEM20-16] Global Rate of TEC Index (ROTI) Observed by Ground-Based GPS TEC in 2009 and 2013

*Shih An Wu[1], JANN-YENQ Liu[1] (1.Institute of Space Science, National Central University, Taiwan)

[PEM20-17] **Design and Preliminary Results for Ionosphere Photometer on FengYun-3(D) Meteorological Satellite**

*Liping Fu[1], Fang Jiang[1], Tian Mao[2], Nan Jia[1], Tianfang Wang[1], Ruyi Peng[1] (1.National Space Science Center,Chinese Academy of Sciences, 2.National Satellite Meteorological Centre)

[PEM20-18] Errors from asymmetric emission rate in spaceborne, limb sounding Doppler interferometry: A correction algorithm with application to ICON/MIGHTI

*Yen-Jung Wu[1], Brian J. Harding[1], Colin C. Triplett[1], Jonathan J. Makela[2], Kenneth D. Marr[3], Christoph R. Englert[3], John M. Harlander[4], Thomas J. Immel[1] (1.Space Sciences Laboratory, University of California, Berkeley, CA, USA, 2.Department of Electrical and Computer Engineering, University of Illinois, Urbana-Champaign, IL, USA, 3.Space Science Division, U.S. Naval Research Laboratory, Washington, DC, USA, 4.Space Systems Research Corporation, Alexandria, VA, USA)

[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM21] Surprises from the Subauroral Zone: Synthesizing Ground and Space-Based Observations and Theory

convener:Connors Martin G(Athabasca University), Kazuo Shiokawa(Institute for Space-Earth Environmental Research, Nagoya University)

[PEM21-01] Magnetospheric-ionosphere dynamics associated with STEVE

★Invited Papers

*Toshi Nishimura[1], Jian Yang[2], Eric Donovan[3], Vassilis Angelopoulos[4], Nozomu Nishitani[5] (1.Boston University, 2.Southern University of Science and Technology, 3.University of Calgary, 4.University of California, Los Angeles, 5.Nagoya University)

[PEM21-02] Magnetosphere-Ionosphere Coupling by Alfvén Waves at Sub-Auroral Latitudes

★Invited Papers

*Robert L Lysak[1], Yan Song[1], Colin L Waters[2], Murray D Sciffer[2], Yuki Obana[3] (1.University of Minnesota, 2.University of Newcastle, 3.Osaka Electrocommunication University)

[PEM21-03] Multi-wavelength imaging observations of STEVE at Athabasca, Canada

*Sneha Yadav[1,2], Kazuo Shiokawa[1], Yuichi Otsuka[1], Martin G Connors[3], Jean-Pierre St. Maurice[4,5] (1.Institute for Space-Earth Environmental Research, 2.Space Physics Laboratory, Vikram Sarabhai Space Centre, Trivandrum, India, 3.Athabasca University Observatories, Athabasca University, Athabasca, Alberta, Canada, 4.Department of Physics and Engineering Physics, University of Saskatchewan, Saskatoon, Saskatchewan, Canada, 5.Department of Physics and Astronomy, University of Western Ontario, London, Ontario, Canada)

[PEM21-04] Pi2 ULF modulation of energetic electron precipitations observed by using VLF/LF transmitter signals

*Hiroyo Ohya[1], Miyashita Takuya[1], Fuminori Tsuchiya[2], Asuka Hirai[2], Mitsunori Ozaki[3], Kazuo Shiokawa[4], Yoshizumi Miyoshi[4], Nozomu Nishitani[4], Tomoaki Hori[4], Mariko Teramoto[5], Martin G Connors[6], Simon G Shepherd[7], Yoshiya Kasahara[3], Atsushi Kumamoto[2], Masafumi Shoji[4], Iku Shinohara[8], Hiroyuki Nakata[1], Toshiaki Takano[1] (1.Graduate School of Engineering, Chiba University, 2.Tohoku University, 3.Kanazawa University, 4.Nagoya University, 5.Kyushu Institute of Technology, 6.Athabasca University, 7.Dartmouth College, 8.Japan Aerospace Exploration Agency)

[PEM21-05] Subauroral GPS TEC and phase variations during geomagnetic storms

*Paul Prikryl[1,2], James M. Weygand[3], Reza Ghoddousi-Fard[4], Bharat S. R. Kunduri[5], P. T. Jayachandran[1], Knut S. Jacobsen[6], Yngvild L. Andalsvik[6], Tibor Durgonics[7], Kjerrmar Oksavik[8,9] (1.Physics Department University of New Brunswick, Canada, 2. Geomagnetic Laboratory Natural Resources Canada, 3.Earth Planetary and Space Sciences, University of California, USA, 4.Canadian Geodetic Survey Natural Resources Canada , 5.Bradley Dept. of Electrical and Computer Engineering, Virginia Tech, USA, 6.Norwegian Mapping Authority, Norway, 7.National Space Institute, Technical University of Denmark, Denmark, 8.Department of Physics and Technology, University of Bergen, Norway, 9.Arctic Geophysics, University Centre in Svalbard, Norway)

[E] Oral | P (Space and Planetary Sciences)：P-AE Astronomy & Extrasolar Bodies

[P-AE22] Exoplanets

convener:Masahiro Ikoma(Department of Earth and Planetary Science, The University of Tokyo), Norio Narita(The University of Tokyo), Yuka Fujii(National Astronomical Observatory of Japan)

[PAE22-01] Population studies of exoplanetary atmospheres with next generation of space and ground telescopes

*Giovanna Tinetti[1] (1.UCL)

[PAE22-02] Solving atmospheric retrievals with deep learning.

★Invited Papers

*Ingo Waldmann[1] (1.University College London)

[PAE22-03] Condensates and Clouds in Exoplanetary Atmospheres: Some Lessons from our Solar System

★Invited Papers

*Tristan Guillot[1,2] (1.Observatoire de la Cote d Azur, 2.JSPS/University of Tokyo)

[PAE22-04] **Twinkle: a visible and near-infrared space-based observatory for exoplanet and solar system spectroscopy**

*Billy Nelson Edwards[1,2], Giovanna Tinetti[1,2], Marcell Tessenyi[2,1], Giorgio Savini[1,2], Jonathan Tennyson[1,2], Richard Archer[2], Ian Stotesbury[2], Max Joshua[2], Benjamin Wilcock[2] (1.University College London , 2.Blue Skies Space Ltd)

[PAE22-05] Detecting molecular lines in thermal emission spectra of temperate planets with SPICA/SMI

*Yuka Fujii[1], Taro Matsuo[2], Yui Kawashima[3], Kazumasa Ohno[4], Ayaka Okuya[4], Teruyuki Hirano[4] (1.Earth-Life Science Institute, Tokyo Institute of Technology, 2.Nagoya University, 3.Netherlands Institute for Space Research, 4.Tokyo Institute of Technology)

[PAE22-06] FUV-driven atmospheric escape from hot Jupiters

*Hiroto Mitani[1], Riouhei Nakatani[2], Naoki Yoshida[1] (1.The University of Tokyo, 2.RIKEN)

[E] Oral | P (Space and Planetary Sciences)：P-AE Astronomy & Extrasolar Bodies

[P-AE22] Exoplanets

convener:Masahiro Ikoma(Department of Earth and Planetary Science, The University of Tokyo), Norio Narita(The University of Tokyo), Yuka Fujii(National Astronomical Observatory of Japan)

[PAE22-07] Pebble Accretion by Planets on Eccentric Orbits and the Mass Ratios of Exoplanets

*Steven J Desch[1], Alan Jackson[1], Chuhong Mai[1], Jessica Noviello[1] (1.Arizona State University, School of Earth and Space Exploration)

[PAE22-08] Theoretical prediction of water contents of terrestrial planets with effects of water production in primordial atmospheres

*Tadahiro Kimura[1], Masahiro Ikoma[1] (1.The University of Tokyo)

[PAE22-09] Water Storage Capacity of Rocky Exoplanet Interiors

*Christine Houser[1], Cayman T Unterborn[2], Jun Tsuchiya[3] (1.Earth-Life Science Institute, Tokyo Institute of Technology, 2.Arizona State University, 3.Geodynamics Research Center, Ehime University)

[PAE22-10] Thermal and magnetic evolution of exoplanetary cores

*Irene Bonati[1], Marine Lasbleis[2,1], Lena Noack[3] (1.Earth-Life Science Institute, Tokyo Institute of Technology, 2.Laboratoire de Planétologie et Géodynamique, Université de Nantes, 3.Freie Universität Berlin)

[PAE22-11] The Coupled Roles of Host Star Age, Exoplanet Radiogenic Heat Budget and Climatic Evolution

*Cayman T Unterborn[1], Steven Desch[1], Patrick Young[1], Greg Vance[1], Lee Chieffle[1], Bradford Foley[2] (1.Arizona State University, 2.Pennsylvania State University)

[PAE22-12] Impact of Stellar Superflares on Planetary Habitability

*Yosuke Alexandre Yamashiki[1], Hiroyuki Maehara[2], Vladimir Airapetian[3,4], Yuta Notsu[5], Tatsuhiko Sato[7], Takanori Sasaki[6] (1.Earth & Planetary Water Resources Assessment Laboratory Graduate School of Advanced Integrated Studies in Human Survivability Kyoto University, 2.Okayama Branch Office, Subaru Telescope, National Astronomical Observatory of Japan, 3.NASA/GSFC/SEEC, 4.American University, 5.Laboratory for Atmospheric and Space Physics, University of Colorado Boulder, 6.Department of Astronomy, Kyoto University, 7.Nuclear Science and Engineering Center, Japan Atomic Energy Agency (JAEA))

[E] Oral | P (Space and Planetary Sciences)：P-CG Complex & General

[P-CG23] Shock responses of planetary materials elucidated from meteorites and laboratory experiments

convener:Takuo Okuchi(Institute for Planetary Materials, Okayama University), Toshimori Sekine(Center for High Pressure Science and Technology Advanced Research), Naotaka Tomioka(Kochi Institute for Core Sample Research, Japan Agency for Marine-Earth Science and Technology)

[PCG23-01] Shock heating origin of anomalous achondrite NWA 6704 from infrared spectroscopy and modal mineralogy

*Matthew Izawa[1], Sean Yokoyama[2], Shigeru Yamashita[1], Takuo Okuchi[1], Takuya Moriguti[1], Andrew P Jephcoat[1], Vishnu Reddy[3], Allison M McGraw[3], Lucille Le Corre[4], Edward A Cloutis[5] (1.Institute for Planetary Materials, Okayama University, 827 Yamada, Misasa, Tottori 682-0193, Japan, 2.University of Toronto, 27 King's College Cir, Toronto, ON M5S, Canada , 3.Lunar and Planetary Laboratory, University of Arizona, 1629 E University Blvd Tucson AZ 85721-0092 USA, 4.Planetary Science Institute, 1700 East Fort Lowell, Suite 106, Tucson, AZ, USA, 5.Center for Terrestrial and Planetary Exploration, University of Winnipeg, 515 Portage Avenue, Winnipeg, Manitoba, R3B 2E9 Canada)

[PCG23-02] A new Mg2SiO4 polymorph “poirierite” in shocked meteorites and its possible high-pressure synthesis conditions

*Naotaka Tomioka[1], Takuo Okuchi[2], Luca Bindi[3], Masaaki Miyahara[4], Toshiaki Iitaka[5], Zhi Li[6], Xiande Xie[7], Narangoo Purevjav[2,8], Kiyoshi Fujino[9], Tetsuo Irifune[9], Riho Tani[4,1], Yu Kodama[10] (1.Kochi Institute for Core Sample Research, Japan Agency for Marine-Earth Science and Technology, 2.Institute for Planetary Materials, Okayama University, 3.Università degli Studi di Firenze, 4.Hiroshima University, 5.RIKEN, 6.Nanjing University of Science and Technology, 7.Guangzhou Institute of Geochemistry, 8.Bayerisches Geoinstitut, University of Bayreuth, 9.Geodynamics Research Center, Ehime University, 10.Marine Works Japan Ltd)

[PCG23-03] Shock degrees of eucrites from petrographic and XRD analyses

*Rei Kanemaru[1], Naoya Imae[1,2], Akira Yamaguchi[1,2], Hirotsugu Nishido[3] (1.the Graduate University for Advanced Studies (SOKENDAI), 2.National Institute of Polar Research (NIPR), 3.Okayama University of Science (OUS))

[PCG23-04] Shock conditions for shergottites: A comparison between Asuka 12325 and other shergottites

★Invited Papers

*Atsushi Takenouchi[1], Akira Yamaguchi[1], Takashi Mikouchi[2] (1.National Institute of Polar Research, 2.The University Museum, The University of Tokyo)

[PCG23-05] Shock and recovery experiments of petrologic type 3 ordinary chondrite

*Masaaki Miyahara[1], Junnosuke Edanaga[1], Akira Yamaguchi[2], Takamichi Kobayashi[3], Toshimori Sekine[4,5] (1.Department of Earth and Planetary Systems Science, Graduate School of Science, Hiroshima University, 2.National Institute of Polar Research, 3.National Institute for Materials Science, 4.Center for High-Pressure Science and Technology Advanced Research, 5.Graduate School of Engineering, Osaka University)

[PCG23-06] An overlooked heat source in impact events and its effect on the degree of devolatilization of natural calcite carbonates

★Invited Papers

*Kosuke Kurosawa[1], Hidenori Genda[2], Shintaro Azuma[3], Keishi Okazaki[4] (1.Planetary Exploration Research Center, Chiba Institute of Technology, 2.Earth-Life Science Institute, Tokyo Institute of Technology, 3.Department of Earth and Planetary Sciences, School of Science, Tokyo Institute of Technology , 4.Kochi Institute for Core Sample Research, JAMSTEC)

[E] Oral | P (Space and Planetary Sciences)：P-CG Complex & General

[P-CG23] Shock responses of planetary materials elucidated from meteorites and laboratory experiments

convener:Takuo Okuchi(Institute for Planetary Materials, Okayama University), Toshimori Sekine(Center for High Pressure Science and Technology Advanced Research), Naotaka Tomioka(Kochi Institute for Core Sample Research, Japan Agency for Marine-Earth Science and Technology)

[PCG23-08] Reproducing the high-pressure metallic, oxide and silicate minerals found in meteorites using novel shock-recovery experiments

★Invited Papers

*Jinping Hu[1], Paul D. Asimow[1] (1.Division of Geological and Planetary Sciences, California Institute of Technology)

[PCG23-09] **Shock-induced melting of iron and the melting temperature at Earth's inner-core boundary revisited**

*Youjun Zhang[1], Jun Li[2], Toshimori Sekine[3] (1.Sichuan University, China, 2.Institute of Fluid Physics, China, 3.Center for High Pressure Science and Technology Advanced Research, China)

[PCG23-10] **Ramp compressed Iron at Super-Earth interior conditions**

*Liang Sun[1], Xiaoxi Duan[1], Liping Peng[1], Yulong Li[1], Youjun Zhang[2], Toshimori Sekine[3], Zhebin Wang[1], Jiamin Yang[1], Shaoen Jiang[1] (1.Laser Fusion Research Center, China Academy of Engineering Physics (CAEP), Mianyang,621900,P. R. China, 2.Sichuan University, Chengdu, P.R. China, 3.Center for High Pressure Science and Technology Advanced Research (HPSTAR), Shanghai, 201203, P. R. China.)

[PCG23-11] Experimental platform using high-power laser with X-ray free-electron laser at SACLA and its capabilities for shock experiments

*Kohei Miyanishi[1], Yuichi Inubushi[1,2], Toshinori Yabuuchi[1,2], Keiichi Sueda[1], Tadashi Togashi[1,2], Norimasa Ozaki[3], Michel Koenig[4], Yoshinori Tange[2], Kensuke Tono[1,2], Makina Yabashi[1,2] (1.RIKEN SPring-8 Center, 2.Japan Synchrotron Radiation Research Institute, 3.Osaka University, 4.LULI, CNRS, CEA, Ecole Polytechnique, UPMC, Univ Paris 06)

[E] Oral | P (Space and Planetary Sciences)：P-CG Complex & General

[P-CG24] Future missions and instrumentation for space and planetary science

convener:Kazuo Yoshioka(Graduate School of frontier Science, The University of Tokyo), Satoshi Kasahara(The university of Tokyo), Kazunori Ogawa(Japan Aerospace Exploration Agency), Mitsunori Ozaki(Faculty of Electrical and Computer Engineering, Institute of Science and Engineering, Kanazawa University)

[PCG24-01] Overview of Smart Lander for Investigating Moon and Scientific Instrument

★Invited Papers

*Makiko Ohtake[1] (1.Department of Planetary Science, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency)

[PCG24-03] Development of an Ion Source for Future Solar System Explorations

*Naho yanase[1], Satoshi Kasahara[1], Yoshifumi Saito[2], Shoichiro Yokota[3], Masafumi Hirahara[4], Oya Kawashima[1] (1.The University of Tokyo, 2.ISAS/JAXA, 3.Osaka University, 4.Nagoya University)

[PCG24-04] Overview of DESTINY$^+$ mission

★Invited Papers

*Takeshi Takashima[1], Kazutaka Nishiyama[1], Hiroyuki Toyota[1], Tomoko Arai[2], Takayuki Yamamoto[1] (1.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 2.Chiba Inst. of Technology)

[PCG24-05] Breadboard model of asteroid tracking system for DESTINY$^+$ mission: concept design and initial performance test

*Peng Hong[1], Ko Ishibashi[1], Shunsuke Sato[2], Kotaro Fujiwara[3], Kanako Machii[4], Hiroyuki Toyota[2], Kazutaka Nishiyama[2], Masatsugu Otsuki[2], Osamu Okudaira[1], Takeshi Takashima[2] (1.Planetary Exploration Research Center, Chiba Institute of Technology, 2.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 3.Division of Mechanical and Space Engineering, Graduate School of Engineering, Hokkaido University, 4.Department of Mechanical Engineering and Intelligent Systems, Faculty of Informatics and Engineering, The University of Electro-Communications)

[PCG24-06] Development of gravity gradiometer for the interior investigation of the solar system small body

*Reiko Nomura[1], Akito Araya[2], Noriyuki Namiki[1], Koji Matsumoto[1], Hiroshi Araki[1], Kazuyoshi Asari[1], Kazushi Asamura[3], Hiroaki Shiraishi[3] (1.National Astronomical Observatory of Japan, 2.Earthquake Research Institute, the University of Tokyo, 3.Insititute of Space and Astronautical Science, JAXA)

[E] Oral | P (Space and Planetary Sciences)：P-CG Complex & General

[P-CG24] Future missions and instrumentation for space and planetary science

convener:Kazuo Yoshioka(Graduate School of frontier Science, The University of Tokyo), Satoshi Kasahara(The university of Tokyo), Kazunori Ogawa(Japan Aerospace Exploration Agency), Mitsunori Ozaki(Faculty of Electrical and Computer Engineering, Institute of Science and Engineering, Kanazawa University)

[PCG24-07] Updated status and future plans of BepiColombo

★Invited Papers

*Go Murakami[1], Johannes Benkhoff[2] (1.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 2.European Space Agency)

[PCG24-08] Current Status of Japanese Participation in JUICE (Jupiter Icy Moons Explorer)

★Invited Papers

*Yoshifumi Saito[1], Yasuhito Sekine[2], Yasumasa Kasaba[3], Keigo Enya[1], Kazushi Asamura[1], YASUKO KASAI[4], Junichi Haruyama[1], Ayako Matsuoka[1], Shoya Matsuda[1] (1.Solar System Science Division, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 2.Earth-Life Science Insitute, Tokyo Institute of Technology, 3.Planetary Plasma and Atmospheric Research Center, Tohoku University, 4.National Institute of Information and Communications Technology (NICT))

[PCG24-09] Scientific Instruments on Martian Moons eXploration (MMX)

★Invited Papers

*Shingo Kameda[1], Jean-Pierre Bibring[2], David Lawrence[3], Hiroki Senshu[4], Shoichiro Yokota[5], Masanori Kobayashi[4], Patrick Michel[6], Stephan Ulamec[7], Hirotaka Sawada[8], Kiyoshi Kuramoto[9], Kazunori Ogawa[8], Koji Wada[4], Tomohiro Usui[8], Tomoki Nakamura[10], Masaki Fujimoto[8], Hidenori Genda[11], Jörn Helbert[7], Naru Hirata[12], Takeshi Imamura[13], Yasuhiro Kawakatsu[8], Hiroki Kusano[14], Koji Matsumoto[15], Hideaki Miyamoto[13], Hiromu Nakagawa[10], Hisashi Otake[8], Sara Russell[16], Sho Sasaki[5], Naoki Terada[10], Sei-ichiro WATANABE[17] (1.School of Science, Rikkyo University, 2.Université de Paris-Sud, 3.The Johns Hopkins University, 4.Chiba Institute of Technology, 5.Osaka University, 6.Observatoire de la Côte d'Azur, 7.Deutschen Zentrums für Luft- und Raumfahrt, 8.Japan Aerospace Exploration Agency, 9.Hokkaido University, 10.Tohoku University, 11.Tokyo Institute of Technology, 12.Aizu University, 13.The University of Tokyo, 14.National Institutes for Quantum and Radiological Science and Technology, 15.National Astronomical Observatory of Japan, 16.Natural History Museum, 17.Nagoya University)

[PCG24-10] Development of the Raman Spectrometer for Martian Moon Exploration (RAX) for the MMX rover

*Yuichiro Cho[1], Koki Yumoto[1], Shingo Kameda[2], Tomohiro Usui[5], Conor Ryan[3], Till Hagelschuer[3], Selene Routley[3], Maximilian Buder[3], Enrico Dietz[3], Ute Böttger[3], Heinz-Wilhelm Hübers[3], Andoni Moral[4], Tomás Belenguer[4], Pablo Rodríguez[4], Fernando Rull[6] (1.Department of Earth and Planetary Science, University of Tokyo, 2.Rikkyo University, 3.German Aerospace Center (DLR), 4. Instituto National de Técnica Aerospacial (INTA), 5.Japan Aerospace Exploration Agency (JAXA), 6.Universidad de Valladolid)

[PCG24-11] Development of a new method for in situ cosmic-ray exposure age measurements using laser ablation

*Naoki Yamamoto[1], Yuichiro Cho[2], Akinojo Ogura[1], Koki Yumoto[2], Yayoi N Miura[3] (1.Department of Earth and Planetary Physics, University of Tokyo , 2.Department of Earth and Planetary Science, University of Tokyo , 3.Earthquake Research Institute, University of Tokyo)

[PCG24-12] Examination of the Magnetic Field Experiment for the OKEANOS Mission

*Ayako Matsuoka[1], Naofumi Murata[2] (1.Research Division for Space Plasma, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 2.Environmental Test Technology Unit, Japan Aerospace Exploration Agency)

[E] Oral | P (Space and Planetary Sciences)：P-CG Complex & General

[P-CG24] Future missions and instrumentation for space and planetary science

convener:Kazuo Yoshioka(Graduate School of frontier Science, The University of Tokyo), Satoshi Kasahara(The university of Tokyo), Kazunori Ogawa(Japan Aerospace Exploration Agency), Mitsunori Ozaki(Faculty of Electrical and Computer Engineering, Institute of Science and Engineering, Kanazawa University)

[PCG24-13] Sounding rocket missions (LAMP and SS520-3) for ionospheric and magnetospheric explorations

★Invited Papers

*Kazushi Asamura[1], Yoshizumi Miyoshi[2], Keisuke Hosokawa[3], Takefumi Mitani[1], Taku Namekawa[1], Takeshi Sakanoi[4], Naoshi Yagi[4], Mizuki Fukizawa[4], Miki Kawamura[4], Reiko Nomura[5], Masahito Nose[2], Yoshifumi Saito[1], Hirotsugu Kojima[6], Shoichiro Yokota[7], Takumi Abe[1] (1.ISAS/JAXA, 2.ISEE/Nagoya U., 3.UEC, 4.Tohoku U., 5.NAOJ, 6.RISH/Kyoto U., 7.Osaka U.)

[PCG24-14] Computer Simulation of Electric Field Sensor in Space Plasma

*Ibuki Fukasawa[1], Hirotsugu Kojima[1], Yohei Miyake[2], Hideyuki Usui[2] (1.Research institute for sustainable humanosphere, Kyoto University, 2.Graduate School of System Informatics, Kobe University)

[PCG24-15] Development of the analog integrated circuit for the new plasma wave receiver

*Takahiro Zushi[1], Hirotsugu Kojima[2] (1.National Institute of Technology, Nara College, 2.Kyoto University)

[PCG24-16] Development of Geant4 application for particle detector design

*PARK INCHUN[1], Yoshizumi Miyoshi[1], Takefumi Mitani[2], Takane Hori[1], Mariko Teramoto[4], Satoshi Kurita[1], Satoshi Kasahara[3], Nana Higashio[5], Fajardo Taipia Isai[4], Keiichi Okuyama[4] (1.Nagoya University Institute for Space-Earth Environmental Research, 2.Japan Aerospace Exploration Agency, Institute of Space and Astronautical Science, 3.The University of Tokyo, 4.Kyushu Institute of Technology, 5.Japan Aerospace Exploration Agency)

[PCG24-17] Development of a miniature Ion-trap Fourier-transform mass spectrometer for future space missions

*Oya Kawashima[1], Satoshi Kasahara[1], Yoshifumi Saito[2], Shoichiro Yokota[4], Masafumi Hirahara[3], Seiji Sugita[1] (1.The university of tokyo, 2.ISAS/JAXA, 3.Nagoya university, 4.Osaka University)

[PCG24-18] Signal and Noise Separation from Satellite Magnetic Field Data Using Independent Component Analysis: Prospect of Magnetic Measurements without Mast and Noise Source Information

*Shun Imajo[1], Masahito Nose[1], Mari Aida[2], Haruhisa Matsumoto[2], Nana Higashio[2], Terumasa Tokunaga[4], Ayako Matsuoka[3] (1.Institute for Space-Earth Environmental Research, Nagoya University, 2.Japan Aerospace eXploration Agency, 3.Kyushu Institute of Technology, 4.Institute of Space and Astronautical Science)

[E] Oral | P (Space and Planetary Sciences)：P-CG Complex & General

[P-CG25] Planetary Magnetosphere, Ionosphere, and Atmosphere

convener:Kanako Seki(Graduate School of Science, University of Tokyo), Takeshi Imamura(Graduate School of Frontier Sciences, The University of Tokyo), Hiroyuki Maezawa(Department of Physical Science Osaka Prefecture University), Naoki Terada(Graduate School of Science, Tohoku University)

[PCG25-01] Seasonal variation of Mercury's exosphere deduced from the analysis MESSENGER data

*Yudai Suzuki[1], Kazuo Yoshioka[1], Go Murakami[2], Ichiro Yoshikawa[1] (1.University of Tokyo, 2.ISAS/JAXA)

[PCG25-03] Study of ion loss mechanisms from ancient Mars with a focus on effects of the global intrinsic magnetic field

*Ryoya Sakata[1], Kanako Seki[1], Shotaro Sakai[1], Naoki Terada[2], Hiroyuki Shinagawa[3], Takashi Tanaka[4] (1.Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, 2.Department of Geophysics, Graduate School of Science, Tohoku University, 3.National Institute of Information and Communications Technology, 4.International Center for Space Weather Science and Education, Kyushu University)

[PCG25-04] Sensitivity of the difference of cumulus convection schemes to the precipitation distributions simulated in a Paleo Mars GCM

*Takeshi Kuroda[1], Katsushige Toriumi[1], Arihiro Kamada[1], Naoki Terada[1], Yasumasa Kasaba[1,2], Isao Murata[1,3], Hiromu Nakagawa[1] (1.Department of Geophysics, Tohoku University, 2.Planetary Plasma and Atmospheric Research Center, Tohoku University, 3.Graduate School of Environmental Studies, Tohoku University)

[PCG25-05] Zonal wind acceleration in the Martian mesosphere during the global dust storm 2018 observed by IR heterodyne spectroscopy

*Akiho Miyamoto[1], Hiromu Nakagawa[1], Takeshi Kuroda[1], Kosuke Takami[1], Isao Murata[1], Nao Yoshida[1], Katsushige Toriumi[1], Shohei Aoki[2], Hideo Sagawa[3], Nicholas McCord Schneider[4], Sonal Jain[4], Yasumasa Kasaba[1], Naoki Terada[1] (1.Major in Geophysics , Graduate School of Science in Tohoku University, 2.Royal Belgian Institute for Space Aeronomy (IASB-BIRA), 3.Kyoto Sangyo University, 4.Laboratory for Atmospheric and Space Physics, Boulder, CO)

[PCG25-06] Study of proton escape from Mars based on MAVEN observations

*Yuki Mori[1], Kanako Seki[1], Shotaro Sakai[1], Takuya Hara[2], David A Brain[3], James P McFadden[2], Jasper S Halekas[4], Gina A DiBraccio[5], Frank G Eparvier[3], Bruce M Jakosky[3] (1.Department of Earth and Planetary Science, Graduate School of Science, University of Tokyo, Tokyo, Japan, 2.Space Sciences Laboratory, University of California, Berkeley, CA, USA, 3.Laboratory for Atmospheric and Space Physics, University of Colorado Boulder, Boulder, CO, USA, 4.Department of Physics and Astronomy, University of Iowa, Iowa City, IA, USA, 5.NASA Goddard Space Flight Center, Greenbelt, MD, USA)

[E] Oral | P (Space and Planetary Sciences)：P-CG Complex & General

[P-CG25] Planetary Magnetosphere, Ionosphere, and Atmosphere

convener:Kanako Seki(Graduate School of Science, University of Tokyo), Takeshi Imamura(Graduate School of Frontier Sciences, The University of Tokyo), Hiroyuki Maezawa(Department of Physical Science Osaka Prefecture University), Naoki Terada(Graduate School of Science, Tohoku University)

[PCG25-07] Study of Molecular Ion Contribution to the Polar Plume from Mars Based on MAVEN Observations

*Sakakura Kotaro[1], Kanako Seki[1], Shotaro Sakai[1], David A Brain[2], James P McFadden[3], James S Halekas[4], Gina A Dibraccio[5], Bruce M Jakosky[2] (1.Department of Earth and Planetary Science, Graduate School of Science, The university of Tokyo, 2.Laboratory for Atmospheric and Space Physics, University of Colorado Boulder, Boulder, Colorado, USA., 3.Space Sciences Laboratory, University of California, Berkeley, California, USA., 4.Department of Physics and Astronomy, University of Iowa, Iowa City, Iowa, USA., 5.Solar System Exploration Division, NASA Goddard Space Flight Center, Greenbelt, MD, USA.)

[PCG25-08] Study of the plasma distribution along a field line between Jupiter and Io related to the auroral electron acceleration process

*Koseki Saito[1], Yuto Katoh[1], Atsushi Kumamoto[1], Tomoki Kimura[1], Yohei Kawazura[1] (1.Department of Geophysics, Graduate School of Science, Tohoku University)

[PCG25-09] Characteristics of Jovian polar atmosphere derived from multispectral and polarimetric observations

*Shuntaro Yokota[1], Mitsuteru Sato[1], Yukihiro Takahashi[1], Seiko Takagi[1], Tatsuharu Ono[1], Yuuki Sato[1], Haruki Sugiyama[1] (1.Department of Cosmosciences, Graduate School of Science, Hokkaido University)

[PCG25-10] Numerical simulations of electron elastic collisions with neutral H_2O originated from Enceladus

*Hiroyasu Tadokoro[1], Yuto Katoh[2] (1.Musashino University, 2.Tohoku University)

[PCG25-11] High-contrast imaging of planetary and satellite atmospheres by the 1.8 m off-axis PLANETS telescope

*Takeshi Sakanoi[1], Masato Kagitani[1], Masahiro Hirahara[2], Mikio Kurita[3], Toshihisa Suzuki[1], Yasumasa Kasaba[1], Takahiro Obara[1], Shoichi Okano[1], Kuhn Jeff[4], Svetlana Berdyugina[5], Emilio Marcelo[6] (1.Planetary Plasma and Atmospheric Research Center, Graduate School of Science, Tohoku University, 2.Graduate School of Environmental Studies, Nagoya University, 3.Graduate School of Science, Kyoto University, 4.Institute for Astronomy, University of Hawaii, USA, 5.Kiepenheuer Institute for Solar Physics, Germany, 6.Universidade Estadual de Ponta Grossa, Brazil)

[PCG25-12] Development of Generic Plasma Irradiation System for Modeling of Space Weathering at Solar System Bodies

*Tomoki Kimura[1], Yusuke Nakauchi[4], Jun Kimura[2], Go Murakami[4], Naoki Terada[3], Hideyuki Usui[6], Masaki N Nishino[4], Shoichiro Yokota[2], Yohei Miyake[6], Kazuo Yoshioka[5] (1.Frontier Research Institute for Interdisciplinary Sciences, Tohoku University, 2.Graduate School of Science, Osaka University, 3.Graduate school of science, Tohoku University, 4.JAXA/ISAS, 5.Department of Complexity Science and Engineering, Tokyo University, 6.Kobe University)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS01] High performance computing for next generation weather, climate, and environmental sciences

convener:Hiromu Seko(Meteorological Research Institute), Takemasa Miyoshi(RIKEN), Chihiro Kodama(Japan Agency for Marine-Earth Science and Technology), Masayuki Takigawa(Japan Agency for Marine-Earth Science and Technology)

[AAS01-01] Big Data Assimilation: Real-time Workflow for 30-second-update Forecasting and Perspectives toward DA-AI Integration

*Takemasa Miyoshi[1], Takumi Honda[1], Shigenori Otsuka[1], Arata Amemiya[1], Yasumitsu Maejima[1], Yoshihiro Ishikawa[2], Hiromu Seko[2], Yoshito Yoshizaki[2], Naonori Ueda[1], Hirofumi Tomita[1], Yutaka Ishikawa[1], Shinsuke Satoh[3], Tomoo Ushio[4], Kana Koike[5], Yasuhiko Nakada[6] (1.RIKEN, 2.Japan Meteorological Agency, 3.National Institute of Information and Communications Technology, 4.Osaka University, 5.MTI Ltd., 6.Tokyo Electric Power Company Holdings)

[AAS01-02] Evaluating the impact of precipitation radar observations from a geostationary satellite on typhoon forecasts

★Invited Papers

*James David Taylor[1], Atsushi Okazaki[3], Moeka Yamaji[2], Takuji Kubota[2], riko Oki[2], Takemasa Miyoshi[1] (1.RIKEN Center for Computational Science, 2.Earth Observatory Research Center, 3.Pennsylvania State University)

[AAS01-03] Formation Process of a Tornado that Formed in a Quasi Linear Convective System Over Kanto Plain, Japan

*Eigo Tochimoto[1], Hiroshi Niino[1] (1.Atmosphere and Ocean Research Institute, The University of Tokyo)

[AAS01-04] **Exploring the potential of assimilating lightning flash observations with an ensemble Kalman filter**

*Takumi Honda[1], Yousuke Sato[2], Takemasa Miyoshi[1] (1.RIKEN, 2.Hokkaido University)

[AAS01-05] Impacts of vessel GNSS data on the heavy rainfall forecasts obtained by JMA's mesoscale data assimilation system (NAPEX)

*Hiromu Seko[1], Yoshinori Shoji[1], Daisuke Hotta[1], Ko Koizumi[2], Yasutaka Ikuta[2] (1.Meteorological Research Institute, 2.Japan Meteorological Agency)

[AAS01-06] Accounting for the horizontal observation error correlation of satellite radiances in ensemble Kalman filter

*Koji Terasaki[1], Takemasa Miyoshi[1] (1.RIKEN Center for Computational Science)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS01] High performance computing for next generation weather, climate, and environmental sciences

convener:Hiromu Seko(Meteorological Research Institute), Takemasa Miyoshi(RIKEN), Chihiro Kodama(Japan Agency for Marine-Earth Science and Technology), Masayuki Takigawa(Japan Agency for Marine-Earth Science and Technology)

[AAS01-07] Projected future changes in tropical cyclone genesis and its seed frequencies by using HighResMIP multi model ensemble simulation

*Yohei Yamada[1], Chihiro Kodama[1], Masaki Satoh[2,1], Masato Sugi[3], Malcolm J Roberts[4], Ryo Mizuta[3], Akira T Noda[1], Tomoe Nasuno[1], Masuo Nakano[1], Pier-Luigi Vidale[5] (1.Japan Agency for Marine-Earth Science and Technology, 2.Atmosphere and Ocean Research Institute, The University of Tokyo, 3.Meteorological Research Institute, Japan Meteorological Agency, 4.UK MetOffice, 5.University of Reading)

[AAS01-08] 100-member ensemble forecast by NICAM to examine forecast bust case Typhoon Krosa (2019)

*Masuo Nakano[1], Ying-Wen Chen[2], Masaki Satoh[2] (1.JAMSTEC Japan Agency for Marine-Earth Science and Technology, 2.AORI / The University of Tokyo)

[AAS01-09] From K to Fugaku: activities toward extended-range prediction using NICAM/NICOCO

*Tomoki Miyakawa[1] (1.Atmosphere and Ocean Research Institute University of Tokyo)

[AAS01-10] Toward an integrated NWP-DA-AI system for precipitation prediction

*Shigenori Otsuka[1], Yasumitsu Maejima[1], Pierre Tandeo[2], Takemasa Miyoshi[1] (1.RIKEN Center for Computational Science, 2.IMT Atlantique)

[AAS01-11] **Parameterization of Subgrid Momentum Transport Using a Global Cloud Resolving Model and AI**

★Invited Papers

*Haruna Tone[1], Masaki Satoh[2], Junshi Ito[2] (1.School of Science, The University of Tokyo, 2.Atmosphere and Ocean Research Institute, The University of Tokyo)

[AAS01-12] Precipitation Nowcasting Based on Convolutional Neural Networks

★Invited Papers

*Maha Mdini[1], Shigenori Otsuka[1], Takemasa Miyoshi[1] (1.RIKEN Center for Computational Science)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS02] Abnormal weathers and disasters in urban environments in East Asia related to climate change

convener:Masaru Inatsu(Faculty of Science, Hokkaido University), Yukari Takayabu(Atmosphere and Ocean Research Institute, the University of Tokyo)

[AAS02-01] A Statistical study of large-scale environment associated with extreme precipitation using AMeDAS and JRA55/ERA5 data

*Ryosuke Shibuya[1], Yukari Takayabu[1], Chie Yokoyama[1], Hiroki Tsuji[1], Hirotaka Kamahori[1] (1.Atmosphere and Ocean Research Institute, The University of Tokyo)

[AAS02-02] Future Projections of Precipitation Characteristics around Japan in Early Summer Combining GPM DPR and CMIP5 Data: Analysis of multi-model variations

*Chie Yokoyama[1], Yukari Takayabu[1], Osamu Arakawa[2], Tomoaki Ose[3] (1.Atmosphere and Ocean Research Institute, University of Tokyo, 2.Japan Agency for Marine-Earth Science and Technology, 3.Meteorological Research Institute)

[AAS02-03] **Spatiotemporal structure of extreme precipitations during landfalling of typhoons over northern Japan**

*Sridhara Nayak[1], Tetsuya Takemi[1] (1.Disaster Prevention Research Institute, Kyoto University)

[AAS02-04] **A composite empirical-pareto distribution approach to correct the bias of daily precipitation from climate models**

*Wenpeng Zhao[1], Tsuyoshi Kinouchi[1] (1.Tokyo institute of technology)

[AAS02-05] Reproducibility of an extremally high-temperature event in d4PDF regional climate model experiment

*Akifumi Nishi[1], Hiroyuki Kusaka[1] (1. Center for Computational Sciences, University of Tsukuba.)

[AAS02-06] Large-eddy simulations of turbulent flow over urban areas of Osaka, Japan

*Guangdong DUAN[1], Tetsuya Takemi[1] (1.DPRI, Kyoto Univ., Japan)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS03] Atmospheric Chemistry in Highly Polluted Environments

convener:Hongliang Zhang(Fudan University), Jianlin Hu(NUIST Nanjing University of Information Science and Technology), Jia Xing(Tsinghua University), Siyu Chen(Lanzhou University)

[AAS03-01] Secondary organic aerosol formation through chlorine-initiated VOCs oxidation in East Asia
★Invited Papers

*Qi Ying[1], Min Su Choi[1] (1.Texas A & M University College Station)

[AAS03-02] **Modeling diurnal variation of surface $PM_{2.5}$ concentration over East China with WRF-Chem: Impacts from boundary layer mixing and anthropogenic emission**
★Invited Papers

*Chun Zhao[1] (1.University of Science and Technology of China, Hefei, China)

[AAS03-03] **Investigation of the Driving Forces for the Recent Trends in Surface Fine Particulate Matter Concentrations in Nanjing, China**

*Jianlin Hu[1], Zhihao Shi[1] (1.NUIST Nanjing University of Information Science and Technology)

[AAS03-04] **The significant role of vehicle ammonia emissions in urban secondary aerosol formation for Chinese megacities**

*Shaojun Zhang[1], Xinyu Liang[1], Yifan Wen[1], Shuxiao Wang[1], Ye Wu[1] (1.Tsinghua University)

[AAS03-05] Fast sulfate production in Beijing haze associated with elevated HONO and N_2O

*Xinlei Ge[1], Junfeng Wang[1] (1.Nanjing University of Information Science and Technology)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS03] Atmospheric Chemistry in Highly Polluted Environments

convener:Hongliang Zhang(Fudan University), Jianlin Hu(NUIST Nanjing University of Information Science and Technology), Jia Xing(Tsinghua University), Siyu Chen(Lanzhou University)

[AAS03-07] **Trend reversal of boundary layer height in China and its influential factors**

★Invited Papers

*Jianping Guo[1] (1.Chi. Aca. Meteorol. Sci., CMA)

[AAS03-08] **A simplified aerosol retrieval algorithm based on Landsat-8 and Sentinel-2 over urban area**

★Invited Papers

*Siwei Li[1], Hao Lin[1], Jie Yang[1], Qingxin Wang[1] (1.Wuhan University)

[AAS03-09] Light-absorbing properties, chromophore composition and sources of brown carbon aerosol in Xi'an, Northwest China

*rujin huang[1], wei yuan[1], lu yang[1], jie guo[1], jing duan[1], haiyan ni[1] (1.Institute of Earth Environment, CAS)

[AAS03-10] Fugitive Road Dust PM 2.5 Emissions and Their Potential Health Impacts

*Siyu Chen[1] (1.Lanzhou University)

[AAS03-11] Online shape and density measurement of single black carbon aerosol particles

Shurong Wang[1], Xin Yang[1], *Xiaofei Wang[1] (1.Fudan University)

[AAS03-12] Heterogeneous Oxidation of SO_2 in Sulfate Production during Nitrate Photolysis at 300 nm: Effect of pH, Relative Humidity, Irradiation Intensity, and the Presence of Organic Compounds

*Masao Gen[1], Chak Chan[2], Ruifeng Zhang[2], DanDan Huang[3], Yongjie Li[4] (1.Faculty of Frontier Engineering, Institute of Science and Engineering, Kanazawa University, 2.School of Energy and Environment, City University of Hong Kong, 3.Shanghai Academy of Environmental Sciences, 4.Department of Civil and Environmental Engineering, Faculty of Science and Technology, University of Macau)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS04] Formation of Air Pollution and Its Interactions with Weather/Climate

convener:Yang Yang(Nanjing University of Information Science & Technology), Meng Gao(State Key Laboratory of Environmental and Biological Analysis), Guangxing Lin(Pacific Northwest National Laboratory)

[AAS04-01] Trends of surface ozone in China in recent years and the roles of anthropogenic emissions and meteorology

★Invited Papers

*Hong Liao[1] (1.Nanjing University of Information Science and Technology)

[AAS04-02] Estimation of Biomass Burning Emissions in Tropical Continents Based on Satellite Observations from 2001 to 2017

★Invited Papers

*Yusheng Shi[1] (1.Aerospace Information Research Institute, Chinese Academy of Sciences)

[AAS04-03] **Numerical Simulation Study on Aerosol-boundary Layer Interaction**

*Zilin Wang[1] (1.Nanjing Univ.)

[AAS04-04] Global and Regional Climate Responses to Black Carbon Emissions from the Arctic and Mid-latitudes

*Yang Yang[1], Sijia Lou[2], Hailong Wang[3], Steven J. Smith[3] (1.Nanjing University of Information Science and Technology, 2.Nanjing University, 3.Pacific Northwest National Laboratory)

[AAS04-05] Mesoscale modeling of aerosol transport over Southeast Asia during the dry season: effects of fire and new emissions

*Shuo Wang[1], Jason Blake Cohen[1] (1.Sun Yat-Sen University)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS04] Formation of Air Pollution and Its Interactions with Weather/Climate

convener:Yang Yang(Nanjing University of Information Science & Technology), Meng Gao(State Key Laboratory of Environmental and Biological Analysis), Guangxing Lin(Pacific Northwest National Laboratory)

[AAS04-06] **Relieved drought in China by 1.5°C global warming under a low emission scenario**

★Invited Papers

*Xu Yue[1] (1.Nanjing University of Information Science and Technology)

[AAS04-07] Observed dependence of surface ozone on increasing temperature in Shanghai, China

*Yixuan Gu[1], Ke Li[2], Jianming Xu[1], Hong Liao[3] (1.Yangtze River Delta Center for Environmental Meteorology Prediction and Warning, 2.John A. Paulson School of Engineering and Applied Sciences, Harvard University, 3.School of Environmental Science and Engineering, Nanjing University of Information Science and Technology)

[AAS04-08] A Study of Air Pollution with Different Synoptic Weather Systems in Taiwan

Hsin-Chih Lai[1], *JUI-TENG OU[1], Li-Wei Lai[1], Mei-Chi Lin[1], Ching-Yen Wang[1] (1.Chang Jung Christian University, Taiwan)

[AAS04-09] Quantifying the Impacts of Cold Airmass on Aerosol Concentrations Over North China Using Isentropic Analysis

*Qian Liu[1], Guixing Chen[1], Toshiki Iwasaki[2] (1.Sun Yat-sen University, 2.Tohoku University)

[AAS04-10] To what extents do urbanization and air pollution affect fog?To what extents do urbanization and air pollution affect fog?

*Shuqi Yan[1,2,3,4], Bin Zhu[1,2,3,4], Yong Huang[5,6], Jun Zhu[7], Hanqing Kang[1,2,3,4], Chunsong Lu[1,2,3,4], Tong Zhu[8] (1.Collaborative Innovation Centre on Forecast and Evaluation of Meteorological Disasters, Nanjing University of Information Science & Technology, Nanjing, China, 2.Key Laboratory for Aerosol-Cloud-Precipitation of China Meteorological Administration, Nanjing University of Information Science & Technology, Nanjing, China, 3.Key Laboratory of Meteorological Disaster, Ministry of Education (KLME), Nanjing University of Information Science & Technology, Nanjing, China, 4.Special test field of National Integrated meteorological observation, Nanjing University of Information Science & Technology, Nanjing, China, 5.Anhui Meteorology Institute, Key Lab of Atmospheric Science and Remote Sensing Anhui Province, Hefei 230031, China, 6.Shouxian National Climatology Observatory, Shouxian 232200, China, 7.Xiangshan Meteorological Bureau, Xiangshan 315700, China, 8.IMSG at NOAA/NESDIS/STAR, 5830 University Research Ct., College Park, MD 20740, USA)

[AAS04-11] **Evolution and Assessment of the Atmospheric Composition in Hangzhou and its Surrounding Areas during the G20 Summit**

*Ping Kang[1], Kai Wu[2], Xiaoling Zhang[1] (1.Plateau Atmosphere and Environment Key Laboratory of Sichuan Province, School of Atmospheric Sciences, Chengdu University of Information Technology, Chengdu, Sichuan 610225, China, 2.Department of Land, Air, and Water Resources, University of California, Davis, One Shields Avenue, Davis, CA 95616, USA)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS05] Large-scale moisture and organized cloud systems

convener:Hiroaki Miura(The University of Tokyo), Atsushi Hamada(University of Toyama), Satoru Yokoi(Japan Agency for Marine-Earth Science and Technology), Masaki Satoh(Atmosphere and Ocean Research Institute, The University of Tokyo)

[AAS05-01] The Madden-Julian Oscillation and Climate Change

★Invited Papers

*Eric D Maloney[1], Hien X Bui[1], Wei-Ting Hsiao[1], Elizabeth A Barnes [1] (1.Colorado State University Fort Collins)

[AAS05-02] Transient aggregation of convection: Observed behavior and underlying processes

*Hirohiko Masunaga[1], Christopher E Holloway[2], Hironari Kanamori[1], Sandrine Bony[3], Thorwald H. M. Stein[2] (1.Nagoya University, 2.University of Reading, 3.LMD/IPSL, CNRS, Sorbonne Universities)

[AAS05-03] Diversity of Initiation Regions of the MJO Associated with the Mutual Relationship Between the Intraseasonal and Low-frequency Variability

*Daisuke Takasuka[1], Masaki Satoh[1] (1.Atmosphere and Ocean Research Institute, The University of Tokyo)

[AAS05-04] The Diurnal Variability of Precipitating Cloud Populations during DYNAMO

★Invited Papers

*Naoko Sakaeda[1], Scott W Powell[4], Dias Juliana[2,3], George Kiladis[3] (1.University of Oklahoma Norman Campus, 2.CIRES, University of Colorado Boulder, 3.NOAA/Earth System Research Laboratory, 4.Naval Postgraduate School)

[AAS05-05] Observational study on energy and moisture budgets in the atmospheric boundary layer of the tropical deep convective regimes

*Satoru Yokoi[1] (1.Japan Agency for Marine-Earth Science and Technology)

[AAS05-06] Case study on mesoscale convective system near Japan from the perspective of diurnal cycle

*Takaya Yamashita[1], Hironobu Iwabuchi[1] (1.Graduate School of Science, Tohoku University)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS05] Large-scale moisture and organized cloud systems

convener:Hiroaki Miura(The University of Tokyo), Atsushi Hamada(University of Toyama), Satoru Yokoi(Japan Agency for Marine-Earth Science and Technology), Masaki Satoh(Atmosphere and Ocean Research Institute, The University of Tokyo)

[AAS05-07] **Effects of microphysical processes on the precipitation spectrum in a strongly forced environment**

★Invited Papers

*Chien-Ming Wu[1], Jin-De Huang[1] (1.Department of Atmospheric Sciences, National Taiwan University)

[AAS05-09] New Critical Length Scale for the Onset of Self-Aggregation of Moist Convection

★Invited Papers

*Tomoro Yanase[1,2,3], Seiya Nishizawa[1], Hiroaki Miura[4,1], Tetsuya Takemi[3], Hirofumi Tomita[1,5] (1.RIKEN Center for Computational Science, 2.Graduate School of Science, Kyoto University, 3.Disaster Prevention Research Institute, Kyoto University, 4.Graduate School of Science, The University of Tokyo, 5.RIKEN Cluster for Pioneering Research)

[AAS05-10] Evaluation of Mesoscale Convective Systems in Climate Simulations: Methodological Development and Results from MPAS-CAM over the U.S.

*Zhe Feng[1], Fengfei Song[1], Koichi Sakaguchi[1], Ruby Leung[1] (1.PNNL)

[AAS05-11] Evaluate the CMIP6 marine stratocumulus cloud albedo using satellite and reanalysis data

*bida jian[1], Jiming Li[1] (1.Lanzhou University)

[AAS05-12] Dependence of the reproducibility of the MJO convection on differences in the surface flux conditions in NICAM

*Tamaki Suematsu[1], Chihiro Kodama[2], Hisashi Yashiro[3], Tomoro Yanase[4], Hiroaki Miura[5], Tomoki Miyakawa[1], Masaki Satoh[1] (1.Atmosphere and Ocean Research Institute, The University of Tokyo, 2.Japan Agency for Marine-Earth Science and Technology, 3.National Institute for Environmental Studies, 4.Graduate School of Science, Kyoto University, 5.Graduate School of Science, The University of Tokyo)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS06] Advances in Tropical Cyclone Research: Past, Present, and Future

convener:Yoshiaki Miyamoto(Faculty of Environment and Information Studies, Keio University), Sachie Kanada(Nagoya University), Akiyoshi Wada(Department of Typhoon and Severe Weather Research, Meteorological Research Institute), Kosuke Ito(University of the Ryukyus)

[AAS06-01] Convective bursts with gravity waves in tropical cyclones: case study with the Himawari-8 satellite and idealized numerical study

★Invited Papers

*Takeshi Horinouchi[1], Udai Shimada[2], Akiyoshi Wada[2] (1.Faculty of Environmental Earth Science, Hokkaido University, 2.Meteorological Research Institute)

[AAS06-02] Inner-core wind field in a concentric eyewall replacement of Typhoon Trami (2018): A quantitative analysis based on the Himawari-8 satellite

*Satoki Tsujino[1], Takeshi Horinouchi[1], Taiga Tsukada[1], Hiroyuki Yamada[2], Kazuhisa Tsuboki[3] (1.Hokkaido University, 2.University of Ryukyus, 3.Nagoya University)

[AAS06-03] Future Changes in a Typhoon in the Midlatitude Regions: Downscaling simulations form d4PDF data by using a 4-km-mesh nonhydrostatic model

*Sachie Kanada[1], Kazuhisa Tsuboki[1], Izuru Takayabu[2] (1.Nagoya University, 2.Meteorological Research Institute)

[AAS06-04] A numerical and theoretical study of the cirrus banding accompanying tropical cyclones

*Kazuya Yamazaki[1], Hiroaki Miura[1] (1.Department of Earth and Planetary Science at the University of Tokyo)

[AAS06-05] Structural and Intensity Changes in simulated Typhoon 1915 before landfall

*Yoshiaki Miyamoto[1], Hironori Fudeyasu, Akiyoshi Wada (1.Faculty of Environment and Information Studies, Keio University)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS06] Advances in Tropical Cyclone Research: Past, Present, and Future

convener:Yoshiaki Miyamoto(Faculty of Environment and Information Studies, Keio University), Sachie Kanada(Nagoya University), Akiyoshi Wada(Department of Typhoon and Severe Weather Research, Meteorological Research Institute), Kosuke Ito(University of the Ryukyus)

[AAS06-06] **Modeling Contribution of Sea Spray in Air-Sea Enthalpy and Momentum Exchange Coefficients in Rapidly Intensifying Tropical Cyclones**

★Invited Papers

*Alexander Soloviev[1], Breanna Vanderplow[1], Roger Lukas[2] (1.Nova Southeastern University, 2.University of Hawaii at Manoa)

[AAS06-07] A Super Best Track Data Set for Tropical Cyclone Studies

★Invited Papers

*Michael Fiorino[1] (1.AORI, University of Tokyo)

[AAS06-08] Direct Multi-class AUC Maximization for Forecasting Rapidly Intensifying Tropical Cyclones

*Hirotaka Hachiya[1,2], Shumpei Kurora[2], Udai Shimada[3], Naonori Ueda[1] (1.Center for Advanced Intelligence Project, RIKEN, 2.Graduate School of Systems Engineering, Wakayama University, 3.Meteorological Research Institute, Japan Meteorological Agency)

[AAS06-09] Warm ocean conditions and increased typhoon intensity in 2019

*Akiyoshi Wada[1] (1.Department of Typhoon and Severe Weather Research, Meteorological Research Institute)

[AAS06-10] Simulated atmosphere-ocean-biogeochemical interaction under the passage of tropical cyclone Trami (2018)

*Kosuke Ito[1], Jaedeok Lee[1], Takahiro Toyoda[2], Kei Sakamoto[2] (1.University of the Ryukyus, 2.Meteorological Research Institute)

[AAS06-11] Binary Tropical Cyclones in a Three-Dimensional Idealized Framework

Jaedeok Lee[1], *Kosuke Ito[1], Johnny Chan[2] (1.University of the Ryukyus, 2.City University of Hong Kong)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS06] Advances in Tropical Cyclone Research: Past, Present, and Future

convener:Yoshiaki Miyamoto(Faculty of Environment and Information Studies, Keio University), Sachie Kanada(Nagoya University), Akiyoshi Wada(Department of Typhoon and Severe Weather Research, Meteorological Research Institute), Kosuke Ito(University of the Ryukyus)

[AAS06-13] Tropical cyclone activity in South China Sea and the link with ENSO events

*Chun Lei Liu[1] (1.Guangdong Ocean University)

[AAS06-14] **A comprehensive analysis of North Indian Ocean cyclonic activity and rainfall contribution over India during current and pre-warming climate**

*KASTURI SINGH[1], JAGABANDHU PANDA[1] (1.National Institute of Technology Rourkela, Odisha, India)

[AAS06-17] **Ageostrophic Winds Associated with a Tropical Cyclone and Northward Moisture Fluxes**

*Kazuo Saito[1,2,3], Takumi Matsunobu[4] (1.Atmosphere and Ocean Research Institute, the University of Tokyo, 2.Meteorological Research Institute, Japan Meteorological Agency, 3.Japan Meteorological Business Support Center, 4.University of Tsukuba)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS07] Atmospheric Chemistry

convener:Naoko Saitoh(Center for Environmental Remote Sensing), Tomoki Nakayama(Graduate School of Fisheries and Environmental Sciences, Nagasaki University), Sakae Toyoda(Department of Chemical Science and Engineering, Tokyo Institute of Technology), Risa Uchida(Japan Automobile Research Institute)

[AAS07-01] Recent research trends in airborne microplastics (AMPs)

★Invited Papers

*Hiroshi Okochi[1], Norihisa Yoshida[1], Somei Yanagitani[1], Yasuhiro Niida[2], Naoki Umezawa[2], Yohei Itaya[3], Hiroko Ogata[3], Naoya Katsumi[4], Hideshige Takada[5] (1.School of Science and Engineering, Waseda University,, 2.PerkinElmer Japan, 3.Shibata Scientific Technology LTD,, 4.Ishikawa Prefectural University, 5.Tokyo University of Agriculture and Technology)

[AAS07-03] Analysis of sources of carbon monoxide at Tsukuba with observed vertical profile

*Daisike Suzuki[1], Hideaki Nakajima[2,1], Isao Murata[1], Isamu Morino[2] (1.Graduate school of Environmental Studies, Tohoku University, 2.National Institute for Environmental Studies)

[AAS07-04] **Multi-Spectral/Multi-Sensor Satellite Retrievals and Cross-Sensor Validation of Ozone and Carbon Monoxide within the TROPESS Framework**

*thomas p kurosu[1], Kevin bowman[1], John Worden[1], Vijay Natraj[1], Kazuyuki Miyazaki[1], James McDuffie[1], Ming Luo[1], Susan Kulawik[2], Elva Kuai[1], Kristen Fahy[1] (1.NASA Jet Propulsion Laboratory/California Institute of Technology, Pasadena, CA 91109, 2.Bay Area Environmental Research Institute, Moffett Field, CA 94035)

[AAS07-05] Atmospheric Trace Gas Retrievals from Hyperspectral Satellite Remote Sensors

*Xu Liu[1] (1.NASA Langley Research Center)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS07] Atmospheric Chemistry

convener:Naoko Saitoh(Center for Environmental Remote Sensing), Tomoki Nakayama(Graduate School of Fisheries and Environmental Sciences, Nagasaki University), Sakae Toyoda(Department of Chemical Science and Engineering, Tokyo Institute of Technology), Risa Uchida(Japan Automobile Research Institute)

[AAS07-06] Cobenefits and Tradeoffs in Reducing Short-Lived Climate Forcers and Air Pollutants by Deep Decarbonization in Asia

★Invited Papers

*Tatsuya Hanaoka[1], Tomoki Hirayama[2], Go Hibino[2], Toshihiko Masui[1] (1.National Institute for Environmental Studies, 2.Mizuho Information and Research Institute)

[AAS07-08] Utilizing continuous multi-component MAX-DOAS observations for the near-surface ozone sensitivity diagnosis at Tsukuba and Chiba, Japan for 2013-2019

*Hitoshi Irie[1], Daichi Yonekawa[1] (1.Center for Environmental Remote Sensing, Chiba University)

[AAS07-09] Model Evaluation of NO_2 horizontal distribution with MAX-DOAS ground measurement during Chiba-Campaign 2015

*Syuichi Itahashi[1], Hitoshi Irie[2] (1.Central Research Institute of Electric Power Industry, 2.Center for Environmental Remote Sensing, Chiba University)

[AAS07-10] A routine 24-hour measurement of total column NO_2 using direct solar and lunar spectra over Table Mountain Facilities, California

*King-Fai Li[1], Thomas J. Pongetti[2], Ryan Khoury[1], Stanley P. Sander[2], Yuk L. Yung[3] (1.University of California, Riverside, California, USA, 2.Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA, 3.California Institute of Technology, Pasadena, California, USA)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS07] Atmospheric Chemistry

convener:Naoko Saitoh(Center for Environmental Remote Sensing), Tomoki Nakayama(Graduate School of Fisheries and Environmental Sciences, Nagasaki University), Sakae Toyoda(Department of Chemical Science and Engineering, Tokyo Institute of Technology), Risa Uchida(Japan Automobile Research Institute)

[AAS07-11] Monitoring anthropogenic and natural sources and sinks of GHGs: Challenges in Asia and Oceania

★Invited Papers

*Nobuko Saigusa[1], Toshinobu Machida[1], Tsuneo Matsunaga[1], Hiroshi Tanimoto[1], Yosuke Niwa[1], Yukio Terao[1], Akihiko Ito[1] (1.National Institute for Environmental Studies)

[AAS07-12] **Greenhouse gases and air quality monitoring system for urban anthropogenic emission estimation around Jakarta megacity**

*Masahide Nishihashi[1], Hitoshi Mukai[1], Yukio Terao[1], Shigeru Hashimoto[1], Rizaldi Boer[2], Muhammad Ardiansyah[2], Bregas Budianto[2], Adi Rakhman[2], Gito Sugih Immanuel[2], Rudi Nugroho[3], Nawa Suwedi[3], Anies Marufatin[3], Muhammad Agus Salim[3], Dodo Gunawan[4], Eka Suharguniyawan[4], Asep Firman Ilahi[4], Muharam Syam Nugraha[4], Ronald Christian Wattimena[4], Bayu Feriaji[4], Qoriana Maulani[4], Tomohiro Oda[5], Thomas Lauvaux[6] (1.National Institute for Environmental Studies, 2.IPB University, Indonesia, 3.Agency for the Assessment and Application of Technology (BPPT), Indonesia, 4.Meteorological, Climatological, and Geophysical Agency (BMKG), Indonesia, 5.Universities Space Research Association/NASA Goddard Space Flight Center, USA, 6.Laboratory for Sciences of Climate and Environment (LSCE), France)

[AAS07-13] Methane vertical profiles over the Indian subcontinent derived from the GOSAT/TANSO-FTS thermal infrared sensor

*Dmitry Belikov[1], Naoko Saitoh[1], Prabir Patra[1,2], Naveen Chandra[2] (1.Center for Environmental Remote Sensing, Chiba University, 2.Research Institute for Global Change, JAMSTEC)

[AAS07-14] Quantifying thermal power plant CO_2 emissions from CO_2 total column measurements with portable FTIR spectrometers

*Hirofumi Ohyama[1], Kei Shiomi[2], Nobuhiro Kikuchi[2], Isamu Morino[1], Akihiro Hori[1], Tsuneo Matsunaga[1] (1.National Institute for Environmental Studies, 2.Japan Aerospace Exploration Agency)

[AAS07-15] **Satellite Cloud Assimilation and its Impact on Air Quality Simulations**

*Arastoo Pour Biazar[1], Andrew White[1,5], Maudood Khan[6,4], Richard T. McNider[1,2,3] (1.University of Alabama in Huntsville (UAH), 2.UAH/Earth System Science Center (ESSC), 3.National Space Science and Technology Center (NSSTC), 4.National Aeronautics and Space Administration (NASA), 5.NASA/Short-term Predication, Research and Transition (SPoRT) Center, 6.Booz Allen Hamilton)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS07] Atmospheric Chemistry

convener:Naoko Saitoh(Center for Environmental Remote Sensing), Tomoki Nakayama(Graduate School of Fisheries and Environmental Sciences, Nagasaki University), Sakae Toyoda(Department of Chemical Science and Engineering, Tokyo Institute of Technology), Risa Uchida(Japan Automobile Research Institute)

[AAS07-16] **The NICAM–SPRINTARS simulations of the transport and wetdeposition of the black carbon emitted from a Siberian forest fire in September 2016**

*Yousuke Yamashita[1,2], Masayuki Takigawa[1], Daisuke Goto[2], Hisashi Yashiro[2,3], Masaki Satoh[4,1], Yugo Kanaya[1], Fumikazu Taketani[1], Takuma Miyakawa[1] (1.Japan Agency for Marine-Earth Science and Technology, 2.National Institute for Environmental Studies, 3.RIKEN Center for Computational Science (R-CCS), 4.Atmosphere and Ocean Research Institute, The University of Tokyo)

[AAS07-17] Spherical tarballs form through chemical and physical evolution of primary organic particles in biomass-burning smoke

*Kouji Adachi[1] (1.Meteorological Research Institute)

[AAS07-18] Concentrations and Size Distributions of Black Carbon in the Surface Snow at Syowa station in Eastern Antarctica in 2011

*Takeshi Kinase[1,2], Kouji Adachi[1], Naga Oshima[1], Kumiko Goto-Azuma[3,4], Yoshimi Ogawa-Tsukagawa[3], Yutaka Kondo[3], Nobuhiro Moteki[5], Sho Ohata[6], Tatsuhiro Mori[7], Masahiko Hayashi[8], Keiichiro Hara[8], Hiroto Kawashima[9], Kazuyuki Kita[2] (1.Meteorological Research Institute, 2.Ibaraki University, 3.National Institute of Polar Research, 4.SOKENDAI, 5.The University of Tokyo, 6.Nagoya University, 7.Tokyo University of Science, 8.Fukuoka University, 9.Akita Prefectural University)

[AAS07-20] Enhanced new particle formation above the marine boundary layer over the Yellow Sea: Potential impacts on cloud condensation nuclei

*Nobuyuki Takegawa[1], Takafumi Seto[2], Nobuhiro Moteki[3], Makoto Koike[3], Naga Oshima[4], Kouji Adachi[4], Kazuyuki Kita[5], Akinori Takami[6], Yutaka Kondo[7] (1.Tokyo Metropolitan University, 2.Kanazawa University, 3.The University of Tokyo, 4.Meteorological Research Institute, 5.Ibaraki University, 6.National Institute for Environmental Studies, 7.National Institute of Polar Research)

[AAS07-21] Enhanced Sulfate Production During Nitrate Photolysis in the Presence of Halide Ions in Atmospheric Particles

*Masao Gen[1], Chak Chan[2], Ruifeng Zhang[2], DanDan Huang[3], Yongjie Li[4] (1.Faculty of Frontier Engineering, Institute of Science and Engineering, Kanazawa University, 2.School of Energy and Environment, City University of Hong Kong, 3.Shanghai Academy of Environmental Sciences, 4.Department of Civil and Environmental Engineering, Faculty of Science and Technology, University of Macau)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS07] Atmospheric Chemistry

convener:Naoko Saitoh(Center for Environmental Remote Sensing), Tomoki Nakayama(Graduate School of Fisheries and Environmental Sciences, Nagasaki University), Sakae Toyoda(Department of Chemical Science and Engineering, Tokyo Institute of Technology), Risa Uchida(Japan Automobile Research Institute)

[AAS07-22] Investigation on new particle formation competing against the growth of pre-existing particles during isoprene ozonolysis

*Satoshi Inomata[1], Jun Hirokawa[2] (1.National Institute for Environmental Studies, 2.Hokkaido University)

[AAS07-23] **Assessment of the role of saltingout effect on the hygroscopicity of urban atmospheric aerosol**

*Phuong Nguyet Phung[1], Michihiro Mochida[1,2], Sho Ohata[2], Yuzo Miyazaki[3], Eri Tachibana[3] (1.Graduate School of Environmental Studies,Nagoya University, Nagoya 464-8601, Japan, 2.Institute for Space-Earth Environmental Research, Nagoya University, Nagoya 464-8601, Japan, 3.Institute of Low Temperature Science, Hokkaido University, Sapporo, 060-0819, Japan)

[AAS07-24] **Investigation on temperature- and acidity-dependence of the formation of secondary organic aerosol from α-pinene ozonolysis**

*Yange Deng[1], Satoshi Inomata[1], Kei Sato[1], Sathiyamurthi Ramasamy[1], Yu Morino[1], Shinichi Enami[1], Hiroshi Tanimoto[1] (1.National Institute for Environmental Studies)

[AAS07-25] Accurate Identification of Dimers from α-Pinene Oxidation Using High-Resolution Collision-Induced Dissociation Mass Spectrometry

*Kanako Sekimoto[1,2], Daisuke Fukuyama[1], Satoshi Inomata[3] (1.Yokohama City University, 2.Osaka University, 3.National Institute for Environmental Studies)

[AAS07-26] **Application of SERS on the chemical speciation of individual nanoparticles**

Ryota Kunihisa[1], Ayumi Iwata[2], Masao Gen[3,4], Chak Keung Chan[4], *Atsushi Matsuki[5] (1.Graduate School of Natural Science and Technology, Kanazawa University, 2.Faculty of Science and Technology, Keio University, 3.Institute of Science and Engineering, Kanazawa University, 4.School of Energy and Environment, City University of Hong Kong, 5.Institute of Nature and Environmental Technology, Kanazawa University)

[AAS07-27] Development of a Novel Particle Mass Spectrometer for Online Measurements of Refractory Sulfate Aerosols

*Yuya Kobayashi[1], Yu Ide[1], Nobuyuki Takegawa[1] (1.Graduate School of Science, Tokyo Metropolitan University)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS08] Stratosphere-troposphere interaction

convener:Takatoshi Sakazaki(Graduate School of Science, Kyoto University), Takenari Kinoshita(Japan Agency for Marine-Earth Science and Technology), Pu Lin(Princeton University/NOAA Geophysical Fluid Dynamics Laboratory), Peter Hitchcock(Cornell University)

[AAS08-01] Influences on the timing of Sudden Stratospheric Warmings

★Invited Papers

*Lesley J Gray[1], Matt Brown[1], Jeff Knight[2] (1.University of Oxford, 2.Met Office)

[AAS08-02] Hindcast Experiment of the 2009 Sudden Stratospheric Warming and Following Elevated Stratopause Event by Using a High-Top Gravity Wave Resolving Model

★Invited Papers

*Shunsuke Noguchi[1], Shingo Watanabe[1], Dai Koshin[2], Kaoru Sato[2] (1.Japan Agency for Marine-Earth Science and Technology, 2.The University of Tokyo)

[AAS08-03] **Seasonal Prediction Skill of Northern Extratropical Surface Temperature Driven by the Stratosphere**

*Liwei Jia[1,2], Xiaosong Yang[1,2], Gabriel Vecchi[3], Richard Gudgel, Thomas Delworth[1], Stephan Fueglistaler[3], Pu Lin[3], Adam Scaife[4], Seth Underwood[1], Shian-Jiann Lin (1.NOAA Geophysical Fluid Dynamics Laboratory, 2.University Corporation for Atmospheric Research, 3.Princeton University, 4.Met Office Hadley Centre)

[AAS08-04] Persisted negative Antarctic oscillations after sudden stratospheric warming in the Southern Hemisphere in 2019

*Chiaki Kobayashi[1], Shuhei Maeda[1] (1.Meteorological Research Institute)

[AAS08-05] Probabilistic skill in seasonal forecasts of stratospheric extreme events

*Peter Hitchcock[1], Daniela Domeisen[2], Mikhail Dobrynin[3], Johanna Baehr[4] (1.Department of Earth and Atmospheric Sciences, Cornell University, Ithaca, NY, USA, 2.Institute for Atmospheric and Climate Science, ETH Zürich, Switzerland, 3.Deutscher Wetterdienst (DWD), Hamburg, Germany, 4.Institute of Oceanography, Center for Earth System Research and Sustainability (CEN), University of Hamburg, Germany)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS08] Stratosphere-troposphere interaction

convener:Takatoshi Sakazaki(Graduate School of Science, Kyoto University), Takenari Kinoshita(Japan Agency for Marine-Earth Science and Technology), Pu Lin(Princeton University/NOAA Geophysical Fluid Dynamics Laboratory), Peter Hitchcock(Cornell University)

[AAS08-06] Investigating the missing gravity wave drag in the Southern Hemisphere via satellite observations

★Invited Papers

*Laura Angelina Holt[1], M Joan Alexander[1], Colby M Brabec[1] (1.NorthWest Research Associates)

[AAS08-07] Gravity waves parameterized by a transient gravity-wave model coupled with convective sources: Wave intermittency

★Invited Papers

*Young-Ha Kim[1], Gergely Bölöni[1], Sebastian Borchert[2], Hye-Yeong Chun[3], Ulrich Achatz[1] (1.Goethe-Univ. Frankfurt, Germany, 2.DWD, Germany, 3.Yonsei Univ., Korea)

[AAS08-08] Formation of the double stratopauses and elevated stratopause associated with the major stratospheric sudden warming in 2018/19

*Haruka Okui[1], Kaoru Sato[1], Dai Koshin[1], Shingo Watanabe[2] (1. Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo , 2.Japan Agency for Marine-Earth Science and Technology)

[AAS08-09] **A tropospheric pathway of the stratospheric QBO impact on the boreal winter polar vortex**

*Koji Yamazaki[1], Tetsu Nakamura[1], Jinro Ukita[2], Kazuhira Hoshi[2] (1.Hokkaido University, 2.Niigata University)

[AAS08-10] Do sudden stratospheric warmings boost convective activity in the tropics?

*Kohei Yoshida[1] (1.Meteorological Research Institute)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS08] Stratosphere-troposphere interaction

convener:Takatoshi Sakazaki(Graduate School of Science, Kyoto University), Takenari Kinoshita(Japan Agency for Marine-Earth Science and Technology), Pu Lin(Princeton University/NOAA Geophysical Fluid Dynamics Laboratory), Peter Hitchcock(Cornell University)

[AAS08-11] The Coupling between the Troposphere and Stratosphere at Middle and High Latitudes

★Invited Papers

*Wenshou Tian[1], Jinlong Huang[1], Ruhua Zhang[1], Jiankai Zhang[1], Shiyan Zhang[1] (1. College of Atmospheric Sciences, Lanzhou University,China)

[AAS08-12] A pause in Southern Hemisphere circulation trends due to the Montreal Protocol

★Invited Papers

*Antara Banerjee[1,2], John C. Fyfe[3], Lorenzo M. Polvani[4], Darryn Waugh[5,6], Kai-Lan Chang[1,2] (1.Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, USA, 2.Chemical Sciences Division, National Oceanic and Atmospheric Administration/Earth System Research Laboratory, Boulder, Colorado, USA, 3.Canadian Centre for Climate Modelling and Analysis, Environment and Climate Change Canada, Victoria, British Columbia, Canada, 4.Department of Applied Physics and Applied Mathematics, Columbia University, New York, NY, USA, 5.Department of Earth and Planetary Sciences, The John Hopkins University, Baltimore, Maryland, USA., 6.School of Mathematics and Statistics, University of New South Wales, Sydney, New South Wales, Australia)

[AAS08-13] Multi-year analysis using the data assimilation system in the middle atmosphere

*Dai Koshin[1], Kaoru Sato[1], Masashi Kohma[1], Shingo Watanabe[2], Kazuyuki Miyazaki[3] (1.Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, 2.Japan Agency for Marine-Earth Science and Technology, 3.National Aeronautics and Space Administration, Jet Propulsion Laboratory)

[AAS08-14] The response of extreme variability in the Arctic stratosphere to 4xCO_2 concentrations in CMIP6 models

*Blanca Ayarzaguena[1], Andrew J. Charlton-Perez[2], Amy H Butler[3], Peter Hitchcock[4], Isla R. Simpson[5], Lorenzo Polvani[6], Neal Butchart[7], Edwin Gerber[8], Lesley Gray[9], Birgit Hassler[10], Pu Lin[11], François Lott[12], Elisa Manzini[13], Ryo Mizuta[14], Clara Orbe[15], Scott Osprey[9], David Saint-Martin[16], Michael Sigmond[17], Masakazu Taguchi[18], Evgeny Volodin[19], Singo Watanabe[20] (1.Departamento de Física de la Tierra y Astrofísica, Universidad Complutense de Madrid, Spain, 2.Department of Meteorology, University of Reading, UK, 3.Cooperative Institute for Environmental Sciences (CIRES)/National Oceanic and Atmospheric Administration (NOAA) Chemical Sciences Division, USA, 4.Department of Earth and Atmospheric Sciences, Cornell University, USA, 5.Climate and Global Dynamics Laboratory, National Center for Atmospheric Research, USA, 6.Columbia University, USA, 7.Met Office Hadley Centre, UK, 8.Courant Institute of Mathematical Sciences, New York University, USA, 9.NCAS-Climate, Department of Physics, University of Oxford, UK, 10.Deutsches Zentrum für Luft-und Raumfahrt (DLR), Oberpfaffenhofen, Germany, 11.Atmospheric and Oceanic Sciences Program, NOAA, USA,, 12.Laboratoire de Météorologie Dynamique, Ecole Normale Supérieure, France, 13.Max-Planck-Institut für Meteorologie, Germany, 14.Meteorological Research Institute, Japan, 15.NASA Goddard Institute for Space Studies, USA, 16.Centre National de Recherches Météorologiques (CNRM), Université de Toulouse, Météo-France, CNRS, Toulouse, France, 17.Canadian Centre for Climate Modelling and Analysis Environment and Climate Change, Canada, 18.Department of Earth Science, Aichi University of Education, Kariya, Japan, 19.Marchuk Institute of Numerical Mathematics, Russia, 20.Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Japan)

[AAS08-15] UTLS aerosol measurements over Japan within eastward shedding vortices coming from the Asian summer monsoon anticyclone

*Masatomo Fujiwara[1], Tetsu Sakai[2], Koichi Shiraishi[3], Masahiko Hayashi[3], Noriyuki Nishi[3], Shin-Ya Ogino[4], Prabir Patra[4], Taku Umezawa[5], Yoichi Inai[6], Masato Shiotani[7], Nawo Eguchi[8], Takashi Shibata[9], Sergey Khaykin[10], Laura L. Pan[11] (1.Faculty of Environmental Earth Science, Hokkaido University, 2.Meteorological Research Institute, JMA , 3.Faculty of Science, Fukuoka University, 4.JAMSTEC, 5.NIES, 6.Tohoku University, 7.RISH, Kyoto University, 8.Kyushu University, 9.Nagoya University, 10.LATMOS/IPSL, UVSQ, Sorbonne Universites, CNRS, 11.NCAR)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS09] Cloud-Resolving Model Simulations for Climate and Weather Studies

convener:Toshihisa Matsui(NASA Goddard Space Flight Center), Masaki Satoh(Atmosphere and Ocean Research Institute, The University of Tokyo), Wei-Kuo Tao(NASA Goddard Space Flight Center)

[AAS09-02] Importance of the cloud-altitude change to the high-cloud response to sea surface temperatures

*Tomoki Ohno[1], Akira T. Noda[1], Masaki Satoh[2,1] (1.Japan Agency for Marine-Earth Science and Technology, 2. Atmosphere and Ocean Research Institute, The University of Tokyo)

[AAS09-03] Climate effects of aerosol-cloud interaction investigated by a global cloud-resolving model.

*Hotta Haruka[1], Kentaroh Suzuki[1] (1.Atmosphere and Ocean Research Institute, Tokyo University)

[AAS09-04] **An intercomparison of tropical clouds using global storm resolving simulations over the Atlantic**

*Woosub Roh[1], Masaki Satoh[1], Cathy Hohenegger[2] (1.AORI, the university of Tokyo, 2.the Max Planck Institute for Meteorology)

[AAS09-05] Improvements in super-cooled liquid water simulations of low-level mixed-phase clouds over the Southern Ocean using a single-column box model

*Tatsuya Seiki[1], Woosub Roh[2] (1.Japan Agency for Marine-Earth Science and Technology, 2.The University of Tokyo)

[AAS09-06] **How well can the Multiscale Modeling Framework (MMF) simulate MCS-associated precipitation over the Central United States?**

*Guangxing Lin[1], Jiwen Fan[1], Zhe Feng[1] (1.Pacific Northwest National Laboratory)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS09] Cloud-Resolving Model Simulations for Climate and Weather Studies

convener:Toshihisa Matsui(NASA Goddard Space Flight Center), Masaki Satoh(Atmosphere and Ocean Research Institute, The University of Tokyo), Wei-Kuo Tao(NASA Goddard Space Flight Center)

[AAS09-07] Numerical study of the lightning frequency in tropical cyclone using a metrological model coupled with a lightning component

*Yousuke Sato[1,2], Yoshiaki Miyamoto[3,2], Hirofumi Tomita[2] (1.Faculty of Science, Department of Earth and Planetary Sciences, Hokkaido University, 2.RIKEN Center for Computational Science, 3.Faculty of Environment and Information Studies, Keio University)

[AAS09-09] Development and applications of the process-tracking scheme based on bulk microphysics to determine the properties of snow particles

*Akihiro Hashimoto[1], Hiroki Motoyoshi[2], Narihiro Orikasa[1], Ryohei Misumi[2], Masashi Niwano[1] (1.Meteorological Research Institute, 2.National Research Institute for Earth Science and Disaster Resilience)

[AAS09-10] Evaluation of microphysical schemes in a meteorological model for winter snowfall events in Hokkaido

*Makoto Kondo[1], Yousuke Sato[2], Masaru Inatsu[2], Yuuta Katsuyama[1] (1.Graduate School of Science, Hokkaido University, 2.Faculty of science, Hokkaido University)

[AAS09-11] Characterizing Convective Cells Using Cloud-Resolving Simulations

*Xiaowen Li[1], Wei-Kuo Tao[2] (1.Morgan State Univ., 2.NASA/GSFC)

[AAS09-12] **BiLateral Operational Storm-Scale Observation and Modeling: BLOSSOM**

*Toshihisa Matsui[1,4], David B. Wolff[5], Karen Mohr[1], Stephen E. Lang[1,3], Minghua Zhang[2] (1.NASA GSFC , 2.Stony Brook University, 3.SCIENCE SYSTEMS AND APPLICATIONS INC, 4.ESSIC UMD, 5.NASA WFF)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS10] Land-Atmosphere interactions and precipitation variations over the Asian monsoon region.

convener:Hiroshi G. Takahashi(Department of Geography, Tokyo Metropolitan University), Hirokazu Endo(Meteorological Research Institute, Japan Meteorological Agency), Shiori Sugimoto(JAMSTEC Japan Agency for Marine-Earth Science and Technology), Hatsuki Fujinami(Nagoya University)

[AAS10-01] Impact of Eurasian Spring Snow Decrement on East Asian Summer Precipitation

*Ruonan Zhang[1], Renhe Zhang[1], Zhiyan Zuo[2] (1.Department of Atmospheric and Oceanic Sciences & Institute of Atmospheric Sciences, Fudan University, Shanghai, China, 2.State Key Laboratory of Severe Weather and Institute of Climate System, Chinese Academy of Meteorological Sciences, Beijing, China)

[AAS10-02] Warm-Season Convection Initiation in South China

*Lanqiang Bai[1], Guixing Chen[1], Ling Huang[2] (1.Sun Yat-sen University, 2.ITMM, CMA)

[AAS10-03] The observed properties of summer convective clouds and precipitation over the central Tibetan Plateau

*Yi Chang[1,2], Xueliang Guo[3], Jie Tang[2,4], Guangxian Lu[1,2], Peng Qi[2,5] (1.State Key Laboratory of Severe Weather (LASW), Chinese Academy of Meteorological Sciences, Beijing, China, 2.Key Laboratory for Cloud Physics, China Meteorological Administration, Beijing, China, 3.Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, 4.Collaborative Innovation Center for Meteorological Disasters Forecast, Early Warning and Assessment, Nanjing University of Information Science and Technology, Nanjing, China, 5.University of Chinese Academy of Sciences, Beijing)

[AAS10-04] **Impact of urban induced land-use change over eastern and southern Indian cities**

*JAGABANDHU PANDA [1], Sudhansu Sekhar Rath[1] (1.National Institute of Technology Rourkela)

[AAS10-05] **A new light on the long-term trends of extreme rainfall characteristics over Central India**

*Anu Gupta[1], Hiroshi G. Takahashi[1] (1.Tokyo Metropolitan University, Tokyo)

[AAS10-06] Future changes in East Asian summer monsoon precipitation and their uncertainty in 60km-mesh MRI-AGCM ensemble simulations

*Hirokazu Endo[1], Akio Kitoh[2,1], Ryo Mizuta[1], Tomoaki Ose[1] (1.Meteorological Research Institute, Japan Meteorological Agency, 2.Japan Meteorological Business Support Center)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS11] Aerosol impacts on air quality, climate system, and our society

convener:Teppei J Yasunari(Arctic Research Center, Hokkaido University), Kyu-Myong Kim(NASA Goddard Space Flight Center), Hongbin Yu(NASA Goddard Space Flight Center), Toshihiko Takemura(Research Institute for Applied Mechanics, Kyushu University)

[AAS11-03] **Observational study on the response of aerosol optical depth over Japan to springtime transboundary air pollution in 2011-2019**

*YING CAI[1] (1.chiba university)

[AAS11-04] Organic functional group composition of particulate matter from fresh and aged biomass burning and coal combustion emissions

*Amir Yazdani[1], Nikunj Dudani[1], Satoshi Takahama[1], Amelie Bertrand[2], André S. H. Prévôt[2], Imad El Haddad[2], Ann M. Dillner[3] (1.ENAC/IIE Swiss Federal Institute of Technology Lausanne (EPFL), Lausanne, Switzerland, 2.Laboratory of Atmospheric Chemistry, Paul Scherrer Institute, Villigen, Switzerland, 3.Air Quality Research Center, University of California Davis, Davis, California, USA)

[AAS11-05] **Fog Droplet Size Distribution** and the Interaction between **Fog Droplets** and **Fine Particles** During Dense Fog in *Tianjin, China*

*Qing Liu[1,2,4], Bingui Wu[2,3], Zhaoyu Wang [1,2] (1.Tianjin Weather Modification Office, China, 2. Tianjin Key Labarotory of Marine Meteorology, China, 3.Tianjin Meteorology Bureau, China, 4.Key Laboratory for Cloud Physics of China Meteorological Administration, Beijing, China)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS11] Aerosol impacts on air quality, climate system, and our society

convener:Teppei J Yasunari(Arctic Research Center, Hokkaido University), Kyu-Myong Kim(NASA Goddard Space Flight Center), Hongbin Yu(NASA Goddard Space Flight Center), Toshihiko Takemura(Research Institute for Applied Mechanics, Kyushu University)

[AAS11-06] Challenges in constraining cloud and precipitation susceptibilities to aerosols: Satellite observations and global climate models

★Invited Papers

*Takuro Michibata[1], Kentaroh Suzuki[2], Toshihiko Takemura[1] (1.Research Institute for Applied Mechanics, Kyushu University, 2.Atmosphere and Ocean Research Institute, The University of Tokyo)

[AAS11-07] Effective Radiative Forcing Estimates of Anthropogenic Aerosols in MRI-ESM2

*Naga Oshima[1], Seiji Yukimoto[1], Makoto Deushi[1], Tsuyoshi Koshiro[1], Hideaki Kawai[1], Taichu Y Tanaka[1], Kohei Yoshida[1] (1.Meteorological Research Institute)

[AAS11-08] **Satellite and model perspectives of dust transport and deposition across tropical Atlantic Ocean and North Pacific Ocean in recent decades**

*Hongbin Yu[1], Qian Tan[2,3], Yingxi Shi[4,1], Huisheng Bian[1,4], Zhibo Zhang[4], Qianqian Song[4], Dongchul Kim[1,5], Mian Chin[1], Lorraine Remer[4] (1.NASA Goddard Space Flight Center, 2.Bay Area Environmental Research Center, 3.NASA Ames Research Center, 4.University of Maryland Baltimore County, 5.Universities Space Research Association)

[AAS11-09] Dependency of surface air temperature change by sulfate aerosols on CO_2 concentration

*Toshihiko Takemura[1] (1.Research Institute for Applied Mechanics, Kyushu University)

[AAS11-10] Quantifying the Impact of Missing Aerosol Sources on Long Range Transport and Extreme Events using Satellites and Models

*Jason Blake Cohen[1] (1.School of Atmospheric Sciences, Sun Yat-Sen University)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS11] Aerosol impacts on air quality, climate system, and our society

convener:Teppei J Yasunari(Arctic Research Center, Hokkaido University), Kyu-Myong Kim(NASA Goddard Space Flight Center), Hongbin Yu(NASA Goddard Space Flight Center), Toshihiko Takemura(Research Institute for Applied Mechanics, Kyushu University)

[AAS11-11] **Impacts of increased Siberian wildfire on air quality, climate, and economy, assessed with MIROC/SPRINTARS sensitivity experiments**

*Teppei J Yasunari[1,2,3], Shigeto Wakabayashi[4], Toshihiko Takemura[5], Daiju Narita[6] (1.Arctic Research Center, Hokkaido University, 2.Global Station for Arctic Research, GI-CoRE, Hokkaido University, 3.Center for Natural Hazards Research, Hokkaido University, 4.School of Engineering, Hokkaido University, 5.Research Institute for Applied Mechanics, Kyushu University, 6.Graduate School of Arts and Sciences, The University of Tokyo)

[AAS11-12] Linking Climate Modeling to Economic Assessment of Climate Change: Analysis of MIROC-SPRINTARS AOGCM Experiments on Siberian Wildfires

★Invited Papers

*Daiju Narita[1], Teppei J Yasunari[2], Toshihiko Takemura[3] (1.University of Tokyo, 2.Hokkaido University, 3.Kyushu University)

[AAS11-14] Towards a globally harmonized air quality forecasting: GAFIS, a new WMO-GAW initiative

*Taichu Y Tanaka[1], Johannes Flemming[2], Alexander Baklanov[3], Greg Carmichael[5], James H. Crawford[6], Vincent-Henri Peuch[2], Guy Brasseur[7], Ranjeet Sokji[8], Sean Khan[9], Slobodan Nickovic[10], Xiao-ye Zhang[11,10], Christopher Gan[12], Kobus Pienaar[13], Nathalie Laure Roebbel[4], Radenko Pavlovic[14], Markus Amann[15], Robert Pinder[16], Giulia Ruggeri[4], Sophie Pauline Gumy[4] (1.Meteorological Research Institute, Japan Meteorological Agency, 2.ECMWF, 3.WMO, 4.WHO, 5.Univ. Iowa, 6.NASA, 7.MPI-MET, 8.Univ. Hertfordshire, 9.UNEP, 10.SDS-WAS, 11.CMA, 12.NEA, 13.North-West Univ, 14.ECCC, 15.IIASA, 16.EPA)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS13] New particle formation and its impacts on atmospheric chemistry

convener:Jun Zheng(Nanjing University of Information Science and Technology), Lin Wang(Fudan University)

[AAS13-01] New particle formation in the polluted atmosphere of the North China Plain

★Invited Papers

*Hu Min[1], Dongjie Shang[1], Xin Fang[1], Song Guo[1], Zhijun Wu[1], Limin Zeng[1], Sihua Lu[1], Shiyi Chen[1], Keding Lu[1], Yuanhang Zhang[1] (1. State Key Joint Laboratory of Environmental Simulation and Pollution Control, College of Environmental Sciences and Engineering, Peking University)

[AAS13-02] **New particle formation and growth in the urban atmospheric environment**

★Invited Papers

*Jingkun Jiang[1] (1.Tsinghua University)

[AAS13-03] The role of NOx in the formation of highly oxygenated organic molecules and new particles

★Invited Papers

*Wei Nie[1], Chao Yan[2], Pontus Roldin[3], Mikael Ehn[2], Aijun Ding[1] (1.Joint International Research Laboratory of Atmospheric and Earth System Sciences, School of Atmospheric Sciences, Nanjing University, 2.Institute for Atmospheric and Earth System Research/Physics, Faculty of Science, University of Helsinki, 3.Division of Nuclear Physics, Department of Physics, Lund University)

[AAS13-05] How does NOx affect new particle formation from biogenic vapors

*Chao Yan[1] (1.University of Helsinki)

[AAS13-06] Theoretical investigation of heterogeneous oxidation of sulfuric dioxide on mineral dusts and its implication on atmospheric new particle formation

*Jun Zhao[1], Kunpeng Chen[1] (1.Sun Yat-Sen University)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS14] Extreme Events: Observations and Modeling

convener:Sridhara Nayak(Disaster Prevention Research Institute, Kyoto University), JAGABANDHU PANDA(National Institute of Technology Rourkela)

[AAS14-01] Changes in “hotter and wetter” events across China

*Hanqing Deng[1] (1.Anhui climate center)

[AAS14-02] Modulations of European and North American weather variability and extremes by interdecadal variability of the atmospheric circulation over the North Atlantic

★Invited Papers

*Hisashi Nakamura[1], Patrick Martineau[1], Yu Kosaka[1], Bunmei Taguchi[2], Masato Mori[1] (1.Research Center for Advanced Science and Technology, University of Tokyo, 2.Faculty of Sustainable Design, University of Toyama, Toyama)

[AAS14-04] Role of midlatitude SSTs on Extreme Precipitation Events

★Invited Papers

*Satoshi Iizuka[1], ATSUYOSHI MANDA[2] (1.National Research Institute for Earth Science and Disaster Resilience, 2.Mie University Graduate School and Faculty of Biosciences)

[AAS14-05] An overall investigation of changing nature of tropical storms in the North West Pacific basin

*Ravi Shankar Pandey[1], Yuei-An Liou[1] (1.National Central University)

[AAS14-06] Variability of Monsoon Onset in India and Different Modes of Climate Variation (1951-2017)

*Atul Saini[1], Netrananda Sahu[1,2] (1.Department of Geography, University of Delhi, 2.Disaster Prevention Research Institiute, Kyoto University)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS14] Extreme Events: Observations and Modeling

convener:Sridhara Nayak(Disaster Prevention Research Institute, Kyoto University), JAGABANDHU PANDA(National Institute of Technology Rourkela)

[AAS14-07] **Contribution of global warming and atmospheric circulation to the hottest spring in Eastern China in 2018**

*Chunhui Lu[1], Ying Sun[1], Nikolaos CHRISTIDIS[2], Peter STOTT[2] (1.Beijing Climate Center, China Meteorological Administration, 2.Met Office Hadley Centre, Met Office, UK)

[AAS14-08] **The Synoptically-Influenced Extreme Precipitation Systems over Asian-Australian Monsoon Region from TRMM PR Measurements**

*Wei-Ting Chen[1], Hong-Wen Jian[1], Peng-Ren Chen[1], Chien-Ming Wu[1], Kristen L. Rasmussen[2] (1.National Taiwan University, 2.Colorado State University)

[AAS14-09] Atmospheric Rivers in a Changing Climate: An Overview from the second phase of the Atmospheric River Tracking Method Intercomparison Project (ARTMIP)

*Ashley Elizabeth Payne[1], Christine Shields[2], Jonathan Rutz[3], L. Ruby Leung[4], Travis O'Brien[5], F. Martin Ralph[6], Michael Wehner[7] (1.Department of Climate and Space Sciences and Engineering, University of Michigan, Ann Arbor, MI, USA, 2.Climate and Global Dynamics Division, National Center for Atmospheric Research, Boulder, CO, USA, 3.Science and Technology Infusion Division, National Weather Service Western Region Headquarters, National Oceanic and Atmospheric Administration, Salt Lake City, UT, USA, 4.Earth Systems Analysis and Modeling, Pacific Northwest National Laboratory, Richland, WA, USA, 5.Earth and Atmospheric Sciences, Indiana University, Bloomington, Indiana, USA, 6.Center for Western Weather and Water Extremes, Scripps Institution of Oceanography at the University of California, San Diego, CA, USA, 7.Computational Research Division, Lawrence Berkeley National Laboratory, Berkeley, CA, USA)

[AAS14-10] An Understanding of the Physical Mechanism for the back-to-back Drought over India in last one Century

*RAJU PATHAK[1], Sandeep Sahany, Saroj Kanta Mishra (1.Centre for Atmospheric Science, Indian Institute of Technology Delhi)

[AAS14-11] Detection and Possible Interpretation of Tropospheric Dispersive Phase Associated with Heavy Rain Events

*Naufal Setiawan[1], Masato Furuya[1] (1.Space Geodesy Research Section, Department of Earth and Planetary Sciences, Hokkaido University, Japan)

[AAS14-12] **Numerical Simulations of Smoke Haze Transport over Southeast Asia by using WRF-Chem**

★Invited Papers

*Srikanth Madala[1], Tan Li[1], Santo V. Salinas [1], Jun Wang[2,3] (1.Centre for Remote Imaging Sensing and Processing, National University of Singapore, Singapore, 2.Center for Global and Regional Environmental Research, University of Iowa, Iowa City, Iowa, USA , 3.Department of Chemical and Biochemical Engineering, University of Iowa, Iowa City, Iowa, USA)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS17] Climate variability and predictability on subseasonal to decadal timescales

convener:Takashi Mochizuki(Department of Earth and Planetary Sciences, Kyushu University), V Ramaswamy(NOAA GFDL), Yushi Morioka(Japan Agency for Marine-Earth Science and Technology)

[AOS17-01] The Role of AMOC in Atlantic Decadal Predictability

★Invited Papers

*Rong Zhang[1] (1.NOAA Geophysical Fluid Dynamics Laboratory)

[AOS17-02] Underestimated Decadal Predictability and the Existence of the Signal-to-noise Paradox in CMIP5 Models

*Wei Zhang[1], Ben Kirtman[1] (1.University of Miami)

[AOS17-03] An overview of seasonal to Decadal Predictions with MIROC6

*Takahito Kataoka[1], Hiroaki Tatebe[1], Hiroshi Koyama[1], Takashi Mochizuki[1,2], Koji Ogochi[1], Hiroaki Naoe[3], Yukiko Imada[3], Hideo Shiogama[4,5], Masahide Kimoto[5], Masahiro Watanabe[5] (1.JAMSTEC Japan Agency for Marine-Earth Science and Technology, 2.Kyusyu University, 3.Meteorological Research Institute, 4.National Institute for Environmental Studies, 5.The University of Tokyo)

[AOS17-04] Detected Climatic Change in Global Distribution of Tropical Cyclones

*Hiroyuki Murakami[1] (1.Geophysical Fluid Dynamics Laboratory/University Corporation for Atmospheric Research)

[AOS17-05] Thermodynamic coupled modes in the tropical atmosphere-ocean

*Faming Wang[1] (1.Chinese Academy of Sciences, Institute of Oceanology)

[AOS17-06] Could Gulf Stream and Kuroshio be synchronized?

★Invited Papers

*Tsubasa Kohyama[1], Yoko Yamagami[2], Hiroaki Miura[3], Shoichiro Kido[3], Hiroaki Tatebe[4], Masahiro Watanabe[2] (1.Department of Information Sciences, Ochanomizu University, 2.Atmosphere and Ocean Research Institute, The University of Tokyo, 3.Graduate School of Science, The University of Tokyo, 4.Japan Agency for Marine-Earth Science and Technology)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS17] Climate variability and predictability on subseasonal to decadal timescales

convener:Takashi Mochizuki(Department of Earth and Planetary Sciences, Kyushu University), V Ramaswamy(NOAA GFDL), Yushi Morioka(Japan Agency for Marine-Earth Science and Technology)

[AOS17-07] Subseasonal Predictions at GFDL

★Invited Papers

*Baoqiang Xiang[1,2] (1.GFDL, 2.UCAR)

[AOS17-08] Does the tidal mixing affect the MJO in the Maritime Continent?

John D. Steffen[1], *Hyodae Seo[1] (1.Woods Hole Oceanographic Institution)

[AOS17-09] The Role of Pacific Subtropical High Belts in the ENSO Cycle

*Yafei Wang[1] (1.Chinese academy of meteorological sciences)

[AOS17-10] Seasonal-to-multiyear prediction of ENSO using machine deep learning technique

*Jing-Jia Luo[1], Fenghua Ling[1], Yoo-Geun Ham[2], Jeong-Hwan Kim[2] (1.ICAR Institute for Climate and Application Research, NUIST, 2.Chonnam National University,South Korea)

[AOS17-11] Predictability of the super IOD event in 2019 and its link with El Niño Modoki

*Takeshi Doi[1], Swadhin Behera[1], Toshio Yamagata[1,2] (1.JAMSTEC APL, 2.NUIST ICAR)

[AOS17-12] Impact of the boreal summer intraseasonal oscillation on typhoon tracks in the western North Pacific

★Invited Papers

*Masuo Nakano[1], Frederic Vitart[2], Kazuyoshi Kikuchi[3] (1.JAMSTEC Japan Agency for Marine-Earth Science and Technology, 2.ECMWF, 3.IPRC / University of Hawaii)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS19] Marine ecosystems and biogeochemical cycles: theory, observation and modeling

convener:Takafumi Hirata(Arctic Research Center, Hokkaido University), Shin-ichi Ito(Atmosphere and Ocean Research Institute, The University of Tokyo), Enrique N Curchitser(Rutgers University New Brunswick), Eileen E Hofmann(Old Dominion University)

[AOS19-01] On three important ecological properties linking ocean changes to marine biodiversity and ecosystems impacts under a changing climate

★Invited Papers

*William Wai Lung Cheung[1], Tayler Clarke[1], Tyler D. Eddy[2], Gabriel Reygondeau[3] (1.Changing Ocean Research Unit, Institute for the Oceans and Fisheries, The University of British Columbia, 2.Fisheries and Marine Institute of Memorial University of Newfoundland, 3.Department of Ecology and Evolution Biology, Yale University)

[AOS19-02] Understanding the effects of dynamic interactions between changing ocean conditions and fishing effort on living marine resources

★Invited Papers

*Wing Yee Lam[1], Andrés Cisneros Montemayor[1], Colette C. C. Wabnitz[1], William Wai Lung Cheung[1] (1.Fisheries Economics Research Unit and Changing Ocean Research Unit, Institute for the Oceans and Fisheries, The University of British Columbia)

[AOS19-03] High resolution observations of a pelagic tunicate bloom in a warm water filament using a video plankton recorder: development, fate, and effect on biogeochemical cycles and planktonic food webs

★Invited Papers

*Kazutaka Takahashi[1] (1.The University of Tokyo)

[AOS19-04] **Large-scale study on patchy distribution of salps and doliolids in North Pacific Ocean: Patterns, Drivers and Impacts.**

*Nurul Huda Ahmad Ishak[1,2], Kentaro Motoki[1], Hiroomi Miyamoto[3], Kazutaka Takahashi[1] (1.University of Tokyo, 2.Universiti Malaysia Terengganu, 3.Tohoku National Fisheries Research Institute)

[AOS19-05] Conspecific comparison on the swimming and metabolic performance of Pacific chub mackerel (*Scomber japonicus*) distributed in different area

*Chenying Guo[1], Shin-ichi Ito[1], Megumi Enomoto[1], Tomoya Aono[1] (1.Atmosphere and Ocean Research Institute, the University of Tokyo)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS19] Marine ecosystems and biogeochemical cycles: theory, observation and modeling

convener:Takafumi Hirata(Arctic Research Center, Hokkaido University), Shin-ichi Ito(Atmosphere and Ocean Research Institute, The University of Tokyo), Enrique N Curchitser(Rutgers University New Brunswick), Eileen E Hofmann(Old Dominion University)

[AOS19-06] **Basin-scale Relations between Marine Ecosystem Indices and Physical Environment in North Pacific**

*Emi Yati[1,6], Shoshiro Minobe[1,2], Nathan Mantua[3], Shin-ichi Ito[4], Emanuele Di Lorenzo[5] (1.Department of Natural History Sciences, Graduate School of Science, Hokkaido University., 2.Department of Earth and Planetary Sciences, Faculty of Science, Hokkaido University. E-mail: minobe@sci.hokudai.ac.jp, 3.Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanographic and Atmospheric Administration, California 95060, USA., 4.Atmosphere and Ocean Research Institute, University of Tokyo., 5.School of Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta, Georgia, USA., 6.Remote Sensing Application Center, Indonesian National Institute of Aeronautics and Space.)

[AOS19-07] Development of the Potential Vulnerability Index for the Arctic Marine Ecosystems

*Takafumi Hirata[1], Yoshio Masuda[2], Jorge García Molinos[1], Keiko Sato[1], Irene Alabia[1], Toru Hirawake[3], EIJI WATANABE[4], Maki Noguchi Aita[5], Sei-Ichi Saitoh[1] (1.Arctic Research Center, Hokkaido University, 2.Faculty of Environmental Earth Science, Hokkaido University, 3.Graduate School of Fisheries Sciences, Hokkaido University, 4.Institute of Arctic Climate and Environment Research, Japan Agency for Marine-Earth Science and Technology, 5.Earth Surface System Research Center, Japan Agency for Marine-Earth Science and Technology)

[AOS19-08] **Environmental drivers of recent biodiversity patterns in the Eastern Bering Sea**

*Irene Alabia[1], Jorge Garcia Molinos[1], Sei-Ichi Saitoh[1], Takafumi Hirata[1], Toru Hirawake[3], Franz Mueter[2] (1.Arctic Research Center, Hokkaido University, 2.University of Alaska Fairbanks, 3.Faculty of Fisheries Sciences, Hokkaido University)

[AOS19-09] **Modeling studies on pan-Arctic ice-algal productivity: Present status and future projection**

*EIJI WATANABE[1] (1.Japan Agency for Marine-Earth Science and Technology (JAMSTEC))

[AOS19-11] **Potential differences between *in-situ* and remote oceanic primary productivity**

*Ko-Mei LIN[1], Chung-Yu Chiang[1], Yung-Yen Shih[1] (1.R.O.C NAVAL ACADEMY Dept. of Applied Science)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS19] Marine ecosystems and biogeochemical cycles: theory, observation and modeling

convener:Takafumi Hirata(Arctic Research Center, Hokkaido University), Shin-ichi Ito(Atmosphere and Ocean Research Institute, The University of Tokyo), Enrique N Curchitser(Rutgers University New Brunswick), Eileen E Hofmann(Old Dominion University)

[AOS19-12] Impact of the deviation of phytoplankton stoichiometry from Redfield ratio on global oceanic net primary production

*Yoshio Masuda[1], Yasuhiro Yamanaka[1], Takafumi Hirata[2], Hideyuki Nakano[3] (1.Graduate School of Environmental Earth Science, Hokkaido University, 2.Arctic Research Center, Hokkaido University, 3.Meteorological Research Institute)

[AOS19-13] Vertical migration by bulk phytoplankton sustains biodiversity and nutrient input to the surface ocean

*S. Lan Smith[1], Kai W. Wirtz[2] (1.Marine Ecosystem Dynamics Research Group, Research Institute for Global Change, Japan Agency for Marine-Earth Science and Technology, 2.HZG, Geesthacht, Germany)

[AOS19-14] Breakup of marine aggregates under laminar shear flow

*Yasuhito Hayashi[1], Shigeki Wada[1], Yasuhisa Adachi[1] (1.University of Tsukuba)

[AOS19-15] **Summertime oxygen depletion and acidification in Bohai Sea, China**

*Guisheng Song[1], Liang Zhao[2], Huixiang Xie[3], Hao Wei[1] (1.Tianjin University, 2.Tianjin Univ. Sci Technol., 3.ISMER-UQAR)

[AOS19-16] **Seasonal oceanic variability and associated biogeochemical responses around a ridge area along the Kuroshio off Japan**

*Xu Zhang[1], Yusuke Uchiyama[1,2], Yota Suzue[3], Eiji Masunaga[4] (1.Kobe University, 2.Port and Airport Research Institute, 3.Construction Technique Institute Engineering Co., Ltd., 4.Ibaraki University)

[AOS19-17] Drivers and dynamics of change in Altamaha, Doboy, and Sapelo Sounds along the Georgia coast

*Kimberly K Takagi[1], Kimberley S Hunter[2], James B Deemy[1], Wei-Jun Cai[3], Samantha B Joye[2] (1.College of Coastal Georgia, 2.University of Georgia, 3.University of Delaware)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS20] Coastal physical processes associated with mixing, eddies, and internal waves

convener:Taira Nagai(Graduate School of Science, The University of Tokyo), Eisuke Tsutsumi(Atmosphere and Ocean Research Institute, The University of Tokyo), Eiji Masunaga(Ibaraki University)

[AOS20-01] Tidally-driven submesoscale coherent eddies at Naruto Strait in the Seto Inland Sea, Japan

*Yusuke Uchiyama[1], Shota Yanase[1], Xu Zhang[1] (1.Graduate School of Engineering, Kobe University)

[AOS20-02] Seasonal variation of water masses and turbulence structure off the Sanriku Coast

*ikeda masashi[1], Eiji Masunaga[1], Toshi Nagata[2], Sachihiko Itoh[2] (1.ibaraki university , 2.Atmosphere and Ocean Research Institude, The University of Tokyo)

[AOS20-03] Material transport processes around Sagami Bay and Suruga Bay using a particle tracking model

*Takayoshi Inoue[1], Eiji Masunaga[1], Yusuke Uchiyama[2] (1.Ibaraki University, 2.Kobe University)

[AOS20-04] Three-dimensional transport of microplastics in the South China Sea using a Lagrangian particle tracking model

*Kosei Matsushita[1], Yusuke Uchiyama[1], Naru Takaura[1] (1.Kobe Univ.)

[AOS20-05] Volume transport due to internal wave generation along the continental shelf in the South China Sea

*Qiang Li[1], Xiaohua Zhang[1], Xiuyu Zheng[1], Jintao Gu[1], Xiaoting Zhu[1] (1.Tsinghua University)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS20] Coastal physical processes associated with mixing, eddies, and internal waves

convener:Taira Nagai(Graduate School of Science, The University of Tokyo), Eisuke Tsutsumi(Atmosphere and Ocean Research Institute, The University of Tokyo), Eiji Masunaga(Ibaraki University)

[AOS20-06] Observations of vertical mixing and sediment heat flux in a shallow lake

*Eiji Masunaga[1], Shunsuke Komuro[2], Tatsumi Kitamura[2] (1.Ibaraki University, 2.Ibaraki Kasumigaura Environmental Science Center)

[AOS20-07] Effects of the wind forcing on a shallow lake associated with the lake size and stratification

*Daiki Asaoka[1], Eiji Masunaga[1], shunsuke komuro[2], Tatsumi Kitamura[2] (1.Ibaraki University, 2.Ibaraki Kasumigaura Environmental Science Center)

[AOS20-08] Estimating internal tidal current in a tidally-energetic shallow estuary, Ariake Sea, Japan

*Eisuke Tsutsumi[1], Chitake Matsufuji[2], Takeshi Matsuno[3], Tomoharu Senjyu[3], Takahiro Endoh[3] (1.Atmosphere and Ocean Research Institute, The University of Tokyo, 2.Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, 3.Research Institute for Applied Mechanics, Kyushu University)

[AOS20-09] The decreasing trend of M_2 tidal amplitude observed along northwestern Kyushu

*Hiromi Matsuura[1], Katsuto Uehara[2], Shinichiro Kida[2], Toshiyuki Hibiya[3] (1.Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, 2.Research Institute for Applied Mechanics, Kyushu University, 3.Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo)

[AOS20-10] **Multimodal fusion for sea level anomaly forecasting**

*Guosong Wang[1,2], Xidong Wang[1], Xinrong Wu[2], Kexiu Liu[2], Chunjian Sun[2], Hongli Fu[2] (1.College of Oceanography Hohai University, 2.National Marine Data and Information Service)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS21] Dynamics of oceanic and atmospheric waves, vortices, and circulations

convener:Yuki Tanaka(Fukui Prefectural University), Ryo Furue(APL/JAMSTEC), Yukiharu Hisaki(University of the Ryukyus), Norihiko Sugimoto(Keio University, Department of Physics)

[AOS21-02] Structure and evolution of the tropical synoptic-scale waves in the Indian Ocean-Maritime Continent region

*Fukutomi Yoshiki[1], Hidenori AIKI[1] (1.Institute for Space-Earth Environmental Reasearch, Nagoya University)

[AOS21-03] Toward practical use of EFSO for weekly weather forecasts: Dynamics of propagation of observation impacts

*Akira Yamazaki[1], Takemasa Miyoshi[2,1], Takeshi Enomoto[3,1], Nobumasa Komori[1], Jun Inoue[4,1] (1.Application Laboratory, Japan Agency for Marine-Earth Science and Technology, 2.RIKEN Center for Computational Science, 3.Disaster Prevention Research Institute, Kyoto University, 4.National Institute of Polar Research)

[AOS21-04] Numerical and Theoretical Study on the relationship between the amplitudes of tsunamis and the associiated atmospheric Lamb waves

*Kensuke Nakajima[1] (1.Department of Earth and Planetary Sciences,Flculty of Sciences,Kyushu University)

[AOS21-05] **Persistent Small-Scale Features of Ocean Winds and Waves**

★Invited Papers

*Lie-Yauw Oey[1,2] (1.National Central University, 2.Princeton University)

[AOS21-06] Effect of swells on the development of wind waves in the real ocean

*Kosei Komatsu[1,2], Hirotaka Omatsu[1,2], Kiyoshi Tanaka[2] (1.GSFS, Univ. Tokyo, 2.AORI, Univ. Tokyo)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS21] Dynamics of oceanic and atmospheric waves, vortices, and circulations

convener:Yuki Tanaka(Fukui Prefectural University), Ryo Furue(APL/JAMSTEC), Yukiharu Hisaki(University of the Ryukyus), Norihiko Sugimoto(Keio University, Department of Physics)

[AOS21-07] Causal Mechanism of Sea Level Rise in the South Pacific Ocean

★Invited Papers

*Ichiro Fukumori[1], Tangdong Qu[2], Ou Wang[1] (1.Jet Propulsion Laboratory, 2.University of California, Los Angeles)

[AOS21-08] Scale interactions in the tropical Pacific Ocean

★Invited Papers

*Kelvin John Richards[1] (1.University of Hawaii at Manoa)

[AOS21-09] Novel use of time-lapse seismic images and in-situ hydrographic data for detecting changes at the interface between oceanic water layers

*Vincent Tong[1], Qunshu Tang[2,3] (1.University College London, 2.CAS Key Laboratory of Ocean and Marginal Sea Geology, 3.Innovation Academy of South China Sea Ecology and Environmental Engineering)

[AOS21-10] Life-time independent approach to Lagrangian vortices detection

*Anass El Aouni[1], Arthur Vidard[1] (1.INRIA/LJK Grenoble, France)

[AOS21-11] Floating tracer clustering in divergent random flows modulated by an unsteady mesoscale ocean velocity field

*Konstantin Koshel[1,2], Pavel Berloff[3], Evgeny Ryzhov[1,3], Dmitry Stepanov[1] (1.V.I. Ilichev Pacific Oceanological Institute, FEB RAS, 2.Institute of Applied Mathematics, FEB RAS, 7, Radio Street, Vladivostok 690022, Russia, 3.Department of Mathematics, Imperial College London, London SW7 2AZ, United Kingdom)

[AOS21-12] **On the Stability of Discrete Vortex Structures in Geostrophic Models Two-Layer Rotating Fluid and Bessel Vortices**

*Leonid Kurakin[1,2], Irina - Lysenko[1], Irina - Ostrovskaya[1], Mikhail - Sokolovskiy[2,3] (1.Southern Federal University, Rostov on Don, Russia, 2.Water Problems Institute, RAS, Moscow, Russia, 3.Shirshov Institute of Oceanology, RAS, Moscow, Russia)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS21] Dynamics of oceanic and atmospheric waves, vortices, and circulations

convener:Yuki Tanaka(Fukui Prefectural University), Ryo Furue(APL/JAMSTEC), Yukiharu Hisaki(University of the Ryukyus), Norihiko Sugimoto(Keio University, Department of Physics)

[AOS21-13] Data-driven improvement of coarse-resolution QG models

★Invited Papers

*Evgenii Ryzhov[1], Berloff Pavel[1], Kondrashov Dmitri[2], Agarwal Niraj[1] (1.Imperial College London, 2.UCLA)

[AOS21-15] Modified View of Barotropic Energy Conversion and its Application to the Kuroshio extension region

*Takuro Matsuta[1], Yukio Masumoto[1] (1.Graduate School of Science, The University of Tokyo)

[AOS21-16] Distribution and interaction of fronts and eddies in the Kuroshio Extension

*YUNTAO WANG[1], Rui Tang[1] (1.Second Institute of Oceanography Ministry of Natural Resources)

[AOS21-17] **Meridional heat transport in the Japan/East Sea from 1990 to 2010**

*Dmitry Stepanov[1] (1.Pacific Oceanological Institute, Far Eastern Branch, Russian Academy of Sciences)

[AOS21-18] Changes of Oyashio water properties due to multi-decadal and 18.6-year period variabilities

*Vigan Mensah[1], Kay I. Ohshima[1] (1.Institute of Low Temperature Science)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS22] Physical, chemical and biological processes and variability in the Indian Ocean

convener:Yukio Masumoto(Graduate School of Science, The University of Tokyo), Hiroaki Saito(Atmosphere and Ocean Research Institute, The University of Tokyo)

[AOS22-01] **Assessing Organic Carbon on Coastal and Continental Shelf of Indonesia Waters Facing Indian Ocean**

*Aan Johan Wahyudi[1], Edwards Taufiqurrahman[1], Afdal Afdal[1], Hanif Budi Prayitno[1], Hanny Meirinawati[1] (1.Research Center for Oceanography Indonesian Institute of Sciences)

[AOS22-02] **Turbulent mixing in the Indonesian throughflow exit passages, the Lesser Sunda waters**

*Adi Purwandana[1], Yannis - Cuypers[2], Pascale - Bouruet-Aubertot[2], Mochamad Furqon - Azis Ismail[1], Dewi - Surinati[1], Ahmad - Bayhaqi[1] (1.Research Center for Oceanography - Indonesian Institute of Sciences, 2.Laboratoire d'Océanographie et de Climatologie par Expérimentation et Approche Numérique (LOCEAN) - Sorbonne Université)

[AOS22-03] Characterisation of mesoscale eddies along the eastern boundary current off the southern coast of Java

*Mochamad Furqon Azis Ismail[1], Adi Purwandana[1], Asep Sandra Budiman[1], Dewi Surinati[1], Ahmad Bayhaqi[1] (1.Research Centre for Oceanography - Indonesian Institute of Sciences)

[AOS22-04] **Estimation of phytoplankton size classes response to the tropical cyclone Ockhi over the Arabian Sea**

*Rebekah Shunmugapandi[1], Shirishkumar Gedam[2], Arun B Inamdar[2] (1.PhD Student,Centre of Studies in Resources Engineering, Indian Institute of Technology Bombay, India, 2.Professor,Centre of Studies in Resources Engineering, Indian Institute of Technology Bombay, India)

[AOS22-05] Influences of the Interdecadal Pacific Oscillation on the locally amplified Ningaloo Niño

Natsumi Tanuma[1], *Tomoki Tozuka[1] (1.Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo)

[AOS22-06] The Mode Water formation in the South Indian Ocean

*Takuro Matsuta[1], Yukio Masumoto[1] (1.Graduate School of Science, The University of Tokyo)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS23] Atlantic climate variability, and its global impacts and predictability

convener:Ingo Richter(JAMSTEC Japan Agency for Marine-Earth Science and Technology), Hiroki Tokinaga(Research Institute for Applied Mechanics, Kyushu University), Andrea Taschetto(University of New South Wales), Noel S Keenlyside(Geophysical Institute Bergen)

[AOS23-01] **Revisiting Mechanisms of Atlantic Niño Phase Locking**

*Lin Chen[1], Tim Li[2,1], Ran Wang[1] (1.Nanjing University of Information Science and Technology, 210044, Nanjing, China, 2.University of Hawaii, Honolulu, HI, 96822, USA)

[AOS23-02] Seasonal forecasting of the Atlantic Niño

★Invited Papers

*Chloe Prodhomme[1,2], Javier García-Serrano[1,2], Eleftheria Exarchou[2], Aurore Voldoire[3], Noel Keenlyside[4] (1.Group of Meteorology, Universitat de Barcelona (UB), Barcelona, Spain, 2.Barcelona Supercomputing Center (BSC), Barcelona, Spain, 3.Centre National de Recherches Météorologiques (CNRM), Météo-France/CNRS UMR3589, Toulouse, France, 4.Bergen University, Bergen, Norway)

[AOS23-03] Atlantic Niño-Pacific connection and its implication for prediction under greenhouse warming

*wenju cai[1], Fan Jia[2], Lixin Wu[2] (1.Centre for Southern Hemisphere Oceans Research (CSHOR), CSIRO Oceans and Atmosphere, Hobart 7004, Tasmania, Australia, 2.CAS Key Laboratory of Ocean Circulation and Waves, Institute of Oceanology, Chinese Academy of Sciences and Qingdao National Laboratory for Marine Science and Technology)

[AOS23-04] **Walker Circulation strengthening due to an Atlantic Meridional Overturning Circulation collapse.**

*Luis Bryam Orihuela Pinto[1], Andrea Taschetto[1], Matthew England[1] (1.University of New South Wales)

[AOS23-05] Mechanisms of Atlantic Multidecadal Variability

*Rong Zhang[1] (1.NOAA Geophysical Fluid Dynamics Laboratory)

[AOS23-06] Bias of jet in the North Atlantic and its relation to SST in the PRIMAVERA air-sea coupled historical runs

*Fumiaki Ogawa[1], Noel S Keenlyside[1,2], Panos Athanasiadis[3], Reinhard Schiemann[4] (1.University of Bergen and Bjerknes Centre for Climate Research, Bergen, Norway, 2.NERSC, Norway, Bergen, 3.CMCC, Bologna, Italy, 4.University of Reading, Reading, UK)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS24] Exploring new frontiers of oceanic mixing research in the next decade

convener:Toshiyuki Hibiya(Department of Earth and Planetary Science, Graduate School of Science, University of Tokyo), Ichiro Yasuda(Atmosphere and Ocean Research Institute, The University of Tokyo), Lakshmi Kantha(Aerospace Engineering Sciences, University of Colorado, Boulder, Colorado, USA)

[AOS24-01] Global modeling of internal tides and the internal gravity wave continuum

*Brian K Arbic[1] (1.University of Michigan Ann Arbor)

[AOS24-02] Direct numerical simulation of stratified turbulence generated by local instability of internal gravity waves

*Yohei Onuki[1], Sylvain Joubaud[2,3], Thierry Dauxois[2] (1.Center for Oceanic and Atmospheric Research, Research Institute for Applied Mechanics, Kyushu University, Japan, 2.Universite de Lyon, ENS de Lyon, Universite Claude Bernard, CNRS, Laboratoire de Physique, France, 3.Institut Universitaire de France, France)

[AOS24-03] **Development of efficient and autonomous microstructure measurement system using fast-response thermistors attached to CTD, glider and deep-profiling float, to elucidate vertical distribution**

*Ichiro Yasuda[1], Keunjong Lee[1], Maki Nagasawa[1], Shuo Zhai[1], Yusuke Sasaki[1], Daigo Yanagimoto[1], Shinzo Fujio[1], Mamoru Tanaka[1], Yasutaka Goto[2], Toshiya Nakano[2], Daisuke Sasano[2], Takahiro Tanaka[4], Shinya Kouketsu[3] (1.Atmosphere and Ocean Research Institute, The University of Tokyo, 2.Japan Meteorological Agency Japan, 3.Japan Agency of Marine-Earth Science and Technology, 4.Tohoku National Fisheries Research Institute, Fisheries Research and Education Agency)

[AOS24-04] Ocean State Estimation by Using Ocean Mixing Observations

*Shuhei Masuda[1], Satoshi Osafune[1] (1.Japan Agency for Marine-Earth Science and Technology)

[AOS24-05] **A new parameterization of tidal mixing enhanced over rough seafloor topography**

*Toshiyuki Hibiya[1] (1.Department of Earth and Planetary Science, Graduate School of Science, University of Tokyo)

[AOS24-06] Virtual tracer analysis of the Pacific meridional overturning circulation

*Takao Kawasaki[1], Hiroyasu Hasumi[1] (1.Atmosphere and Ocean Research Insitutute, the University of Tokyo)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS24] Exploring new frontiers of oceanic mixing research in the next decade

convener:Toshiyuki Hibiya(Department of Earth and Planetary Science, Graduate School of Science, University of Tokyo), Ichiro Yasuda(Atmosphere and Ocean Research Institute, The University of Tokyo), Lakshmi Kantha(Aerospace Engineering Sciences, University of Colorado, Boulder, Colorado, USA)

[AOS24-07] Diagnostic evaluation of vertical mixing effects on meridional overturning circulatoin

*Yutaka Yoshikawa[1], Takao Kawasaki[1], Hiroyasu Hasumi[1] (1.Graduate School of Science, Kyoto University)

[AOS24-08] Role of deep ocean mixing on climate change assessed by an Earth system model

*Michio Watanabe[1], Akitomo Yamamoto[1], Tomohiro Hajima[1], Hiroaki Tatebe[1] (1.Japan Agency for Marine-Earth Science and Technology)

[AOS24-09] Eddy-resolved ocean characteristics of the MIROC coupled model incorporating effects of tidal mixing of the 18.6-yr modulation

*Tomonori Matsuura [1], Hiromasa Tatebe[2], Ichiro Yasuda[1] (1.The University of Tokyo , 2.Japan Agency for Marine-earth Science and Technology)

[AOS24-12] Enhanced vertical mixing along a shelf-slope front east of Japan

*Sachihiko Itoh[1], Eiji Masunaga[2], TSUTSUMI EISUKE[1], Takashi T Sakamoto[1], Ishikawa Kazuo[1], Daigo Yanagimoto[1], Hitoshi Kaneko[1], Yasuhiro Hoshiba[1], Daisuke Hasegawa[3], Toshi Nagata[1] (1.Atmosphere and Ocean Research Institute, The University of Tokyo, 2.Center for Water Environment Studies, Ibaraki University, 3.Tohoku National Fisheries Research Institute)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS24] Exploring new frontiers of oceanic mixing research in the next decade

convener:Toshiyuki Hibiya(Department of Earth and Planetary Science, Graduate School of Science, University of Tokyo), Ichiro Yasuda(Atmosphere and Ocean Research Institute, The University of Tokyo), Lakshmi Kantha(Aerospace Engineering Sciences, University of Colorado, Boulder, Colorado, USA)

[AOS24-14] The observational evidence of double diffusive instability in the Arabian Sea during winter and spring

*ASHIN KURIAKOSE[1], Jofia Joseph[1], Girishkumar M. S.[1], Sureshkumar N[1], Sivaprasad S[1], Thangaprakash V P[1], Pattabhi Ram Rao E[1] (1.ESSO - Indian National Centre for Ocean Information Services)

[AOS24-16] Temporal variations of nutrient concentration east of Taiwan and its influence on downstream area

*Xinyu Guo[1], Yingying Hu[2], Yoshikazu Sasai[3], Chung-Chi Chen[4], Sen Jan[5] (1.Center for Marine Environmental Studies, Ehime University, 2.National Marine Environmental Forecasting Center, Ministry of Natural Resources of China, China, 3.Japan Agency for Marine-Earth Science and Technology, Japan, 4.Department of Life Science, National Taiwan Normal University, Taiwan, 5.Institute of Oceanography, National Taiwan University, Taiwan)

[AOS24-17] Flow-topography interaction within the Kuroshio and energy dissipation: observation and numerical simulation in the Tokara Strait south-west of Japan and the I-Lan Ridge east of Taiwan

*Eisuke Tsutsumi[1], Takeshi Matsuno[2], Takeyoshi Nagai[3], Daisuke Hasegawa[4], Hirohiko Nakamura[5], Ayako Nishina[5], Tomoharu Senjyu[2], Takahiro Endoh[2], Ming-Huei Chang[6], Yiing Jang Yang[6], Sen Jan[6], Sachihiko Itoh[1], Xinyu Guo[7] (1.Atmosphere and Ocean Research Institute, The University of Tokyo, 2.Research Institute for Applied Mechanics, Kyushu University, 3.Department of Ocean Sciences, Tokyo University of Marine Science and Technology, 4.Tohoku National Fisheries Research Institute, Japan Fisheries Research and Education Agency, 5.Faculty of Fisheries, Kagoshima University, 6.Institute of Oceanography, National Taiwan University, 7.Center for Marine Environmental Studies, Ehime University)

[AOS24-18] The long lasting strong turbulence along the Kuroshio flowing over seamounts in the Tokara Strait

*Takeyoshi Nagai[1], Eisuke Tsutsumi[2], Daisuke Hasegawa[3], Hirohiko Nakamura[4], Ayako Nishina[4], Takeshi Matsuno[5], Tomoharu Senjyu[5] (1.Department of Ocean Sciences, Tokyo University of Marine Science and Technology, 2.The Atmosphere and Ocean Research Institute, The University of Tokyo, 3.Tohoku National Fisheries Research Institute, Japan Fisheries Research and Education Agency, Miyagi, 4.Faculty of Fisheries, Kagoshima University, 5.Research Institute for Applied Mechanics, Kyushu University)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS24] Exploring new frontiers of oceanic mixing research in the next decade

convener:Toshiyuki Hibiya(Department of Earth and Planetary Science, Graduate School of Science, University of Tokyo), Ichiro Yasuda(Atmosphere and Ocean Research Institute, The University of Tokyo), Lakshmi Kantha(Aerospace Engineering Sciences, University of Colorado, Boulder, Colorado, USA)

[AOS24-19] **Effects of nutrient supply with strong turbulent mixing on lower-trophic level ecosystem around the Tokara strait**

*Naoki Yoshie[1], Kazuki Ohgi[1], Anri Kabe[1], Yuma Hayashi[1], Toru Kobari[2], Eisuke Tsutsumi[3], Daisuke Hasegawa[4], Joji Ishizaka[5] (1.Center for Marine Environmental Studies, Ehime University, 2.Faculty of Fisheries, Kagoshima University, 3.Atmosphere and Ocean Research Institute, The University of Tokyo, 4.Tohoku National Fisheries Research Institute, Japan Fisheries Research and Education Agency, 5.Institute for Space-Earth Environmental Research Nagoya University)

[AOS24-20] Observation of anticyclonic eddies in the western subarctic North Pacific

*Ueno Hiromichi[1], Ryo Dobashi[2], Yuki Okada[2], Takahiro Tanaka[3], Jun Nishioka[4], Toru Hirawake[1], Atsushi Ooki[1], Sachihiko Itoh[5], Yoshikazu Sasai[6], Hideharu Sasaki[6], Ichiro Yasuda[5] (1.Faculty of Fisheries Sciences, Hokkaido University, 2.Graduate School of Fisheries Sciences, Hokkaido University, 3.Tohoku National Fisheries Research Institute, Japan Fisheries Researh and Education Agency, 4.Institute of Low Temperature Science, Hokkaido University, 5.Atmosphere and Ocean Research Institute, The University of Tokyo, 6.Japan Agency for Marine-Earth Science and Technology)

[AOS24-21] **Importance of the intermediate water nutrient pool and mixing around island chains for constructing HNLC region in the subarctic Pacific**

*Jun Nishioka[1,2], Hajime Obata[3], Toru Hirawake[2,4], Youhei Yamashita[5], Hiroshi Ogawa[3], Ichiro Yasuda[3] (1.Institute of low temperature sciences, Hokkaido University, 2.Arctic Research Center, Hokkaido University, 3.Atmosphere and Ocean Research Institute, The University of Tokyo, 4.Faculty of Fisheries Sciences, Hokkaido University, 5.Faculty of Environmental Earth Science, Hokkaido University)

[AOS24-22] Decadal variation of biological settling particle fluxes controlled by physical process in the subarctic western North Pacific.

*Naomi Harada[1], Makio Honda[1], Maki Noguchi Aita[1], Miyako Sato[1], Fujiki Tetsuichi[1], Minoru Kitamura[1], Ueno Hiromichi[2] (1.Japan Agency for Marine-Earth Science and Technology, 2.Hokkaido University)

[AOS24-23] Geographical distributions of primary production phenology and nutrient/iron supply in the subarctic North Pacific Ocean

*Toru Hirawake[1], Jun Nishioka[2], Hajime Obata[3] (1.Faculty of Fisheries Sciences, Hokkaido University, 2.Institute of low temperature sciences, Hokkaido University, 3.Marine inorganic chemistry division, Atmosphere and Ocean Research Institute, University of Tokyo)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS25] Continental-Oceanic Mutual Interaction: Planetary scale Material Circulation

convener:Yosuke Alexandre Yamashiki(Earth & Planetary Water Resources Assessment Laboratory Graduate School of Advanced Integrated Studies in Human Survivability Kyoto University), Yukio Masumoto(Graduate School of Science, The University of Tokyo), Swadhin Behera(Climate Variation Predictability and Applicability Research Group, Application Laboratory, JAMSTEC, 3173-25 Showa-machi, Yokohama 236-0001), Takanori Sasaki(Department of Astronomy, Kyoto University)

[AOS25-01] Impact of Extreme UV fluxes on Atmospheric Escape of the Hadean Earth and Earth-like Exoplanets

★Invited Papers

*Vladimir Airapetian[1,2], Jared Bell[1], Alex Glocer[1] (1.NASA Goddard Space Flight Center, 2.American University, DC)

[AOS25-02] Lunar water exploration expands human activity in space

★Invited Papers

*Yuko Inatomi[1] (1.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency)

[AOS25-03] The inner edge of habitable zone for terrestrial exoplanets

★Invited Papers

*Takanori Kodama[1] (1.University of Bordeaux)

[AOS25-04] **Plant culture system as a water recycling device in space farming**

*Kitaya Yoshiaki[1] (1.Graduate School of Life and Environmental Sciences, Osaka Prefecture University)

[AOS25-05] Probabilistic Risk Assessment of Solar Particle Events Considering the Cost of Counter Measures to Reduce the Aviation Exposure Dose

*Moe Fujita[1], Yosuke Yamashiki[1], Tatsuhiko Sato[2] (1.Graduate School of Advanced Integrated Studies in Human Survivability Kyoto University, 2.Japan Atomic Energy Agency)

[AOS25-06] Space educational program: Space camp at Biosphere 2

*Masahiro Terada[1], Yosuke Ymashiki[1], Takao Doi[1] (1.Kyoto University)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS25] Continental-Oceanic Mutual Interaction: Planetary scale Material Circulation

convener:Yosuke Alexandre Yamashiki(Earth & Planetary Water Resources Assessment Laboratory Graduate School of Advanced Integrated Studies in Human Survivability Kyoto University), Yukio Masumoto(Graduate School of Science, The University of Tokyo), Swadhin Behera(Climate Variation Predictability and Applicability Research Group, Application Laboratory, JAMSTEC, 3173-25 Showa-machi, Yokohama 236-0001), Takanori Sasaki(Department of Astronomy, Kyoto University)

[AOS25-07] Impacts of riverine discharges on the overturning circulation and material circulation in the Sea of Okhotsk and the North Pacific Ocean

★Invited Papers

*Humio Mitsudera[1], Toru Miyama[2], Hatsumi Nishikawa[1] (1.Institute of Low Temperature Science, Hokkaido University, 2.JAMSTEC)

[AOS25-08] **The AI/ML based IOD predictions**

*Swadhin Behera[1], J Venkata Ratnam[1] (1. Application Laboratory, VAiG, JAMSTEC, 3173-25 Showa-machi, Yokohama 236-0001)

[AOS25-09] Space Architecture Reinforced by Internal Ocean on the Moon

★Invited Papers

*Takuya ONO[1], Makiko NAGURA[1] (1.Kajima Corporation)

[AOS25-10] Ultra-high resolution numerical weather simulation on the heavy rainfall event over the western Japan 2018

*Tsutao OIZUMI[1,2], Kazuo Saito[1,3,2], Duc Le[1,2], Junshi Ito[3,2] (1.The Japan Meteorological Business Support Center, 2.Meteorological Research Institute, 3.The Atmosphere and Ocean Research Institute)

[AOS25-12] Bioparticle deposition at a stratospheric altitude

*Kenji Miki[1] (1.Tokyo Institute of Technology Earth-Life Science Institute)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-HW Hydrology & Water Environment

[A-HW30] Hydrology & Water Environment

convener:Ayumi Kotani(Graduate School of Bioagricultural Sciences, Nagoya University), Takeshi Hayashi(Faculty of Education and Human Studies, Akita University), Keisuke Fukushi(Institute of Nature & Environmental Technology, Kanazawa University), Masahiro Tanoue(School of Engineering, The University of Tokyo)

[AHW30-01] **Comparing tritium concentrations and water transit times in the Chikuma and Fujikawa River basins, Japan**

*Maksym Gusyev[1], Naofumi Akata[2], Tsutomu Yamanaka[3], Kimio Hirabayashi[4], Masashi Toyota[4], Uwe Morgenstern[5], Michael Stewart[5] (1.International Centre for Water Hazard Risk Management, Public Works Research Institute, 2.Hirosaki University, Japan, 3.University of Tsukuba, Japan, 4.Shinshu University, Japan, 5.GNS Science, New Zealand)

[AHW30-02] Variation of carbon isotope ($\delta^{13}C$ and $\Delta^{14}C$) of organic matter in suspended solids at Lake Kiba-gata

*Seiya Nagao[1], Kohei Sakaguchi[2], Tetsuya Matsunaka[1], Shinya Ochiai[1], Naoya Katsumi[3] (1.Institute of Nature and Environmental Technology, Kanazawa University, 2.Graduate School of Natural Science and Technology, Kanazawa University, 3.Department of Environmental Science, Ishikawa Prefectural University)

[AHW30-03] **Integrating Method of Waste Water Treatment and Desalination: Opportunities for Innovation**

*Mst. Shamsun Nahar[1] (1.Safety- Hygiene Department, Earth Consultant Co. Ltd, Toyama, Japan)

[AHW30-04] Water Scarcity Assessment in Thailand River Basin Using Geo-Informatics Technology

*pudtraporn napang[1] (1.Kasetsart University)

[AHW30-05] **Migration and aggregation of foamed plastic debris in the urban river of Mongolia**

*Batdulam Battulga[1], Masayuki Kawahigashi[1], Bolormaa Oyuntsetseg[2] (1.Department of Geography, Tokyo Metropolitan University, Tokyo, 192-0397, Japan , 2.Department of Chemistry, National University of Mongolia, Ulaanbaatar, 210646, Mongolia)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-HW Hydrology & Water Environment

[A-HW30] Hydrology & Water Environment

convener:Ayumi Kotani(Graduate School of Bioagricultural Sciences, Nagoya University), Takeshi Hayashi(Faculty of Education and Human Studies, Akita University), Keisuke Fukushi(Institute of Nature & Environmental Technology, Kanazawa University), Masahiro Tanoue(School of Engineering, The University of Tokyo)

[AHW30-06] MERIT Hydro: a new global hydrography map based on multiple satellite observations, and its application to model-satellite integration in global river hydrodynamic simulations

★Invited Papers

*Dai Yamazaki[1] (1.Institute of Industrial Sciences, The University of Tokyo)

[AHW30-07] **Assessment of Climate Change Effects on the Rice Water Requirements for Hsin-Chu Irrigation Area in Taiwan**

YUAN-TUNG HSU[2], MEI-CHANG CHEN[2], SHU-HUE CHU[2], TA-WEI CHIEN[2], *SHIH-WEI CHIANG[1] (1.Agricultural Engineering Research Center, 2.Taiwan Hsinchu Irrigation Association)

[AHW30-08] Land use / land cover and discharge in the Altamaha River 1992-2016, Georgia, USA

*James Deemy[1], Kimberly Takagi[1], Cameron Atkinson[1], Nicholas Harris[1], Nellie Little[1] (1.College of Coastal Georgia Department of Natural Sciences)

[AHW30-09] **Role of colloids on the (im)mobility of toxic elements in mine drainage systems with acidic and circumneutral pH**

*Frances Chikanda[1], Tsubasa Otake[2], Tatsuya Matsui[1], Sereyroith Tum[1], Tsutomu Sato[2] (1.Division of Sustainable Resources Engineering, Graduate School of Engineering, Hokkaido University, 2.Division of Sustainable Resources Engineering, Faculty of Engineering, Hokkaido University)

[AHW30-10] Source Identification of Molybdenum in Natural Water Around Erdenet City, Mongolia

*Solongo Tsetsgee[1,3], Fukushi Keisuke[1], Altansukh Ochir[3], Takahashi Yoshio[2], Munemoto Takashi[4], Akitoshi Akehi[1], Ariuntungalag Yunden[3], Enkhjin Odgerel[3], Taivanbat Batbold[3], Noriko Hasebe[1] (1.Kanazawa University, 2.The University of Tokyo, 3.National University of Mongolia, 4.Industrial Research Institute of Ishikawa)

[AHW30-11] **Spatio-temporal changes of hydrochemical properties and factors controlling hydrochemistry of springs in the Seyfe Basin**

*Cansu Yurteri[1] (1.Hacettepe University)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-HW Hydrology & Water Environment

[A-HW30] Hydrology & Water Environment

convener:Ayumi Kotani(Graduate School of Bioagricultural Sciences, Nagoya University), Takeshi Hayashi(Faculty of Education and Human Studies, Akita University), Keisuke Fukushi(Institute of Nature & Environmental Technology, Kanazawa University), Masahiro Tanoue(School of Engineering, The University of Tokyo)

[AHW30-12] Hydrology and astrobiology on early Mars: Insights from hydrology in cold semiarid areas in central Aria, Mongolia

★Invited Papers

*Yasuhito Sekine[1,2], Keisuke Fukushi[2] (1.Tokyo Institute of Technology, 2.Kanazawa University)

[AHW30-14] Advantages of continuous modelling for design hydrograph estimation in small and ungauged basins

*Salvatore Grimaldi[1,4], Maria Cristina Rulli[2], Aldo Fiori[3], Elena Volpi[3] (1.Università degli Studi della Tuscia, Italy, 2.Politecnico di Milano, Italy, 3.Universita' Roma Tre, Italy, 4.International Association of Hydrological Sciences)

[AHW30-15] Comparison of speciation and solubility of arsenic, lead, and cadmium in contaminated soils from Kamegai mine tailing, Toyama, Japan

*Baasansuren Gankhurel[1], Keisuke Fukushi[1], Akitoshi Akehi[1], Yoshio Takahashi[2], Xiaolan Zhao[3], Kazuo Kawasaki[4] (1.Kanazawa University, 2.The University of Tokyo, 3.Chang'an University, 4.University of Toyama)

[AHW30-16] Amount effect on the diurnal isotopic composition of precipitation in the Kra Isthmus of Thailand

*Jeerapong Laonamsai[1], Kimpei Ichiyanagi[1], Kiattipong Kamdee[2] (1.Kumamoto University, 2.Thailand Institute of Nuclear Technology)

[AHW30-17] Seasonal fluctuation of Tritium concentration in precipitation at Akita, north east Japan

*Takeshi Hayashi[1] (1.Faculty of Education and Human Studies, Akita University)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-HW Hydrology & Water Environment

[A-HW30] Hydrology & Water Environment

convener:Ayumi Kotani(Graduate School of Bioagricultural Sciences, Nagoya University), Takeshi Hayashi(Faculty of Education and Human Studies, Akita University), Keisuke Fukushi(Institute of Nature & Environmental Technology, Kanazawa University), Masahiro Tanoue(School of Engineering, The University of Tokyo)

[AHW30-18] Remobilization mechanism of sediments phosphorus under microbial activity in a polluted river, South China

*Rui Li[1], Jianyao Chen[1], Lei Gao[1] (1.Sun yat-sen Univ.)

[AHW30-19] **Hydrogeochemical and Isotopic Evidence of Groundwater Evolution and Characterization in Upper Walawe Basin, Sri Lanka**

*Sachintha Lakshan Senarathne[1], J.M.C.K Jayawardana[1], Rohana Chandrajith[2], E.A.N.V Edirisinghe[3] (1.Sabaragamuwa University of Sri Lanka, 2.University of Peradeniya, Sri Lanka, 3.Sri Lanka Atomic Energy Board)

[AHW30-20] Application of Optimization Model for Urban Drainage Layout Design under Street Flow and Operation of Pumping Station

*Chien-Lin Huang[1], Nien-Sheng Hsu[1], Gene Jiing-Yun You[1], Sih-Wen Cheng[1], Hung-Ren Liu[1] (1.National Taiwan University, Taiwan)

[AHW30-21] **Estimation of Evapotranspiration Fluxes using METRIC Model over Sub-tropical Moist Deciduous Forest in Doon Valley, India**

*Saurabh Purohit[1,2], N R Patel[1], Bhaskar R Nikam[1], S P Aggarwal[1], Triparna Sett[1], Prakash Chauhan[1] (1.Indian Institute of Remote Sensing, Dehradun, India, 2.Forest Research Institute Deemed to be University, Dehradun, India)

[AHW30-22] Effect of precipitation on interannual variability of permafrost active layer thickness at larch forests in eastern Siberia

*Ayumi Kotani[1], Tetsuya Hiyama[2], Taro Nakai[3], Takeshi Yamazaki[4], Trofim Maximov[5] (1.Graduate School of Bioagricultural Sciences, Nagoya University, 2.Institute for Space-Earth Environmental Research, Nagoya University, 3.School of Forestry and Resource Conservation, National Taiwan University, 4.Graduate School of Science, Tohoku University, 5.Institute for Biological Problems of Cryolithozone)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-HW Hydrology & Water Environment

[A-HW31] Surface and subsurface hydrologic models: From uncertainty analysis to water management

convener:Tomochika Tokunaga(Department of Environment Systems, University of Tokyo), Rene Therrien(Laval University), Philip Brunner(Center for Hydrogeology and Geothermics, University of Neuchatel), Jiaqi Liu(The University of Tokyo)

[AHW31-01] Numerical analysis of the hyporheic flow in a gravel aquifer subjected to an extraction scheme using multiple radial collector wells

*Sue Tse Jhong[1], Jun Ying Huang[2], Chih Tse Wang[2], Tai Sheng Liou[3] (1.National Chung Cheng University Institute of applied geophysics and environmental science, 2.Stantec Consulting Services Inc., Taiwan Branch, 3.Department of Earth and Environmental Sciences, National Chung Cheng University)

[AHW31-02] Study on utilization of groundwater under emergency situations caused by natural disasters: A modeling approach in the Kanto Plain, Japan.

*Fukazawa Souki[1], Kazuhiro TADA[1], Hiroyuki TOSAKA[1], Yasuhiro TAWARA[1] (1.Geosphere Environmental Technology Corp.)

[AHW31-03] Simulating Two-Way Feedbacks between Surface-Water and Groundwater Management with the Surface Water Operations Process

*Scott E Boyce[1], Ian M. Ferguson[2] (1.U.S. Geological Survey, California Water Science Center, 2.U.S. Bureau of Reclamation)

[AHW31-04] **Predicting baseflow at the basin scale with an integrated surface and subsurface flow model**

*Rene Therrien[1], Hugo Delottier[1] (1.Laval University)

[AHW31-05] Metrics for Environmental Simulation in Decision Support

★Invited Papers

*John Doherty

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-HW Hydrology & Water Environment

[A-HW32] Material transportation and cycling in aquatic ecosystems; from headwaters to coastal areas

convener:Syuhei Ban(The University of Shiga Prefecture), Adina Paytan(University of California Santa Cruz), Takahiro Hosono(Faculty of Advanced Science and Technology, Kumamoto University), Morihiro Maeda(Okayama University)

[AHW32-01] **Geologic controls on source water drive baseflow generation and geochemistry across watershed scales**

★Invited Papers

*Adina Paytan[1], Christina Richardson[1], Margaret Zimmer[1], Joseph Fackrell[1] (1.University of California Santa Cruz)

[AHW32-02] The Processes Controlling Stream Water Chemistry at the Terrestrial-Aquatic Interface, Great Lakes Region, USA

*Fengjing Liu[1], Veronica Porter[1] (1.Michigan Technological University)

[AHW32-03] **Agriculture and brackish fishpond impact on the vulnerability of coastal groundwater in Southeast Asia**

*Anna Fadliah Rusydi[1,4], Shin-ichi Onodera[1], Mitsuyo Saito[2], Seiichiro Ioka[3], Rizka Maria[4] (1.Graduate School of Integrated Arts and Sciences, Hiroshima University, Japan, 2.Graduate School of Environmental and Life Sciences, Okayama University, Japan, 3.Institute of Regional Innovation, Hirosaki University, Japan, 4.Research Center for Geotechnology, Indonesian Institute of Sciences, Indonesia)

[AHW32-04] Permafrost distribution controls dFe concentrations in rivers, Russian Far East

*Yuto Tashiro[1], Muneoki Yoh[1], Takayuki Shiraiwa[2], Takeo Onishi[3] (1.Tokyo University of Agriculture and Technology, 2.Hokkaido University , 3.Gifu University)

[AHW32-05] **Identification of autotrophic denitrification anomaly in the fast flowing karst aquifer using $\delta^{15}N$, $\delta^{34}S$ and $\delta^{13}C$ tracers in the Ryukyu limestone aquifers, southern Okinawa, Japan**

*Oktanius Richard Hermawan[1], Takahiro Hosono[2], Jun Yasumoto[3], Masashi Nozaki[3] (1.Earth and Environmental Science, Graduate School of Science and Technology, Kumamoto University, 2.Faculty of Advanced Science and Technology, Kumamoto University, 3.Department of Regional Agriculture Engineering, University of the Ryukyu)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-HW Hydrology & Water Environment

[A-HW32] Material transportation and cycling in aquatic ecosystems; from headwaters to coastal areas

convener:Syuhei Ban(The University of Shiga Prefecture), Adina Paytan(University of California Santa Cruz), Takahiro Hosono(Faculty of Advanced Science and Technology, Kumamoto University), Morihiro Maeda(Okayama University)

[AHW32-06] Methanotrophic food webs in tropical lakes

*Noboru Okuda[1], Milette U. Mendoza[9], Jaydan I. Aguilar[2], Karol Sophia Agape R. Padilla[2], Jonathan Carlo A. Briones[2], Rey Donne S. Papa[2], Masayuki Ito[3], Megumu Fujibayashi[4], Tzu-Hsuan Tu[5], Li-Hung Lin[5], Pei-Ling Wang[5], Yuki Kobayashi[6], Eleanor Austria[7], Fuh-Kwo Shiah[8] (1.Research Institute for Humanity and Nature, 2.University of Santo Tomas, 3. University of Hyogo, 4.Kyushu University, 5.National Taiwan University, 6.Yamaguchi University, 7.Adamson University, 8.Academia Sinica, 9.Ateneo de Manila University)

[AHW32-07] Did artificial re-oligotrophication induce a reduction of fish catch in Lake Biwa?

*Syuhei Ban[1], Xin Liu[1], Masahiro Maruo[1], Naoshige Goto[1], Ken'ichi Osaka[1], Shin-ichi Onodera[2], Mitsuyo Saito[3], Takuya Ishida[4], Noboru Okuda[4] (1.The University of Shiga Prefecture, 2.Hiroshima University, 3.Okayama University, 4.Research Institute for Humanity and Nature)

[AHW32-08] Phosphorus dynamics related to phytoplankton growth with newly sensitive measurement of orthophosphate and growth experiments in north basin of Lake Biwa

*Xin Liu[1], Rong Yi[1,2], Masahiro Maruo[1], Syuhei Ban[1] (1.The University of Shiga Prefecture, 2.Gannan Normal University)

[AHW32-09] Detection of Organophosphonates and Phosphite in Suspended Matter of P-limited Lakes

*Masahiro Maruo[1], Kazuma Tsuji[2], Tomoya Iwata[3], Maki Oyagi[4], Hajime Obata[5] (1.Department of Ecosystem Studies, School of Environmental Science, The University of Shiga Prefecture, 2.Graduate School of EnvironmentalScience, The University of Shiga Prefecture, 3.Faculty of Life and Environmental Sciences, 4.Facluty of Environment and Infromation Science, 5.Atmosphere and Ocean Research Institute, The University of Tokyo)

[AHW32-10] Role of groundwater and river discharge on phosphorus supply into the lake

*Shin-ichi Onodera[1], Mitsuyo Saito[2], Kunyang Wang[1], Syuhei Ban[3], Noboru Okuda[4], Yusuke Tomozawa[1] (1.Graduate School of Integrated and Arts Sciences, Hiroshima University, 2.Okayama University, 3.Shiga Prefecture University, 4.Research Institute of Human and Nature)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-HW Hydrology & Water Environment

[A-HW32] Material transportation and cycling in aquatic ecosystems; from headwaters to coastal areas

convener:Syuhei Ban(The University of Shiga Prefecture), Adina Paytan(University of California Santa Cruz), Takahiro Hosono(Faculty of Advanced Science and Technology, Kumamoto University), Morihiro Maeda(Okayama University)

[AHW32-12] Coffee-waste biochar and nano-biochar applications to reduce nitrous oxide and carbon dioxide emissions from agricultural soils

*Morihiro Maeda[1], Thuong Thi Thu Nguyen[1], Chiyu Nakano[1], Yuta Nishina[1] (1.Okayama University)

[AHW32-13] **Suppression of phosphorous release from sediment in agricultural drainages flowing into Lake Kojima by using biochar-amended sediment microbial fuel cells**

*Gamamada Liyanage Erandi Priyangika Perera[1], Morihiro Maeda[1] (1.Graduate School of Environmental and Life Science, Okayama University)

[AHW32-14] Assessment of hydrological processes and sediment yield in Dakbla catchment, Kon Tum province, Vietnam.

*Tram Ngoc Quynh Vo[1], Hiroaki Somura[1] (1.Okayama University)

[AHW32-15] Acidic fresh submarine groundwater discharge around mud diapirs in southwestern Taiwan

*Hon-Kit Lui[1], Chen-Tung Arthur Chen[1], Wei-Ping Hou[2], Rae Chang[1] (1.Department of Oceanography, National Sun Yat-sen University, Kaohsiung 80424, Taiwan, 2.Taiwan Ocean Research Institute, National Applied Research Laboratories, Kaohsiung 80143,Taiwan.)

[AHW32-16] Spatio-temporal dynamics of submarine groundwater discharge (SGD) on an intertidal beach scale, temperate coastal area

*Mitsuyo Saito[1], Shin-ichi Onodera[2], Shingo Nozaki[2], Yusuke Tomozawa[2] (1.Okayama University, 2.Hiroshima University)

[AHW32-17] **Impact of terrestrial nutrients in groundwater on coral reefs via submarine groundwater discharge around Yoron Island of the Southwest Islands, Japan**

*Shinji Nakaya[1], Sho Nagata[1], Masashi Toyota[1], Jun Yasumoto[2], Tetsuya Shintani[3], Takashi Nakamura[4] (1.Department of Water Environment and Civil Engineering, Faculty of Engineering, Shinshu University, 2.Department of Regional Agriculture Engineering, University of the Rykuyus, Japan, 3.Department of Civil and Environmental Engineering, Tokyo Metropolitan University, 4.Biology Program, Faculty of Science, University of the Ryukyus)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-HW Hydrology & Water Environment

[A-HW32] Material transportation and cycling in aquatic ecosystems; from headwaters to coastal areas

convener:Syuhei Ban(The University of Shiga Prefecture), Adina Paytan(University of California Santa Cruz), Takahiro Hosono(Faculty of Advanced Science and Technology, Kumamoto University), Morihiro Maeda(Okayama University)

[AHW32-18] **Evaluation of the long-term impact of forest growth and change on water and sediment yield in forested watershed of Kikuchi river using SWAT model**

*Yuko Nagano[1], Soichiro Fujii[1], Masahiko Kanamori[1], Maki Kinoshita[2], Masatoshi Yamazaki[3], Yuta Shimizu[4], Shin-ichi Onodera[5] (1.Japan Forest Technology Association, 2.Field Partners, 3.PASCO Corporation, 4.Western Region Agricultural Research Center, National Agriculture and Food Research Organization, 5.Graduate School of Integrated and Arts Sciences, Hiroshima University)

[AHW32-19] **Estimation of Change in Groundwater Recharge by Urbanization in a Granitic Mountain Catchment, Using SWAT Model**

*Sharon Bih Kimbi[1], Kunyang Wang[1], Shin-ichi Onodera[1], Yusuke Tomozawa[1], Shingo Nozaki[1], Anna Fadliah Rusydi[1] (1.Graduate School of Integrate Arts and Sciences, Hiroshima University)

[AHW32-20] Understanding of Subsurface Flow Systems: Role of Environmental Tracers in Model Calibration

*A T M Sakiur Rahman[1], Takahiro Hosono[1], Yasuhiro Tawara[2], Dennis Boateng[1], Jun Shimada[1] (1.Department of Earth and Environmental Science, Kumamoto University, Japan, 2.Geosphere Environmental Technology Corporation, NCO Kanda, Awajicho, Chiyoda-ku, Tokyo 101-0063, Japan)

[AHW32-21] **Impact of Urban Functional Area Subdivision on Simulation of Flash Flood in Hydrological Model**

*Kunyang Wang[1], Shin-ichi Onodera[1], Shuxue Qu[2], Yuta Shimizu[3], Mitsuyo Saito[4] (1.Graduate School of Integrated Arts and Science, Hiroshima University, 2.College of Resources, Environment and Tourism, Capital Normal University, 3. National Agriculture and Food Research Organization, 4.Faculty of Environmental Science and Technology, Okayama University)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-HW Hydrology & Water Environment

[A-HW33] Prediction of water and sediment dynamics from small to large scales

convener:Yoshiyuki Yokoo(Fukushima University), Yuko Asano(The University of Tokyo)

[AHW33-01] Effect of spatial scales on runoff / sediment transport in mountain catchments

*Yuko Asano[1], Taro Uchida[2], Takashi Gomi[3], Shigeru Mizugaki[4], Marino Hiraoka[5], Masanori Katsuyama[6], Satoshi Niwa[7], Yoshiyuki Yokoo[8] (1.The University of Tokyo, 2.Tsukuba University, 3.Tokyo University of Agriculture and Technology, 4.Civil Engineering Research Institute for cold region, Public Works Research Institute, 5.Public Works Research Institute , 6.Kyoto Prefectural University, 7.Japan Conservation Engineers & Co., Ltd., 8.Fukushima University)

[AHW33-03] Contrasting patterns in the decrease of spatial variability with increasing catchment area between stream discharge and water chemistry

★Invited Papers

*Tomohiro Egusa[1], Tomo'omi Kumagai[1,2], Tomoki Oda[1], Takashi Gomi[3], Nobuhito Ohte[4] (1.The University of Tokyo, 2.Nagoya University , 3.Tokyo University of Agriculture and Technology, 4.Kyoto University)

[AHW33-04] Effects of small-scale vertical unsaturated flow on the exponent of a runoff-storage power-law relationship in catchment storm runoff models

*Makoto Tani[1], Yuki Matsushi[2], Takahiro Sayama[2], Roy C Sidle[3], Nagahiro Kojima[4] (1.University of Human Environments, 2.Disaster Prevention Research Institute, Kyoto University, 3.University of Central Asia, 4.Lake Biwa Environmental Research Institute)

[AHW33-05] Towards improving predictivity of runoff and sediment transport for mountainous catchments through measurement of spatial patterns of hydrological behaviors

*Taro Uchida[1], Yuko Asano[2], Shigeru Mizugaki[3], Yoshiyuki Yokoo[4], Marino Hiraoka[5], Takashi Gomi[6], Satoshi Niwa[7], Masanori Katsuyama[8] (1.University of Tsukuba, 2.University of Tokyo, 3.Civil Engineering Research Institute for cold region, Public Works Research Institute, 4.Fukushima University, 5.Public Works Research Institute, 6.Tokyo University of Agriculture and Technology , 7.Japan Conservation Engineers & Co., Ltd. , 8.Kyoto Prefectural University)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-HW Hydrology & Water Environment

[A-HW33] Prediction of water and sediment dynamics from small to large scales

convener:Yoshiyuki Yokoo(Fukushima University), Yuko Asano(The University of Tokyo)

[AHW33-06] Linking micro scale hillslope properties and a meso scale constitutive equation used in rainfall-runoff modeling

★Invited Papers

*Yutaka Ichikawa[1] (1.Graduate School of Engineering, Kyoto University)

[AHW33-07] **Sediment Transport Modeling Beyond Normality: Estimation of Sediment Concentrations Accounting for Spatial Influence of Turbulence Coherent Structures**

★Invited Papers

*Christina Tsai[1], Kuang-Ting Wu[1] (1.National Taiwan University)

[AHW33-08] **Change in Sediment Yield Dynamics in Bhagirathi Basin (Large Watershed) with Climatic Variables Having One Outlet by Using SWAT Model and SUFI-2 Algorithm.**

*Jagriti jain[1], Deepak Khare[1] (1.Indian Institute of Technology, Roorkee)

[AHW33-09] Characteristics of Discharge and Tidal Asymmetry over Two Inlets Lagoon: A Case Study on Segara Anakan Lagoon, Central Java, Indonesia

*Faruq Khadami[1,2], Kiyoshi Kawanishi[1] (1.Department of Civil and Environmental Engineering, Hiroshima University, 2.Oceanography Study Group, Faculty of Earth Science and Technology, Institut Teknologi Bandung)

[AHW33-10] Understanding catchment processes and scale effect on catchment flows

*Chris Leong[1], Yoshiyuki Yokoo[1] (1.Fukushima University)

[AHW33-11] Applying a data-based rainfall-runoff modeling approach to interpret the mechanisms of decreasing spatial variability of subcatchment-specific discharge with increasing subcatchment area

*Yoshiyuki Yokoo[1], Takeshi Sakairi[1], Chris Leong[1] (1.Fukushima University)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-HW Hydrology & Water Environment

[A-HW37] Interdisciplinary approach to support climate change adaptation measures in regional scale

convener:TEBAKARI TAICHI(Toyama Prefectural University), Yadu Pokhrel(Michigan State University), Masashi Kiguchi(University of Tokyo), Sompratana Ritphring(Kasetsart University)

[AHW37-01] ADAP-T for water-related adaptation to climate change and supporting its policy making

★Invited Papers

*Taikan Oki[1], Thanya Kiatiwat[2], Hiroaki Shirakawa[3], Weerakaset Suanpaga[2], Taichi Tebakari[4], Sompratana Ritphring[2], Masashi Kiguchi[5], Kyoko Matsumoto[5] (1.Institute for Future Initiatives, The University of Tokyo, 2.Faculty of Engineering, Kasetsart University, 3.Granduate School of Environmental Studies, Nagoya University, 4.Department of Civil and Environmental Engineering, Toyama Prefectural University, 5. Institute of Industrial Science, The University of Tokyo)

[AHW37-02] Land use and climate change impact assessments in humid tropics regions

*Eva Mia Siska Yamamoto[1], Takahiro Sayama[1], Kodai Yamamoto[2], Apip Apip[3] (1.Disaster Prevention Research Institute, Kyoto University, 2.Graduate School of Engineering, Kyoto University, 3.Indonesian Institute of Sciences)

[AHW37-03] Effects of ocean acidification on marine ecosystem services: use of natural analogues around volcanic CO_2 vents

*Shigeki Wada[1], Sylvain Agostini[1], Ben Paul Harvey[1], Koetsu Kon[1], Masanori Take[1] (1.University of Tsukuba)

[AHW37-04] Encouraging Climate Change Adapatation and Mitigation Measures Platform from Indonesia

*Komariah Komariah[1], Dwi Priyo Ariyanto[1], Sumani Sumani[1] (1.Sebelas Maret University, Indonesia)

[AHW37-05] **Impact of Sea Level Rise on Tourism Carrying Capacity in Thailand**

*Sompratana Ritphring[1], Pattrakorn Nidhinarangkoon[1], Keiko Udo[2] (1.Faculty of Engineering, Kasetsart University, 2. International Research Institute of Disaster Science,Tohoku University)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-HW Hydrology & Water Environment

[A-HW37] Interdisciplinary approach to support climate change adaptation measures in regional scale

convener:TEBAKARI TAICHI(Toyama Prefectural University), Yadu Pokhrel(Michigan State University), Masashi Kiguchi(University of Tokyo), Sompratana Ritphring(Kasetsart University)

[AHW37-06] The GEWEX Regional Hydroclimate Projects in High Mountainous Terrains: Barriers that Bridge

★Invited Papers

*Petrus J van Oevelen[1] (1.Universities Space Research Association Columbia)

[AHW37-07] Transportation in the UK's Third Climate Change Risk Assessment

*David John Jaroszweski[1] (1.University of Birmingham)

[AHW37-08] Analysis for impacts of urban flood on traffic flow in Bangkok

*Shinichiro NAKAMURA[1], Napaporn Piamsa-nga[2], Sanit Wongsa[3], Varameth Vichiensan[2] (1.Nagoya University, 2.Kasetsart University, 3.King Mongkut's University of Technology Thonburi)

[AHW37-09] Validaion of land surface model considering groundwater level change

*Daiya Shiojiri[1], Kenji Tanaka[2], Shigenobu Tanaka[2] (1.Graduate School of Engineering, Kyoto Univ., 2.Disaster Prevention Research Institute, Kyoto Univ.)

[AHW37-10] Climate Change Impacts on Groundwater Recharge in the Yom and Nan River basins, Northern Thailand

*Chaiwat Ekkawatpanit[1], Chanchai Petpongpan[1], Duangrudee Kositgittiwong[1], Naota Hanasaki[2] (1.King Mongkut s University of Technology Thonburi, 2.National Institute for Environmental Studies, Tsukuba, Japan)

[AHW37-11] **Shallow Groundwater Plays as a Key of Water Supply Management for Crop Land during Severe Drought Crisis Situation in Thailand**

*Desell Suanburi[1], Koshi Yoshida[2], Weerakaset Suanpaga[1], Naruekamon Janjirawuttikul[3] (1.Kasetsart University, 2.Ibaraki University, 3.Land Development Department)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CC Cryospheric Sciences & Cold District Environment

[A-CC38] Ice cores and paleoenvironmental modeling

convener:Ayako Abe-Ouchi(Atmosphere and Ocean Research Institute, The University of Tokyo), Ryu Uemura(Nagoya University), Kenji Kawamura(National Institute of Polar Research, Research Organization of Information and Systems), Nozomu Takeuchi(Chiba University)

[ACC38-01] Variations in nitrate stable isotopes in ice cores from two glaciers in central Asia

*Nozomu Takeuchi[1], Nobuhito Ohte[2], Koji Fujita[3] (1.Chiba University, 2.Kyoto University, 3.Nagoya University)

[ACC38-02] Reconstructions of past microbial flora from ice core samples on Gregoriev Glacier, Kyrgyz Tienshan

*Segawa Takahiro[1], Ryo Matsuzaki[2], Ayumi Akiyoshi[3], Takahiro Yonezawa[4], Hiroshi Mori[5], Nozomu Takeuchi[6] (1.University of Yamanashi, 2.National Institute for Environmental Studies, 3.National Institute of Polar Research, 4.Tokyo University of Agriculture, 5.National Institute of Genetics, 6.Chiba University)

[ACC38-03] Collaborative studies for locating the oldest ice near Dome Fuji, Antarctica

*Kenji Kawamura[1,2,3], Ayako Abe-Ouchi[4,1], Shuji Fujita[1,2], Prasad Gogineni[5], David Braaten[6], Jean-Charle Gallet[7], Kumiko Goto-Azuma[1,2], Ralf Greve[8], Elisabeth Isaksson[7], Brice van Liefferinge[7], Kenichi Matsuoka[7], Hideaki Motoyama[1,2], Fumio Nakazawa[1,2], Takashi Obase[4], Hiroshi Ohno[9], Ikumi Oyabu[1], John Paden[6], Fernando Rodriguez-Morales[6], Fuyuki SAITO[3], Ryan A. Taylor[5], Shun Tsutaki[1], Members of Third Dome Fuji Project Promotion Committee (1.National Institute of Polar Research, Research Organization of Information and Systems, 2.Graduate University for Advanced Studies, SOKENDAI, 3.Japan Agency for Marine-Earth Science and Technology (JAMSTEC), 4.University of Tokyo, 5.University of Alabama, 6.University of Kansas, 7.Norwegian Polar Institute, 8.Hokkaido University, 9.Kitami Insittute of Technology)

[ACC38-04] Mapping near-surface layers with UWB microwave radar and optimized processing of sounder data to enhance deep layers

★Invited Papers

Sivaprasad Gogineni[1], *Ryan Andrew Taylor[1], Shriniwas Kolpuke[1], Jordan Larson[1], Linfeng Li[1], Charles O'Neill[1], Ryan Thomas[1], Shashank Wattal[1], Jie-Bang Yan[1], David Braaten[2], Ayako Abe-Ouchi[3], Shuji Fujita[4], Kenji Kawamura[4], Shun Tsutaki[4], Brice van Liefferinge[5], Kenichi Matsuoka[5] (1.University of Alabama, 2.University of Kansas, 3.University of Tokyo, 4.National Institute of Polar Research, 5.Norwegian Polar Institute)

[ACC38-05] Features of the ice sheet radio-echoes from deep internal layers and ice/bed boundaries observed with radars of the Japanese Antarctic Research Expedition: a summary

★Invited Papers

*Shuji Fujita[1,2], Kenji Kawamura[1,2,3], Ayako Abe-Ouchi[1,4], Kotaro FUKUI[5], Kenichi Matsuoka[6] (1.National Institute of Polar Research, Research Organization of Information and Systems(ROIS), 2.The Graduate University for Advanced Studies (SOKENDAI), 3.Japan Agency for Marine-Earth Science and Technology (JAMSTEC), 4.Atmosphere and Ocean Research Institute, The University of Tokyo, 5.Tateyama Caldera Sabo Museum, Japan, 6.Norwegian Polar Institute)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CC Cryospheric Sciences & Cold District Environment

[A-CC38] Ice cores and paleoenvironmental modeling

convener:Ayako Abe-Ouchi(Atmosphere and Ocean Research Institute, The University of Tokyo), Ryu Uemura(Nagoya University), Kenji Kawamura(National Institute of Polar Research, Research Organization of Information and Systems), Nozomu Takeuchi(Chiba University)

[ACC38-06] Fine-Resolution Radar Measurements for Ice-Core Drilling Site identification Near Dome-Fuji

★Invited Papers

*Fernando Rodriguez Morales[1,2], David Braaten[1,2], John Paden[1,2], Prasad Gogineni, Ryan Taylor, Ayako Abe-Ouchi, Shuji Fujita, Kenji Kawamura, Shun Tsutaki, Brice Van Liefferinge, Kenichi Matsuoka (1.University of Kansas, 2.Center for Remote Sensing of Ice Sheets)

[ACC38-07] A basal topographic map in the Dome Fuji area, East Antarctica, constructed from a ground-based radar survey

★Invited Papers

*Shun Tsutaki[1], Shuji Fujita[1,2], Kenji Kawamura[1,2,3], Prasad Gogineni[4], Ayako Abe-Ouchi[5,1], David Braaten[6], Jean-Charles Gallet[7], Elisabeth Isaksson[7], Brice van Liefferinge[7], Kenichi Matsuoka[7], Charles O'Neil[4], John Paden[6], Fernando Rodriguez-Morales[6], Ryan Taylor[4], Jie-Bang Yan[4], Kumiko Goto-Azuma[1,2], Ralf Greve[8], Stephen Hudson[7], Jack Kohler[7], Shriniwas Kolpuke[4], Linfeng Li[4], Geir Moholdt[7], Hideaki Motoyama[1,2], Takashi Obase[5], Fuyuki SAITO[3], Kotaro FUKUI[9] (1.National Institute of Polar Research, 2.The Graduate University for Advanced Studies, 3.Japan Agency for Marine-Earth Science and Technology, 4.The University of Alabama, 5.The University of Tokyo, 6.The University of Kansas, 7.Norwegian Polar Institute, 8.Hokkaido University, 9.Tateyama Caldera Sabo Museum)

[ACC38-08] Searching potential sites of million year-old ice by modelling ice sheet age near New Dome Fuji region

*Ayako Abe-Ouchi[1], Takashi Obase[1], Kenji Kawamura[2], Shuji Fujita[2], Fuyuki SAITO[3], Shun Tsutaki[2], Prasad Gogineni[4], David Braaten[5], Fernando Rodriguez-Morales[5], John Paden[5], Kenichi Matsuoka[6], Hideaki Motoyama[2], Ralf Greve[7], Brice van Liefferinge[6], Ryan Taylor[4] (1.Atmosphere and Ocean Research Institute, The University of Tokyo, 2.NIPR, 3.JAMSTEC, 4.The University of Alabama, 5.University of Kansas, 6.Norwegian Polar Institute, 7.Institute of Low Temperature Science, Hokkaido University)

[ACC38-09] Antarctic warmth in the last interglacial driven by Northern insolation and deglaciation

*Takashi Obase[1], Ayako Abe-Ouchi[1,2], Fuyuki SAITO[3] (1.Atmosphere and Ocean Research Institute, the University of Tokyo, 2.National Institute of Polar Research, 3.Japan Agency for Marine-Earth Science and Technology)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-GE Geological & Soil Environment

[A-GE40] Subsurface Mass Transport and Environmental Assessment

convener:Hirotaka Saito(Department of Ecoregion Science, Tokyo University of Agriculture and Technology), Shoichiro Hamamoto(Department of Biological and Environmental Engineering, The University of Tokyo), Yuki Kojima(Department of Civil Engineering, Gifu University), Yasushi Mori(Graduate School of Environmental and Life Science, Okayama University)

[AGE40-01] **Impacts of Si on Se(IV) immobilization on ferrihydrite: An *in-situ* ATR-IR spectroscopic investigation**

*Paul Clarence Magdael Francisco[1], Yukio Tachi[1] (1.Japan Atomic Energy Agency)

[AGE40-02] **Reaction and alteration of mudstone with cement pore fluids**

*Keith Bateman[1], Yuki Amano[1], Yukio Tachi[1] (1.Japan Atomic Energy Agency)

[AGE40-03] Measurement and analysis of real-world pore micromodel for multiphase flow displacement

*Chun-Wei Peng[1] (1.Taiwan National Chiao Tung University)

[AGE40-04] Assessment of Soil Quality as Affected by Topography and Farming Practices in the Rice Terraces in Ifugao, the Philippines

★Invited Papers

*Tomoyo Kurozumi[1], Yasushi Mori[1], Hiroaki Somura[1], Milagros Ong How[2], Pearl Basilio Sanchez[3] (1.Graduate School of Environmental and Life Science, Okayama University,, 2.Universal Harvester Incorporated, 3.University of the Philippines Los Banos)

[AGE40-05] Effect of surface and weather conditions on subsurface water flow and heat transport

*Shintaro Kubota[1], Mito Nishioka[1], Yuki Kojima[2], Megumi Yamashita[1], Hirotaka Saito[1] (1.Graduate School of Agriculture, Tokyo University of Agriculture and Technology, 2.Department of Civil Engineering, Gifu University)

[AGE40-06] Effect of soil type on estimating infiltration front depth using time-lapse array antenna GPR data: A numerical study

*Koki Oikawa[1], Seiichiro Kuroda[2], Hirotaka Saito[1] (1.Tokyo University of Agriculture and Technology, 2.NARO Institute for Rural Engineering)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-GE Geological & Soil Environment

[A-GE41] Energy-Environment-Water Nexus and Sustainable Development

convener:Ming Zhang(Institute for Geo-Resources and Environment, Geological Survey of Japan, AIST), Yonghong Hao(Tianjin Normal University), Jet-Chau Wen(National Yunlin University of Science and Technology), Ken Kawamoto(Graduate School of Science and Engineering, Saitama University)

[AGE41-01] Impacts of the aquifer depletion on ground surface temperature in north China plain

★Invited Papers

*You-Kuan Zhang[1] (1.Southern University of Science and Technology)

[AGE41-02] **Investigate Sustainable Development for Micro-hydropower Generation of Water-food-energy Nexus of Irrigated Agriculture**

*Jen-Chieh Shih[1], Sheng-Hsin Hsieh [2], Ming-Der Hong [2], Hong-Ru Lin [3], Jyun-Lin Chen[4], Shao-Yang Huang [4], Jet-Chau Wen [4,5] (1. Graduate School of Safety Health and Environmental Engineering, National Yunlin University of Science and Technology., 2.Department of Irrigation and Engineering, Council of Agriculture, Executive Yuan., 3.Graduate School of Engineering Science and Technology, National Yunlin University of Science and Technology., 4.Research Center for Soil and Water Resources and Natural Disaster Prevention (SWAN), National Yunlin University of Science and Technology., 5.Department and Graduate School of Safety Health and Environmental Engineering, National Yunlin University of Science and Technology.)

[AGE41-03] ANALYSIS OF PORE STRUCTURAL PARAMETERS WITH MICROFOCUS X-RAY COMPUTED TOMOGRAPHY AND GAS TRANSPORT MEASURMENTS

★Invited Papers

*Arjun Baniya[1], Akihiro Matsuno[1], Takeshi Saito[1], Ken Kawamoto[1] (1.Graduate School of Science and Engineering, Saitama University, Japan)

[AGE41-04] Using ship's device-produced drinking water to achieve a ballast free management

*Kun-Tu Lu[1], Hon-Kit Lui[2], Chen-Tung Arthur Chen[2], Li-Lian Liu[2] (1.Department of Marine Environment and Engineering, National Sun Yat-sen University, Kaohsiung 80424, Taiwan., 2.Department of Oceanography, National Sun Yat-sen University, Kaohsiung 80424, Taiwan.)

[AGE41-05] Possible Pathways and Microorganisms Associated with Biodegradation of Chlorinated Ethanes

*Ming Zhang[1], Miho Yoshikawa[1] (1.Institute for Geo-Resources and Environment, Geological Survey of Japan, AIST)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-GE Geological & Soil Environment

[A-GE42] Interactions between Earth Critical Zone Hydrogeological Processes and Ecosystem

convener:Wang Wenke(Chang'an University), Yaqian Zhao(Xian University of Technology), Jet-Chau Wen(National Yunlin University of Science and Technology), Ming Zhang(Institute for Geo-Resources and Environment, Geological Survey of Japan, AIST)

[AGE42-01] Subsurface hydrology and ecological effect in arid and semi-arid regions

★Invited Papers

*Wang Wenke[1], Lei Duan[1], Zhoufeng Wang[1], Zaiyong Zhang[1] (1.Chang'an University)

[AGE42-02] **Using the Artificial Lake to Evaluate the Efficiency of Groundwater Recharge in Taiwan**

*Yi-Yu Li[1], Sheng-Hsin Hsieh[2], Ming-Der Hong[2], Jyun-Lin Chen[3], Hong-Ru Lin[4], Shao-Yang Huang[3], Jet-Chau Wen[3,5] (1.Graduate School of Safety Health and Environmental Engineering, National Yunlin University of Science and Technology, 2.Department of Irrigation and Engineering, Council of Agriculture, Executive Yuan, 3.Research Center for Soil and Water Resources and Natural Disaster Prevention (SWAN), National Yunlin University of Science and Technology, 4.Graduate School of Engineering Science and Technology, National Yunlin University of Science and Technology, 5.Department and Graduate School of Safety Health and Environmental Engineering, National Yunlin University of Science and Technology)

[AGE42-03] **Assessment of acidification hazard by acid sulfate soils in the critical zone of Muthurajawela marsh, Sri Lanka**

*Prashani Amoditha Kumari Ulapane[1], Chamindra L Vithana[1,2], Rohana Chandrajith[1], Leigh A Sullivan[3], Jochen Bundschuh[4], Atula Senaratne[1], Nick J Ward[2], Nadia Toppler[5] (1.Department of Geology, University of Peradeniya, Sri Lanka, 2.Southern Cross Geoscience, Southern Cross University, Australia, 3.University of Canberra, Australia, 4.University of Southern Queensland, Australia, 5.Environmental Analysis Laboratory, Southern Cross University, Australia)

[AGE42-04] **Analysis of one-dimensional vertical unsaturated flow in layered soils**

*Zaiyong Zhang[1], Wenke Wang[1], Chengcheng Gong[1], Tian-chyi Jim Yeh[2], Zhan Wang[1] (1.Chang'an University, 2.University of Arizona)

[AGE42-05] **Simulation of karst spring discharge using deep learning**

Lixing An[1], *Yonghong Hao[1], Tian-Chyi Jim Yeh [2], Yan Liu[1] (1.Tianjin Normal University, 2.The University of Arizona)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-GE Geological & Soil Environment

[A-GE43] Extending Hydropedology- -in memory of Professor Henry Lin

convener:Kosuke Noborio(Meiji University), Yasushi Mori(Graduate School of Environmental and Life Science, Okayama University)

[AGE43-01] Performance of moisture release curves created using *in situ* measurements for estimating infiltration and runoff

★Invited Papers

*Colin Campbell[1], Alton Campbell[2], Neil Hansen[2] (1.METER Group, Inc., 2.Dept. of Plant and Wildlife Sciences, Brigham Young University)

[AGE43-02] **Inverse Estimation of Soil Water Retention Curve from Infiltration Data**

*Hamed Ebrahimian[1,2], Mehrnaz Amini[3], Abdolmajid Liaghat[4], Haruyuki Fujimaki[5] (1.Associate professor, Department of Irrigation and Reclamation Engineering, University of Tehran, Karaj, Iran , 2.Visiting associate professor, Arid Land Research Center, Tottori University, Tottori, Japan., 3.Graduate student, Department of Irrigation and Reclamation Engineering, University of Tehran, Karaj, Iran., 4.Professor, Department of Irrigation and Reclamation Engineering, University of Tehran, Karaj, Iran., 5.Professor, Arid Land Research Center, Tottori University, Tottori, Japan.)

[AGE43-03] Soil moisture estimation using low-cost GPS multipath receiver.

*Yasushi Mori[1], Hiromitsu Funahashi[1], Tadaomi Saito[2], Kosuke Noborio[3] (1.Graduate School of Environmental and Life Science, Okayama University, 2.Fac. of Agriculture, Tottori University, 3.Fac. of Agriculture, Meiji University)

[AGE43-04] **Relationship between Soil Thermal Conductivity and Electrical Conductivity at Room Temperatures**

★Invited Papers

Lin Liu[1], Weiliu Li[1], Yili Lu[1], *Tusheng Ren[1] (1.China Agricultural University)

[AGE43-05] Gravity effect on water movement in pore space of glass beads porous media under microgravity.

*Yuichi Maruo[1], Naoto Sato[2], Kento Nogawa[1], Maho Tsukano[3], Hayato Mizutani[3], Natsumi Naganuma[1], Kosuke Noborio[3] (1.Graduate school of Agriculture, Meiji University, 2.Organization for the Strategic Coordination of Research and Intellectual Property, Meiji University, 3.Department of Agriculture, Meiji University)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG44] Extratropical oceans and atmosphere

convener:Youichi Kamae(Faculty of Life and Environmental Sciences, University of Tsukuba), Toyama Katsuya(Meteorological Research Institute), Hyodae Seo(Woods Hole Oceanographic Institution), Yoshi N(Hokkaido University)

[ACG44-01] **Western boundary currents and their extension regions as conduits for the ejection of bomb-radiocarbon from the thermocline**

★Invited Papers

*Keith Bradley Rodgers[1,2], Ping Zhai[3], Richard D Slater[3], Brendan R Carter[4,5], Daniele Iudicone[6], Olivier Aumont[7], Jesse Farmer[8,9], Ivy Frenger[10], Yves Plancherel[11], Laure Replandy[12], Andrea Fassbdner[13], Katsuya Toyama[14] (1.IBS Center for Climate Physics, Busan, Republic of Korea, 2.Pusan National University, Busan, Republic of Korea, 3.Atmospheric and Oceanic Sciences Program, Princeton University, NJ, 4.Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Seattle, WA, 5.NOAA Pacific Marine Environmental Laboratory, Seattle, WA, 6.Department of Integrated Marine Ecology, Stazione Zoologica, Anton Dohrn, Naples, Italy, 7.Sorbonne Universités, UPMC, Univ. Paris 06-CNRS-IRD-MHNH, LOCEAN/IPSL, Paris, France, 8.Princeton University, Department of Geosciences, Princeton, NJ, 9.Climate Geochemistry, Max-Planck INstitute for Chemistry, Mainz, Germany, 10.GEOMAR Helmholz Centre for Ocean Research, Kiel, Germany, 11.Grantham Institute, Imperial College, London, UK, 12.Princeton Environmental Institute, Princeton, NJ, 13.Monterey Bay Aquarium Research Institute, Moss Landing, CA, 14.Oceanography and Geochemsitry Research Department, Meteorological Research Insistute, Japan Meteorological Agency, Tsukuba, Japan)

[ACG44-02] Modulation of western boundary current influence on the troposphere by atmospheric fronts

*Rhys Parfitt[1,2], Hyodae Seo[2], Young-Oh Kwon[2] (1.Florida State University, 2.Woods Hole Oceanographic Institution)

[ACG44-03] Processes Shaping the Time-Mean Surface Wind Convergence Patterns Aound the Kuroshio Extension and Gulf Stream in Winter

*Ryusuke Masunaga[1], Hisashi Nakamura[2], Bunmei Taguchi[4], Takafumi Miyasaka[3,2] (1.International Pacific Research Center, University of Hawaii, 2.Research Center for Advanced Science and Technology, The university of Tokyo, 3.Japan Meteorological Business Support Center, 4.University of Toyama)

[ACG44-04] *Climatic Hotspot2* project in Japan

★Invited Papers

*Masami Nonaka[1] (1.Application Laboratory, Research Institute for Value-Added Information Generation, Japan Agency for Marine-Earth Science and Technology)

[ACG44-05] Coupled ocean-atmosphere interactions over oceanic boundary currents

*Hyodae Seo[1] (1.Woods Hole Oceanographic Institution)

[ACG44-06] **Forced atmospheric circulation response and its uncertainty to decadal SST variability in the Kuroshio Extension**

*Bunmei Taguchi[1,2], Kazuaki Nishii[3,2], Hisashi Nakamura[2,4] (1.Faculty of Sustainable Design, University of Toyama, 2.Research Center for Advanced Science and Technology, The University of Tokyo, 3.Graduate School of Bioresources, Mie University , 4.APL, Japan Agency for Marine-Earth Science and Technology)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG44] Extratropical oceans and atmosphere

convener:Youichi Kamae(Faculty of Life and Environmental Sciences, University of Tsukuba), Toyama Katsuya(Meteorological Research Institute), Hyodae Seo(Woods Hole Oceanographic Institution), Yoshi N(Hokkaido University)

[ACG44-07] Deep learning for mesoscale air-sea interactions

★Invited Papers

*Thomas Kilpatrick[1], Shang-Ping Xie[1], Will Chapman[1] (1.Scripps Institution of Oceanography)

[ACG44-08] Extratropical cyclone processes as a key to understanding climate sensitivity

*Daniel McCoy[1], Paul Field[1,2], Alejandro Bodas-Salcedo[2], Gregory Elsaesser[3], Mark Zelinka[4] (1.University of Leeds, 2.UK Met Office, 3.Columbia University and NASA Goddard Institute for Space Studies, 4.Lawrence Livermore National Laboratory)

[ACG44-09] Stability Index for Marine Low Cloud Cover over the Mid-latitudes

*Hideaki Kawai[1], Tsuyoshi Koshiro[1] (1.Meteorological Research Institute)

[ACG44-10] Air-sea fluxes and ocean variability associated with atmospheric rivers

*Toshiaki Shinoda[1], Weiqing Han[2], Luis Zamudio[3], Joe Metzger[4], Chris Fairall[5], Yanjuan Guo[6] (1.Texas A&M University Corpus Christi, 2.University of Colorado, 3.Florida State University, 4.Naval Research Laboratory, 5.NOAA, 6.University of Maryland)

[ACG44-11] On the Importance of a Midlatitude Oceanic Frontal Zone for the Baroclinic Annular Mode

*Morio Nakayama[1], Hisashi Nakamura[1], Fumiaki Ogawa[2] (1.Research Center for Advanced Science and Technology, the University of Tokyo , 2.University of Bergen)

[ACG44-12] North and South Pacific Decadal Oscillations: Tropical Pacific Forcing versus Internal Variability

*Yu Zhang[1,2], Shang-Ping Xie[3], Yu Kosaka[4], Jun-Chao Yang[1,2] (1.Physical Oceanography Laboratory, Ocean University of China, 2.Qingdao National Laboratory for Marine Science and Technology, 3.Scripps Institution of Oceanography, University of California San Diego, 4.Research Center for Advanced Science and Technology, The University of Tokyo)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG45] Multi-scale ocean-atmosphere interaction in the tropical Indo-Pacific region

convener:Yu Kosaka(Research Center for Advanced Science and Technology, University of Tokyo), Sang-Wook Yeh(Hanyang University), Takanori Horii(Research and Development Center for Global Change (RCGC), Strategic Research and Development Area, Japan Agency for Marine-Earth Science and Technology (JAMSTEC)), Hiroki Tokinaga(Disaster Prevention Research Institute, Kyoto University)

[ACG45-01] **Impacts of Arabian Sea SST biases on Indian monsoon precipitation and eastern Mediterranean climate in a coupled GCM**

★Invited Papers

*Yoko Yamagami[1], Hiroaki Tatebe[2], Masahiro Watanabe[1] (1.Atmosphere and Ocean Research Institute, The University of Tokyo, 2.Japan Agency for Marine-Earth Science and Technology)

[ACG45-02] Radiative impacts of low-level clouds on the subtropical high in the South Indian Ocean and their seasonal differences simulated in a coupled general circulation model

*Ayumu Miyamoto[1], Hisashi Nakamura[1], Takafumi Miyasaka[1,2], Yu Kosaka[1] (1.Research Center for Advanced Science and Technology, The University of Tokyo, 2.Japan Meteorological Business Support Center)

[ACG45-03] Salt-Stratified Barrier Layers in the Eastern Tropical North Pacific

*Shota Katsura[1], Janet Sprintall[1] (1.Scripps Institution of Oceanography, University of California, San Diego)

[ACG45-04] **ENSO Modulation of ISO intensity and Upscale Feedback of ISO on Seasonal Mean SST in the Western North Pacific**

★Invited Papers

*Renguang Wu[1], Xi Cao[2], Yuqi Wang[2] (1.Zhejiang University, 2.Institute of Atmospheric Physics, Chinese Academy of Sciences)

[ACG45-05] Incorporating the convection-SST sensitivity to understand ENSO and its diversity

*Ruihuang Xie[1] (1.Institute of Oceanology, Chinese Academy of Sciences)

[ACG45-06] **Effects of Tropical Cyclones on ENSO**

*Tao Lian[1], Hongli Ren[2] (1.State Key Laboratory of Satellite Ocean Environment Dynamics, Second Institute of Oceanography, Ministry of Natural Resources, Hangzhou, China, 2.Laboratory for Climate Studies, National Climate Center, China Meteorological Administration, Beijing, China)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG45] Multi-scale ocean-atmosphere interaction in the tropical Indo-Pacific region

convener:Yu Kosaka(Research Center for Advanced Science and Technology, University of Tokyo), Sang-Wook Yeh(Hanyang University), Takanori Horii(Research and Development Center for Global Change (RCGC), Strategic Research and Development Area, Japan Agency for Marine-Earth Science and Technology (JAMSTEC)), Hiroki Tokinaga(Disaster Prevention Research Institute, Kyoto University)

[ACG45-07] **Marginal sea surface temperature variation as a pre-cursor of heat waves over the Korean Peninsula**

★Invited Papers

*Yoo-Geun Ham[1] (1.Department of Oceanography, Chonnam National University)

[ACG45-08] Rethinking the ENSO–monsoon relationship in light of trans-basin interactions

★Invited Papers

*Yuhei Takaya[1], Yu Kosaka[2], Masahiro Watanabe[3], Shuhei Maeda[1], Naoaki Saito[1], Ichiro Ishikawa[1] (1.Meteorological Research Institute, 2.Research Center for Advanced Science and Technology, University of Tokyo, 3.Atmosphere and Ocean Research Institute, University of Tokyo)

[ACG45-09] Indo-Pacific Climate Modes in Warming Climate: Consensus and Uncertainty Across Model Projections

*Xiao-Tong Zheng[1] (1.Ocean University of China)

[ACG45-10] Understanding the mechanisms associated with an unstable relationship between Pacific Decadal Oscillation and Indian Ocean Basin mode

*Sang-Wook Yeh[1] (1.Hanyang University)

[ACG45-11] Observed cross-basin interaction of decadal climate variability over the Indo-Pacific region

*Yuma Miyaji[1], Youichi Tanimoto[2] (1.Hokkaido University, Graduate School of Environmental Science, 2.Hokkaido University, Faculty of Environmental Earth Science)

[ACG45-12] Origin of Equatorial Pacific Decadal Variability: Thermodynamic or Dynamic Coupling?

*Yu Zhang[1,2], Shang-Ping Xie[3], Dillon J. Amaya[4,5], Qihua Peng[6], Yu Kosaka[7], Xiaopei Lin[1,2], Jun-Chao Yang[1,2], Sarah M. Larson[8], Arthur J. Miller[3] (1.Physical Oceanography Laboratory, Ocean University of China, 2.Qingdao National Laboratory for Marine Science and Technology, 3.Scripps Institution of Oceanography, University of California San Diego, 4.Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, 5.Department of Atmospheric and Oceanic Sciences, University of Colorado Boulder, 6.State Key Laboratory of Tropical Oceanography, South China Sea Institute of Oceanology, Chinese Academy of Sciences, 7.Research Center for Advanced Science and Technology, The University of Tokyo, 8.Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG47] Global Carbon Cycle Observation and Analysis

convener:Kazuhito Ichii(Chiba University), Prabir Patra(Research Institute for Global Change, JAMSTEC), Forrest M. Hoffman(Oak Ridge National Laboratory), Makoto Saito(National Institute of Environmental Studies)

[ACG47-01] Relative contributions of different methane emission categories in the continental East Asia inferred from stable carbon isotope measurements at Hateruma Station

★Invited Papers

*Taku Umezawa[1], Takuya Saito[1], Yasunori Tohjima[1], Yukio Terao[1], Akihiko Ito[1] (1.National Institute of Environmental Studies)

[ACG47-02] **Process analysis of GHGs seasonal variabilty in the UT/LS region on account of emissions, dynamics and atmospheric chemistry**

*Jagat Bisht[1], Prabir Patra[1,2], Naveen Chandra[1], Toshinobu Machida[3], Naoko Saitoh[2] (1.Research Institute for Global Change (RIGC), JAMSTEC, Yokohama, 236-0001, Japan, 2.Center for Environmental Remote Sensing, Chiba University, Chiba, 263-8522, Japan, 3.CGER, National Institute for Environmental Studies, Tsukuba, Japan)

[ACG47-03] An observation-based synthetic reconstruction of surface ocean inorganic carbon variables

*Yosuke Iida[1,2], Yusuke Takatani[1], Atsushi Kojima[1], Takashi Nakamura[1,2], Masao Ishii[2,1] (1.Japan Meterological Agency, 2.Meteorological Research Institute)

[ACG47-04] Decoupling of projected oceanic uptake of carbon and heat in the 21st century in a high carbon emission pathway

*Eric Mortenson[1], Andrew Lenton[1,2,3], Tom Trull[1,2], Elizabeth Shadwick[1,2,3], Xuebin Zhang[1,3], Matt Chamberlain[1] (1.Commonwealth Scientific and Industrial Research Organization, Australia, 2.Australian Antarctic Program Partnership, 3.The Centre for Southern Hemisphere Oceans Research)

[ACG47-05] **Utility of total column CO_2 observations by satellites and atmospheric CO_2 inversion for evaluating carbon cycle processes in the Earth System Models**

*Prabir Patra[1,2], Tomohiro Hajima[1], Ryu Saito[3], Naveen Chandra[1], Yukio Yoshida[4], Michio Kawamiya[1], Masayuki Kondo[2], Kazuhito Ichii[2], Akihiko Ito[4], Dave Crisp[5] (1.Research Institute for Global Change, JAMSTEC, 2.Center for Environmental Remote Sensing, Chiba University, Chiba 263-8522, Japan, 3.Disaster Risk Reduction and Environ. SBU, Kokusai Kogyo Co., Ltd., Tokyo, 183-0057, Japan, 4.Center for Global Environmental Research, NIES, Tsukuba, 305-8506, Japan, 5.NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA)

[ACG47-06] Diagnosing Climate–Carbon Cycle Feedbacks Constrained by ILAMB

*Forrest M. Hoffman[1,2], Nathan Collier[1], Mingquan Mu[3], Cheng-En Yang[2], Gretchen Keppel-Aleks[4], David M. Lawrence[5], Charles D. Koven[6], William J. Riley[6], James T. Randerson[3] (1.Oak Ridge National Laboratory, 2.University of Tennessee Knoxville, 3.University of California Irvine, 4.University of Michigan, 5.National Center for Atmospheric Research, 6.Lawrence Berkeley National Laboratory)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG47] Global Carbon Cycle Observation and Analysis

convener:Kazuhito Ichii(Chiba University), Prabir Patra(Research Institute for Global Change, JAMSTEC), Forrest M. Hoffman(Oak Ridge National Laboratory), Makoto Saito(National Institute of Environmental Studies)

[ACG47-07] On reliable pattern of historical land-use and land-cover change transition in Southeast Asia

★Invited Papers

*Masayuki Kondo[1] (1. Center for Environmental Remote Sensing, Chiba University)

[ACG47-08] Detecting the Borneo ecosystem changes caused by 2015 El Nino events using Satellite SIF data

*Kazutaka Murakami[1], Makoto Saito[1], Hibiki M Noda[1], Haruki Oshio[1], Yukio Yoshida[1], Kazuhito Ichii[2,1] (1.National Institute for Environmental Studies, 2.Chiba University)

[ACG47-09] **Response of tropical terrestrial gross primary production to the super El Niño event in 2015**

*Jiawen Zhu[1], Minghua Zhang[2], Yao Zhang[3], Xiaodong Zeng[1], Xiangming Xiao[4] (1.Institute of Atmospheric Physics, CAS, 2.Stony Brook Univ., 3.Columbia Univ., 4.Univ. of Oklahoma)

[ACG47-10] **Fixed Nonlinear Multiregression Based Spectral Modelling Approach for Predictive Quantification of Biomass and Carbon stocks of Tree Outside Forest areas (TOFs) over Arid zone of Jodhpur, Rajasthan, India**

*SWATI UNIYAL[1], Sitiraju Srinivasa Rao[2], Eadara Amminedu[1] (1.Andhra University,Visakhapatnam,Andhra Pradesh,India, 2.National Remote Sensing Center,Hyderabad,India)

[ACG47-11] Updating data-driven estimation of terrestrial carbon fluxes across Asia

*Kazuhito Ichii[1], Riku Kawase[1], Zhiyan Liu[1] (1.Chiba University)

[ACG47-12] **Regional estimates of CO_2 budget using inverse modelling for the past two decades (1996-2018)**

*Naveen Chandra[1], Prabir Patra[1] (1.Japan Agency for Marine Earth Science and Technology)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG48] Projection and detection of global environmental change

convener:Michio Kawamiya(Japan Agency for Marine-Earth Science and Technology), Kaoru Tachiiri(Japan Agency for Marine-Earth Science and Technology), Hiroaki Tatebe(Japan Agency for Marine-Earth Science and Technology), V Ramaswamy(NOAA GFDL)

[ACG48-01] Exploring physical and biological environmental responses to differing rates of carbon emissions

★Invited Papers

*John P Krasting[1], John P Dunne[1], Jasmin G John[1], Michael Winton[1] (1.NOAA - Geophysical Fluid Dynamics Laboratory)

[ACG48-02] Highlighted results from the latest MIROC-based ESM and activities of TOUGOU-B

*Michio Kawamiya[1], Kaoru Tachiiri[1], Tomohiro Hajima[1], Tokuta Yokohata[2], Junichi Tsutsui[4], Takashi Arakawa[3], Takahiro Inoue[1] (1.Japan Agency for Marine-Earth Science and Technology, 2.National Institute for Environmental Studies, 3.Research Organization for Information Science and Technology, 4.Central Research Institute of Electric Power Industry)

[ACG48-03] Evaluation of carbon cycles in a suite of CMIP6-C^{4}MIP experiments by Meteorological Research Institute Earth System Model version 2.0 (MRI-ESM2.0)

*Hiroyuki Tsujino[1], Atsushi Obata[1], Seiji Yukimoto[1], Masahiro Hosaka[1], Taichu Y Tanaka[1], Toyama Katsuya[1], Tsuyoshi Koshiro[1], Shogo Urakawa[1], Hideyuki Nakano[1] (1.Japan Meteorological Agency / Meteorological Research Institute)

[ACG48-04] Evaluation of terrestrial carbon cycle processes in MIROC-ES2L

*Tomohiro Hajima[1], Akihiko Ito[2], Prabir Patra[1], Kaoru Tachiiri[1], Kazuhito Ichii[3], Manabu Abe[1] (1.Japan Agency for Marine-Earth Science and Technology, 2.National Institute for Environmental Studies, 3.Center for Environmental Remote Sensing, Chiba University)

[ACG48-05] Using UAVs and deep learning techniques to detect invasive species in forests and wetlands

*Sarah Kentsch[1,2], Maximo Larry Lopez Caceres[1], Yago Diez Donoso[1], Jens Gross[3] (1.Yamagata University, 2.United Graduate school of Agriculture Sciences (UGAS), 3.Leibniz University of Hannover)

[ACG48-06] Modeling ocean-ice shelf interaction over the Southern Ocean under RCP8.5 scenario

*Kazuya Kusahara[1], Hiroaki Tatebe[1], Tomohiro Hajima[1], Fuyuki SAITO[1] (1.Japan Agency for Marine-Earth Science and Technology)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG48] Projection and detection of global environmental change

convener:Michio Kawamiya(Japan Agency for Marine-Earth Science and Technology), Kaoru Tachiiri(Japan Agency for Marine-Earth Science and Technology), Hiroaki Tatebe(Japan Agency for Marine-Earth Science and Technology), V Ramaswamy(NOAA GFDL)

[ACG48-07] Toward marine ecosystem prediction with a global ESM

★Invited Papers

*Jong-yeon Park[1], Charles A. Stock[2], John P. Dunne[2], Xiaosong Yang[2], Anthony Rosati[2] (1.Jeonbuk National University (JBNU), 2.Geophysical Fluid Dynamics Laboratory (GFDL))

[ACG48-08] Estimating global air–sea and air–land CO2 flux fluctuations over the past forty years with an Earth system model incorporating a data assimilation system

*Michio Watanabe[1], Hiroaki Tatebe[1], Hiroshi Koyama, Tomohiro Hajima[1], Masahiro Watanabe[2], Michio Kawamiya[1] (1.Japan Agency for Marine-Earth Science and Technology, 2.The University of Tokyo)

[ACG48-09] Overview of the processes interacting between Earth and socio-economic systems

*Kaoru Tachiiri[1], Ken'ichi Matsumoto[2], Xuanming Su[1] (1.Japan Agency for Marine-Earth Science and Technology, 2.Nagasaki University)

[ACG48-10] **Quantify allowable warmings for 2 °C and 1.5 °C climate targets**

*Xuanming Su[1], Katsumasa Tanaka[2,3], Kaoru Tachiiri[1], Michio Watanabe[1], Michio Kawamiya[1] (1.Japan Agency for Marine-Earth Science and Technology, 2.Laboratoire des Sciences du Climat et de l'Environnement (LSCE), Commissariat à l'énergie atomique et aux énergies alternatives (CEA), Gif-sur-Yvette, France, 3.National Institute for Environmental Studies (NIES))

[ACG48-11] Impacts of climate and socio-economic changes on water, food, bio-energy and land use investigated with an integrated land surface model (MIROC-INTEG)

*Tokuta Yokohata[1], Tsuguki Kinoshita[2], Gen Sakurai[3], Akihiko Ito[1], Yusuke Satoh[1], Yadu Pokhrel[4], Masashi Okada[1], Etsushi Kato[5], KIYOSHI TAKAHASHI[1], Naota Hanasaki[1], Shinichiro Fujimori[6], Seita Emori[1] (1.National Institute for Environmental Studies, 2.Ibaraki University, 3.National Agriculture and Food Research Organization, 4.Michigan State University, 5.The Institute of Applied Energy, 6.Kyoto University)

[ACG48-12] Multi-type global drought projection using multi-model hydrological simulations

*Yusuke Satoh[1], Tokuta Yokohata[1], Yadu Pokhrel[2], Naota Hanasaki[1], Julien ERIC STANISLAS Boulange[1], Peter Burek[3], Kumiko TAKATA[1], Hideo Shiogama[1] (1.National Institute for Environmental Studies, 2.Department of Civil and Environmental Engineering, Michigan State University, 3.International Institute for Applied Systems Analysis)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG49] Greenhouse Gas Monitoring from Space: Current Capabilities, Challenges, and Future Needs

convener:kurosu thomas p(Jet Propulsion Laboratory, California Institute of Technology), Annmarie Eldering(Jet Propulsion Laboratory), Akihiko Kuze(Japan Aerospace Exploration Agency), Tsuneo Matsunaga(Center for Global Environmental Research and Satellite Observation Center, National Institute for Environmental Studies)

[ACG49-01] Current status of GOSAT and GOSAT-2 operation

*HIROKO IMAI[1], Hiroshi Suto[1], Kei Shiomi[1], Nobuhiro Kikuchi[1], Fumie Kataoka[2], Hiroyuki Miyamoto[1], Akihiko Kuze[1] (1.Japan Aerospace Exploration Agency, 2.Remote Sensing Technology Center of Japan)

[ACG49-02] Greenhouse gas concentrations retrieved from a combined use of SWIR and TIR observations by the GOSAT series satellites

*Nobuhiro Kikuchi[1], Akihiko Kuze[1], Fumie Kataoka[2], Kei Shiomi[1], Makiko Hashimoto[1], Hiroshi Suto[1] (1.Japan Aerospace Exploration Agency, 2.Remote Sensing Technology Center of Japan)

[ACG49-03] GOSAT collaboration activities with OCO-2 for calibration and validation

*Kei Shiomi[1], Akihiko Kuze[1], Hiroshi Suto[1], Nobuhiro Kikuchi[1], Mariko HASHIMOTO[1], Fumie KATAOKA[2] (1.Japan Aerospace Exploration Agency, 2.RESTEC)

[ACG49-04] The OCO-3 Mission: Performance of the Snapshot Area Map and Target Mode Observations and Coincident Measurements with the OMPS and TROPOMI Air Quality Sensors

*thomas p kurosu[1], Annmarie Eldering[1], Ralph basilio[1], matthew Bennett[1], Christopher O'Dell[2], Peter Somkuti[2], Thomas Taylor[2], Matthäus Kiel[1], Robert Nelson[1], Gary Spiers[1], Brendan Fisher[1], Ryan Pavlick[1], Gregory Osterman[1], Joshua Laughner[3], Graziela Keller-Rodrigues[1], Shanshan Yu[1], David Crisp[1], Paul Wennberg[3] (1.NASA Jet Propulsion Laboratory/California Institute of Technology, Pasadena, CA 91109, 2.Colorado State University, Fort Collins, CO 80523, 3.California Institute of Technology, Pasadena, CA 91125)

[ACG49-05] Early Comparison of OCO-3 XCO2 Measurements with TCCON

*Matthäus Kiel[1], Joshua Laughner[2], Annmarie Eldering[1], Brendan M. Fisher[1], thomas p kurosu[1], Ryan P. Pavlick[1], Gregory B. Osterman[1], Robert R. Nelson[1], Christopher W. O'Dell[3], Peter Somkuti[3], Thomas E. Taylor[3], Coleen M. Roehl[2], TCCON Team (1.NASA Jet Propulsion Laboratory, 2.Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA (USA), 3.Colorado State University, Fort Collins, CO (USA))

[ACG49-06] Temporally and spatially coincident observation of NO_2, CO_2 and CH_4 by manned and unmanned airplanes toward to detection of anthropogenic carbon signature

*Hiroshi Suto[1], Akihiko Kuze[1] (1.JAXA)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG50] Earth & Environmental Sciences and Artificial Intelligence

convener:Tomohiko Tomita(Faculty of Advanced Science and Technology, Kumamoto University), Shigeki Hosoda(Japan Marine-Earth Science and Technology), Ken-ichi Fukui(Osaka University), Satoshi Ono(Kagoshima University)

[ACG50-01] What is "Explainable AI"?

★Invited Papers

*Satoshi Hara[1] (1.Osaka University)

[ACG50-02] Predicting global potential natural vegetation with an image recognition AI

*Hisashi Sato[1], Takeshi Ise[2] (1.Department of Environmental Geochemical Cycle Research, Japan Agency for Marine-Earth Science and Technology (JAMSTEC), 2.Field Science Education and Research Center, Kyoto University)

[ACG50-03] **Digital Soil Mapping of Soil Fertility in Thung Kula Rong-Hai Region, Thailand using Machine Learning Algorithm**

*Sasirin Srisomkiew[1], Masayuki Kawahigashi[1], Pitayakon Limtong[2] (1.Tokyo Metropolitan University, 2.Land Development Department)

[ACG50-04] **Robustness of optical remote sensing of cloud by deep convolutional neural network using multi-channel imaging spectroradiometer**

*Hironobu Iwabuchi[1], Hana Kato[1], Aki Masuda[1] (1.Graduate School of Science, Tohoku University)

[ACG50-05] Multi-location meteorological observation system and micro-satellites for extreme weather forecast

★Invited Papers

*Yukihiro Takahashi[1,2], Mitsuteru Sato[1,2], Hisayuki Kubota[1,2], Kozo Yamashita[3], Tetsuro Ishida[1,2], Ellison Caparas Castro[4], Loren Joy De Vera Estrebillo[1], Purwadi Purwadi[1], Gay Perez[4], Joel Marciano[4], Jun Matsumoto[5], Jun-Ichi Hamada[5] (1.Department of Cosmosciences, Graduate School of Science, Hokkaido University, 2.Faculty of Science, Hokkaido University, 3.Faculty of Engineering, Ashikaga University, 4.University of the Philippines, Diliman, 5.Tokyo Metropolitan University)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG51] Satellite Earth Environment Observation

convener:Riko Oki(Japan Aerospace Exploration Agency), Yoshiaki HONDA(Center for Environmental Remote Sensing, Chiba University), Yukari Takayabu(Atmosphere and Ocean Research Institute, the University of Tokyo), Tsuneo Matsunaga(Center for Global Environmental Research and Satellite Observation Center, National Institute for Environmental Studies)

[ACG51-01] GOSAT and GOSAT-2 Higher Level Products: Current Status and Future Plan

★Invited Papers

*Tsuneo Matsunaga[1], Isamu Morino[1], Yukio Yoshida[1], Makoto Saito[1], Hibiki M Noda[1], Hirofumi Ohyama[1], Yosuke Niwa[1], Akihide Kamei[1], Fumie Kawazoe[1], Tazu Saeki[1], Ryoichi Imasu[2], Naoko Saitoh[3], Takashi Nakajima[4], Teruyuki Nakajima[5], Makiko Hashimoto[5] (1.National Institute for Environmental Studies, 2.The University of Tokyo, 3.Chiba University, 4.Tokai University, 5.Japan Aerospace Exploration Agency)

[ACG51-02] Progress on validation of GOSAT and GOSAT-2 FTS SWIR L2 Products

*Isamu Morino[1], Yukitomo Tsutsumi[1], Osamu Uchino[1], Hirofumi Ohyama[1], Thi Ngoc Trieu Tran[1], Frey Max Matthias[1], Yukio Yoshida[1], Tsuneo Matsunaga[1], Akihide Kamei[1], saito makoto[1], Hibiki M Noda[1], TCCON partners[2] (1.NIES National Institute of Environmental Studies, 2.https://tccon-wiki.caltech.edu)

[ACG51-03] **Spatiotemporal variabilities of ammonia in China as seen from IASI and AMoN**

*Xuehui Guo[1], Rui Wang[1], Da Pan[1], Kang Sun[2], Lieven Clarisse[3], Martin Van Damme[3], Simon Whitburn[3], Pierre-François Coheur[3], Yuepeng Pan[4], Mark Zondlo[1] (1.Princeton University, 2.University at Buffalo, 3.Université libre de Bruxelles , 4.Chinese Academy of Sciences)

[ACG51-04] Scientific Overview of the GCOM-W/AMSR2 Mission and Outlook for GOSAT-GW/AMSR3

★Invited Papers

*Naoto Ebuchi[1,2], Misako Kachi[2], Hideyuki Fujii[2], Takashi Maeda[2], Nodoka Ono[2], Kazuya Inaoka[2], Marehito Kasahara[2], Yasushi Kojima[2] (1.Institute of Low Temperature Science, Hokkaido University, 2.JAXA)

[ACG51-05] Current Status of AMSR2 on board GCOM-W and Development of AMSR3 on GOSAT-GW

*Misako Kachi[1], Naoto Ebuchi[2,1], Takashi Maeda[1], Nodoka Ono[1], Hideyuki Fujii[1], Kazuya Inaoka[3], Marehito Kasahara[3], Yasushi Kojima[3] (1.Earth Observation Research Center, Japan Aerospace Exploration Agency, 2.Institute of Low Temperature Science, Hokkaido University, 3.GOSAT-GW Project Team, Japan Aerospace Exploration Agency)

[ACG51-06] **The Inversion and Quality Validation of FY3 MWRI Sea Surface Temperature**

*miao zhang[1] (1.National satellite meteorological center)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG51] Satellite Earth Environment Observation

convener:Riko Oki(Japan Aerospace Exploration Agency), Yoshiaki HONDA(Center for Environmental Remote Sensing, Chiba University), Yukari Takayabu(Atmosphere and Ocean Research Institute, the University of Tokyo), Tsuneo Matsunaga(Center for Global Environmental Research and Satellite Observation Center, National Institute for Environmental Studies)

[ACG51-07] 2018-2019 global environment observation by GCOM-C “SHIKISAI”

★Invited Papers

*Hiroshi Murakami[1], Masahiro Hori[1], Kazuhisa Tanada[1], Toshiyuki Kobayashi[1], Megumi Okata[1], Kazunori Ogata[1], Rigen Shimada[1], Yukio Kurihara[1] (1.Earth Observation Research Center, Japan Aerospace Exploration Agency)

[ACG51-08] Two distinct modes of variability in the Euphotic depth in the Arctic ocean as revealed by satellite obsevation

*Takafumi Hirata[1] (1.Arctic Research Center, Hokkaido University)

[ACG51-09] Retrieval of Atmospheric Aerosol Properties for geostationary and polar-orbital Satellite Imaging Sensors: GCOM-C/SGLI and Himawari8/AHI results

*Mayumi Yoshida[1], Maki Kikuchi[1], Takashi M. Nagao[2], Hiroshi Murakami[1], Keiya Yumimoto[3], Taichu Y Tanaka[4] (1.Japan Aerospace Exploration Agency, 2.Tokyo University, 3.Kyushu University, 4.Meteorological Research Institute of Japan Meteorological Agency)

[ACG51-10] Satellite analysis by a multi-wavelength multi-pixel method and simultaneous method using GCOM-C/SGLI data

*Miho Sekiguchi[1], Makiko Hashimoto[2], Hideaki Takenaka[2], Chong Shi[2], Teruyuki Nakajima[2] (1.Tokyo University of Marine Science and Technology, 2.Japan Aerospace Exploration Agency)

[ACG51-11] **Quality assessment of SGLI/GCOM-C observed cloud properties using surface observation data**

*Pradeep Khatri[1], Tadahiro Hayasaka[1], Hitoshi Irie[2], Tamio Takamura[2] (1.Center for Atmospheric and Oceanic Studies,Tohoku University, 2.Center for Environmental Remote Sensing, Chiba University)

[ACG51-12] **Variabilities of Western Himalayan Forest Fire with Relation to Primary Productivity**

*SOMNATH BAR[1], Bikash Ranjan Parida[1], Deep Prakash Sarkar[1] (1.Dept. of Geoinformatics, School of Natural Resource Management, Central University of Jharkhand)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG51] Satellite Earth Environment Observation

convener:Riko Oki(Japan Aerospace Exploration Agency), Yoshiaki HONDA(Center for Environmental Remote Sensing, Chiba University), Yukari Takayabu(Atmosphere and Ocean Research Institute, the University of Tokyo), Tsuneo Matsunaga(Center for Global Environmental Research and Satellite Observation Center, National Institute for Environmental Studies)

[ACG51-13] An Overview of NASA's Aerosols and Clouds-Convection-Precipitation (A-CCP) Pre-formulation Study

★Invited Papers

*Arlindo da SIlva[1] (1.NASA Goddard Space Flight Center)

[ACG51-14] **Cloud liquid water database derived from a global cloud-system resolving model for precipitation retrievals of GPM/DPR observations**

*Takuji Kubota[1], Masaki Satoh[2], Shinta Seto[3], Toshio Iguchi[4], Takeshi Masaki[5], Tomoe Nasuno[6], Riko Oki[1] (1.Earth Observation Research Center,Japan Aerospace Exploration Agency, 2.Atmosphere and Ocean Research Institute, University of Tokyo, 3.Graduate School of Engineering, Nagasaki University, 4.Earth System Science Interdisciplinary Center, University of Maryland, 5.Remote Sensing Technology Center of Japan, 6.Research Institute for Global Change, Japan Agency for Marine-Earth Science and Technology)

[ACG51-15] Validation of DPR products by using MP-PAWR data - thunder storm case on August 27, 2018 –

*Nobuhiro Takahashi[1], Takeharu Kouketsu[1] (1.Institute for Space-Earth Environmental Research, Nagoya University)

[ACG51-16] Near-global three-dimensional hail signals detected by using GPM-DPR observations

*Tatsuya Seiki[1] (1.Japan Agency for Marine-Earth Science and Technology)

[ACG51-17] Precipitation and latent heating distribution in extratropical cyclones observed by the Global Precipitation Measurement Dual-frequency Precipitation Radar

*Hiroki Tsuji[1], Yukari Takayabu[1], Eigo Tochimoto[1] (1.Atmosphere and Ocean Research Institute, The University of Tokyo)

[ACG51-18] Ensemble-Based Data Assimilation of GPM/DPR Reflectivity into the Nonhydrostatic Icosahedral Atmospheric Model NICAM

*Shunji Kotsuki[1], Koji Terasaki[2], Masaki Satoh[3], Takemasa Miyoshi[2] (1.Center for Environmental Remote Sensing, Chiba University, 2.RIKEN Center for Computational Science, 3.Atmosphere and Ocean Research Institute, The University of Tokyo)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG51] Satellite Earth Environment Observation

convener:Riko Oki(Japan Aerospace Exploration Agency), Yoshiaki HONDA(Center for Environmental Remote Sensing, Chiba University), Yukari Takayabu(Atmosphere and Ocean Research Institute, the University of Tokyo), Tsuneo Matsunaga(Center for Global Environmental Research and Satellite Observation Center, National Institute for Environmental Studies)

[ACG51-19] Improvement and Evaluation of 1-moment Cloud Microphysics using GPM Satellite Data

*Yasutaka Ikuta[1] (1.Japan Meteorological Agency)

[ACG51-20] Satellite-based Data Assimilation Systems by Using Microwave Radiometers

★Invited Papers

*Toshio Koike[1] (1.International Centre for Water Hazard and Risk Management)

[ACG51-21] How much is the accuracy of land emissivity representation necessary for adequate cloud water content estimation over land using satellite-based passive microwave remote sensing?

*Rie Seto[1], Kentaro Aida[2], Toshio Koike[2], Shinjiro Kanae[1] (1.Tokyo Institute of Technology, 2.The International Centre for Water Hazard and Risk Management under the auspices of UNESCO)

[ACG51-22] Detectability of Heavy Rainfall and Drought in East Asia and Western Pacific Region using GSMaP

*Tashima Tomoko[1], Takuji Kubota[1], Riko Oki[1] (1.Japan Aerospace Exploration Agency)

[ACG51-23] Identifying Gaps Between Satellite Measurement Capability and Decision-making in Water Resource Management – A Case Study from Australia

*Maki Kikuchi[1,2], Anthony S. Kiem[2], Andrew D. Magee[2], Matthew Armstrong[2] (1.Japan Aerospace Exploration Agency (JAXA), 2.The University of Newcastle)

[ACG51-24] Rice planted area mapping using ALOS-2 ScanSAR data with Machine Learning Algorithm

*Kei Oyoshi[1], Shinichi Sobue[1] (1.JAXA Japan Aerospace Exploration Agency)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG52] Large Ensemble Modeling Approaches as Tools for Climate and Impacts Research

convener:Rodgers Keith Bradley(IBS Center for Climate Physics), Shoshiro Minobe(Graduate School of Science, Hokkaido University), Hideo Shiogama(Center for Global Environmental Research, National Institute for Environmental Studies), Ryo Mizuta(Meteorological Research Institute)

[ACG52-01] **Evaluating ocean physical biogeochemical interactions in ESM large ensembles**

★Invited Papers

*Takamitsu Ito[1], Filippos Tagklis[1], Yohei Takano[2] (1.Georgia Institute of Technolog, 2.Los Alamos National Laboratory)

[ACG52-02] Event attribution using large ensemble model simulations by MIROC5-AGCM, MRI-AGCM, and NHRCM

★Invited Papers

*Yukiko Imada[1], Hiroaki Kawase[1], Hideo Shiogama[3], Masato Mori[4], Chiharu Takahashi[2], Miki Arai[5], Masahiro Watanabe[2], Izuru Takayabu[1] (1.Meteorological Research Institute, Japan Meteorological Agency, 2.Atmosphere and Ocean Research Institute, the University of Tokyo, 3.National Institute for Environmental Studies, 4.Research Center for Advanced Science and Technology, the University of Tokyo, 5.Japan Agency for Marine-Earth Science and Technology)

[ACG52-03] Changes in global terrestrial ecosystem respiration with future warming: a probabilistic approach

*Irina Melnikova[1], Takahiro Sasai[1] (1.Tohoku University)

[ACG52-04] Global warming changes tropical cyclone translation speed

*Munehiko Yamaguchi[1], Johnny C. L. Chan[2], Il-Ju Moon[3], Kohei Yoshida[1], Ryo Mizuta[1] (1.Meteorological Research Institute, Japan Meteorological Agency, 2.City University of Hong Kong, 3.Jeju National University)

[ACG52-05] Nonlinear forced change implies nonergodicity and vice-versa: The case of ENSO teleconnections

*Tamas Bodai[1,2], Axel Timmermann[1,2], Gabor Drotos[3], Timea Haszpra[4] (1.Pusan National University, 2.Center for Climate Physics, Institute for Basic Science, South Korea, 3.Instituto de Física Interdisciplinar y Sistemas Complejos, CSIC-UIB, Palma de Mallorca, Spain, 4.Institute for Theoretical Physics, Eötvös Loránd University, Budapest, Hungary)

[ACG52-06] Parallel Analog Ensemble: The Power of Weather Analogs

*Weiming Hu[1], Guido Cervone[1], Martina Calovi[1], Laura Clemente-Harding[2] (1.Pennsylvania State University Main Campus, 2.Engineer Research and Development Center)

[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG53] Terrestrial monitoring using new-generation geostationary satellites

convener:Yuhei Yamamoto(Center for Environmental Remote Sensing, Chiba University), Yunyue Yu(NOAA National Environmental Satellite, Data, and Information Service), Tomoaki Miura(Univ Hawaii), Kazuhito Ichii(Chiba University)

[ACG53-01] GeoNEX: Earth observations from operational geostationary satellite systems

★Invited Papers

*Ramakrishna R Nemani[1] (1.NASA Ames Research Center)

[ACG53-02] Preliminary research on validation for the atmospheric correction of HIMAWARI-8 AHI data using SKYNET data

*Hirokazu YAMAMOTO[1], Satoshi Tsuchida[1] (1.Geological Survey of Japan, AIST)

[ACG53-03] An analysis of land surface temperature during summer clear-sky days focusing on the diurnal change characteristics using Himawari-8 data

*Yuhei Yamamoto[1], Kazuhito Ichii[1] (1.Center for Environmental Remote Sensing, Chiba University)

[ACG53-04] An Enterprise Land Surface Temperature (LST) Algorithm for the GOES-R and Himawari Satellites

*Yunyue Yu[1], Jaime Daniels[1], Satya Kalluri[1], Peng Yu[1] (1.NOAA National Environmental Satellite, Data, and Information Service)

[ACG53-05] Analysis of differences between NDVI-based indices of Himawari 8 AHI and Aqua MODIS using Rayleigh-corrected reflectances

*Kenta Obata[1], Hiroki Yoshioka[1] (1.Aichi Prefectural University)

[ACG53-06] Functional grassland phenology discrimination and analyses with Himawari-8 geostationary data

★Invited Papers

*Alfredo R Huete[1], Ngoc Nguyen Tran[1], Qiaoyun Xie[1], Tomoaki Miura[2] (1.University of Technology Sydney, 2.University of Hawaii)

[E] Oral | H (Human Geosciences)：H-GM Geomorphology

[H-GM02] Geomorphology

convener:Tsuyoshi Hattanji(Faculty of Life and Environmental Sciences, University of Tsukuba), Masayuki Seto(Fukushima Future Center for Regional Revitalization, Fukushima University)

[HGM02-01] Detecting geomorphic and sedimentary effects of modern climate change: how much do we know?

*Amy E East[1], Joel B Sankey[2] (1.U.S. Geological Survey, Santa Cruz, California, U.S.A., 2.U.S. Geological Survey, Flagstaff, Arizona, U.S.A.)

[HGM02-02] Effects of different controlling factors on the experimental landform development

*Shunji Ouchi

[HGM02-03] Measurement of landslide surface deformation along Kali Gandaki River, Nepal using time-series Sentinel-1 InSAR images

*Hiroshi, P. Sato[1], Masahiro Chigira[2], Ching-Ying Tsou[3] (1.College of Humanities and Sciences, Nihon University, 2.Disaster Prevention Research Institute, Kyoto University, 3.Faculty of Agriculture and Life Science, Hirosaki University)

[HGM02-04] UAV SfM monitoring of coastal morphology on Kujukuri beach

*Mergen Kungaa[1], Toshihiko Sugai[1], Natsuki Sasaki[1], Tatsuki Miyamoto[1], Tatsuya Terada[1] (1.Tokyo University, Graduate School of Frontier Sciences, Department of Natural Environmental Studies)

[HGM02-05] Evaluating soil physical properties and their spatial variability in a headwater catchment

*Ingrid Lima[1], Takashi GOMI[1], Taro UCHIDA[2], Takao YAMAKOSHI[3], Yohei ARATA[1], Kenta Koyanagi[1] (1.Tokyo University of Agriculture and Technology , 2.University of Tsukuba , 3.National Institute for Land and Infrastructure)

[HGM02-06] Four major geomorphological debates in Japan

*Takashi Oguchi[1] (1.Center for Spatial Information Science, The University of Tokyo)

[E] Oral | H (Human Geosciences)：H-QR Quaternary research

[H-QR04] Innovative Applications of Trapped-Charge Dating to Quaternary Geochronology

convener:Toru Tamura(Institute of Geology and Geoinformation Geological Survey of Japan, AIST), Shin Toyoda(Department of Applied Physics, Faculty of Science, Okayama University of Science), Yuji Ishii(National Institute of Advanced Industrial Science and Technology), Sumiko Tsukamoto(Leibniz Institute for Applied Geophysics)

[HQR04-01] **East Asian summer monsoon dynamics over the last interglacial-glacial cycle inferred from fluctuations of Lake Daihai in northern China**

★Invited Papers

*Hao Long[1], Yandong Hou[1], Lei Gao[1], Qian Liu[2] (1.NIGLAS, 2.Nanjing Normal Univ.)

[HQR04-02] Fine-grained quartz OSL dating for reconstructing the Holocene evolution of the Mekong River floodplain

*Yuji Ishii[1,2], Toru Tamura[2], Ben Bunnarin[3] (1.Research Fellow of the Japan Society for the Promotion of Science, 2.Geological Survey of Japan, AIST, 3.Department of Geology, GDMR, MIME, Cambodia)

[HQR04-03] Feldspar pIRIR dating for defining glacial-interglacial depositional sequences in the Kanto Plain, eastern Japan

*Toru Tamura[1,4], Hiroko Okazaki[2], Hiroomi Nakazato[3], Tomonori Naya[1], Rei Nakashima[1] (1.Institute of Geology and Geoinformation Geological Survey of Japan, AIST, 2.Natural Hisory Museum and Institute, Chiba, 3.The National Agriculture and Food Research Organization, 4.Graduate School of Frontier Sciences, The University of Tokyo)

[HQR04-04] **Testing the reliability of the fading correction near saturation for the Infrared stimulated luminescence dating**

★Invited Papers

*Yan Li[1,2], Sumiko Tsukamoto[2], Hao Long[3], Jingran Zhang[4], Linhai Yang[5], Manfred Frechen[2] (1.China Univ. of Geosci., 2.LIAG, 3.NIGLAS, 4.Nanjing Normal Univ., 5.Shaanxi Normal Univ.)

[HQR04-05] The production mechanism of the E_1' center by low-velocity friction based on the particle characteristics

*Kiriha Tanaka[1], Jun Muto[1], Yasuo Yabe[2], Toshitaka Oka[3], Hiroyuki Nagahama[1] (1.Earth Science, Graduate School of Science, Tohoku University, 2.Research Center for Prediction of Earthquakes and Volcanic Eruptions, Graduate School of Science, Tohoku University, 3.Japan Atomic Energy Agency)

[HQR04-06] ESR dating of quartz: issues on sediment dating and on thermochronometry

*Shin Toyoda[1] (1.Department of Applied Physics, Faculty of Science, Okayama University of Science)

[E] Oral | H (Human Geosciences)：H-DS Disaster geosciences

[H-DS08] Tsunami and tsunami forecast

convener:Hiroaki Tsushima(Meteorological Research Institute, Japan Meteorological Agency), Tatsuya Kubota(National Research Institute for Earth Science and Disaster Resilience)

[HDS08-01] N-net: Nankai Trough Seafloor Observation Network for Earthquakes and Tsunamis

*Shin Aoi[1], Tetsuya Takeda[1], Takashi Kunugi[1], Kenji Uehira[1], Masanao Shinohara[1], Toshikazu Tanada[1], Shigeru Nagata[1], Takayuki Miyoshi[1], Narumi Takahashi[1] (1.National Research Institute for Earth Science and Disaster Resilience)

[HDS08-02] Probabilistic Tsunami Hazard Assessment for next Nankai Earthquake sequence

*Kenji Hirata[1], Hiroyuki Fujiwara[1], Hiromitsu Nakamura[1], Tsuneo Ohsumi[1], Nobuyuki Morikawa[1], Shinichi Kawai[1], Takahiro Maeda[1], DOHI YUJI1[1], Hisanori Matsuyama[2], Nobuhiko Toyama[2], Tadashi Kito[2], Kenshi Ohshima[2], Xuelei Zhang[2], Yasuhiro Murata[3], Ryu Saito[3], Tomoyuki Shibuki[3], Shin'ichi Akiyama[4], Mariko Korenaga[4], Yuta Abe[4], Teppei Ono[4] (1.National Research Institue for Earth Science and Diaster resilience, 2.OYO corporation, 3.KKC, 4.CTC)

[HDS08-03] **J-THIS** - a Public System for Sharing Information on Nationwide Probabilistic Tsunami Hazard Assessment in Japan -

*DOHI YUJI[1], Hiromitsu Nakamura[1], Hiroyuki Fujiwara[1], Tsuneo Ohsumi[1], Kenji Hirata[1], Shinichi Kawai[1], Nobuyuki Morikawa[1], Takahiro Maeda[1] (1.National Research Institute for Earth Science and Disaster Resilience)

[HDS08-04] Tsunami height variations due to stochastic self-similar slip distributions on a non-planar fault for megathrust earthquakes

*Masaru Nakano[1], Shane Murphy[2], Ryoichiro Agata[1], Yasuhiko Igarashi[3], Masato Okada[3], Takane Hori[1] (1.Japan Agency for Marine-Earth Science and Technology, 2.Ifremer, France, 3.Graduate School of Frontier Sciences, The University of Tokyo)

[HDS08-05] Tsunami synthetics using mechanic-based earthquake rupture scenarios

*Tatsuhiko Saito[1], Akemi Noda[1] (1.National Research Institute for Earth Science and Disaster Resilience)

[HDS08-06] Probabilistic tsunami hazard assessment for the Japan Sea region

*Iyan E. Mulia[1], Takeo Ishibe[2], Kenji Satake[1], Aditya Riadi Gusman[3] (1.Earthquake Research Institute, The University of Tokyo, 2.Association for the Development of Earthquake Prediction, 3.GNS Science)

[E] Oral | H (Human Geosciences)：H-DS Disaster geosciences

[H-DS08] Tsunami and tsunami forecast

convener:Hiroaki Tsushima(Meteorological Research Institute, Japan Meteorological Agency), Tatsuya Kubota(National Research Institute for Earth Science and Disaster Resilience)

[HDS08-07] Numerical simulation of debris avalanche and tsunami caused by the 2018 sector collapse of Anak Krakatau

*Hideaki Yanagisawa[1], Tatok Yatimantoro[2] (1.Department of regional Management, Faculty of Liberal Arts, Tohoku Gakuin University, 2.Indonesian Agency for Meteorology, Climatology and Geophysics)

[HDS08-08] **Tsunami hazards in East Indonesia: the case of 14 November 2019 Mw7.1 earthquake and tsunami in Molucca Sea, Indonesia**

*Mohammad Heidarzadeh[1], Takeo Ishibe[2], Tomoya Harada[3], Bayu Triyogo Widyantoro[4] (1.Brunel Univ. London, UK, 2.Association for the Development of Earthquake Prediction, Japan, 3.Univ. of Tokyo, Japan, 4.Indonesian Geospatial Information Agency, Indonesia)

[HDS08-09] *Augmenting GNSS and Teleseismic networks for improved tsunami early warning*

*Y Tony Song[1] (1.Jet Propulsion Laboratory)

[HDS08-10] Determination of Appropriate Source Models for Tsunami Forecasting: Application to Large Earthquakes in Central Sumatra, Indonesia

*Yuichiro Tanioka[1], Rinda Nita Ratnasari[1] (1.Hokkaido University, Institute of Seismology and Volcanology)

[HDS08-11] Tsunami analysis using the S-net pressure gauge records during the Mw 7.0 Off-Fukushima earthquake on 22 Novenver 2016 to reduce the effects of tsunami-irrelevant pressure components

*Tatsuya Kubota[1], Naotaka Yamamoto Chikasada[1], Hiroaki Tsushima[2], Wataru Suzuki[1], Takeshi Nakamura[1] (1.National Research Institute for Earth Science and Disaster Resilience, 2.Meteorological Research Institute)

[HDS08-12] Operational use of tsunami source inversion in near-field tsunami warning by JMA

*Hiroaki Tsushima[1], Takeyasu Yamamoto[2] (1.Japan Meteorological Agency, 2.Meteorological Research Institute, Japan Meteorological Agency)

[E] Oral | H (Human Geosciences)：H-DS Disaster geosciences

[H-DS08] Tsunami and tsunami forecast

convener:Hiroaki Tsushima(Meteorological Research Institute, Japan Meteorological Agency), Tatsuya Kubota(National Research Institute for Earth Science and Disaster Resilience)

[HDS08-13] Point-to-point Tsunami Ray Tracing Method

*Tungcheng Ho[1,2], Shingo Watada[2], Kenji Satake[2] (1.Disaster Prevention Research Institute, Kyoto University, 2.Earthquake Research Institute, the University of Tokyo)

[HDS08-15] Derivation of Time Difference Equation using Continuous Expression in Nonlinear Long Wave Equation and Evaluation of its Discretization Error

*Masaaki MINAMI[1], Takeyasu Yamamoto[1] (1.Meteorological Research Institute)

[HDS08-16] Estimating tsunami currents from shipborne Automatic Identification System data

*Daisuke Inazu[1], Tsuyoshi Ikeya[1], Toshio Iseki[1], Takuji Waseda[2] (1.Tokyo University of Marine Science and Technology, 2.The University of Tokyo)

[HDS08-18] Hydraulic experiments to investigate how vegetation coverage affects sediment transport during a tsunami

*Ako YAMAMOTO[1], Yuki Kanemaru[2], Ryunosuke Matsunaga[3], Takayuki Minamino[3], Tsuyoshi Tada[2], yo Fukutani[3], Yoshinori Shigihara[2] (1.Forest of Research and Management Organization Forestry and Forest Products Research Institute, 2.National Defense Academy, 3.Kanto Gakuin University)

[E] Oral | H (Human Geosciences)：H-DS Disaster geosciences

[H-DS09] Landslides and related phenomena

convener:Masahiro Chigira(Disaster Prevention Research Institute, Kyoto University), Fumitoshi Imaizumi(Faculty of Agriculture, Shizuoka University), Gonghui Wang(Disaster Prevention Research Institute, Kyoto University)

[HDS09-01] Examining the mobility of earthquake-induced landslides materials using small flume apparatus

*Rozaqqa Noviandi[1], Hefryan Sukma Kharismalatri[2], Takashi Gomi[3], Yoshiharu Ishikawa[3], Rasis Putra Ritonga[4] (1.Department of International Environmental and Agricultural Science, Tokyo University of Agriculture and Technology, Japan, 2.Institute of Global Innovation Research, Tokyo University of Agriculture and Technology, Japan, 3.Graduate School of Agriculture, Tokyo University of Agriculture and Technology, Japan, 4.United Graduate School of Agricultural Science, Tokyo University of Agriculture and Technology, Japan)

[HDS09-02] Seismic signal analysis of the 2011 landslide in Misakubo, Shizuoka prefecture and the potential for the real-time landslide detection

*Masumi Yamada[1], Ryo Okuwaki[2], Hikaru Osawa[2] (1.Disaster Prevention Research Institute, Kyoto University, 2.Mountain Science Center, Univ. of Tsukuba)

[HDS09-03] Steady-state shear resistance and viscosity of brittle dense grain flows appear to be independent of grain material and normal stress

★Invited Papers

*wei hu[1], Mauri McSaveney[2] (1.Chegndu University of Technology, 2.GNS Science, New Zealand)

[HDS09-04] A discussion on the characteristics of seismic signals of different landslide movement types by coupling PFC and FLAC codes

*Rui-Jia Zhuang[1], Zheng-yi Feng[1] (1.National Chung Hsing University Department of Soil and Water Conservation)

[HDS09-05] Tertiary Creep Behavior of Soils and Corresponding Power Law Singularity

*Chengrui Chang[1], Gonghui Wang[2] (1.Graduate School of Science, Kyoto University, 2.Disaster Prevention Research Institute, Kyoto University)

[E] Oral | H (Human Geosciences)：H-DS Disaster geosciences

[H-DS09] Landslides and related phenomena

convener:Masahiro Chigira(Disaster Prevention Research Institute, Kyoto University), Fumitoshi Imaizumi(Faculty of Agriculture, Shizuoka University), Gonghui Wang(Disaster Prevention Research Institute, Kyoto University)

[HDS09-06] Long-term rates of gravitational slope deformations on a low-angle fault that forms a dip slope in the Shimanto Belt, in the Kanto Mountains

Masakazu Mashiko[1], *Masahiro Chigira[1], Hirokazu Furuki[2], Takehiko Suzuki[3] (1.Disaster Prevention Research Institute, Kyoto University, 2.Nippon Koei Co. Ltd., 3.Tokyo Metropolitan University)

[HDS09-07] Hydrological and Seismic Observations at a Gravitationally Deformed Slope

*Noriyuki Arai[1], Masahiro Chigira[1], Issei Doi[1] (1.Disaster Prevention Research Institute,Kyoto University)

[HDS09-08] Post Deformation Characteristics of a Large-scale Slope in the Reservoir Area

*Yao Jiang[1], Shenghua Cui[2] (1.Institute of Mountain Hazards and Environment, Chinese Academy of Sciences, 2.State Key Laboratory of Geohazard Prevention and Geoenvironment Protection, Chengdu University of Technology, China)

[HDS09-09] Geological structural control on rock mass movement in response to fluvial incision along the plateau margin of Tibet

*Siyuan Zhao[1], Masahiro Chigira[2], Xiyong Wu[3] (1.College of Water Resources and Hydropower, Sichuan University, Chengdu 610065, Sichuan, China, 2.Disaster Prevention Research Institute, Kyoto University, Gokasho, Uji, Kyoto 611–0011, Japan, 3.Faculty of Geosciences and Environmental Engineering, Southwest Jiaotong University, Chengdu, 611756, China)

[HDS09-10] A field example of flexural toppling at Song-Mao Village in central Taiwan

*Ching-Ying Tsou[1], Osamu Yokoyama[2], Fumitoshi Imaizumi[3], Hsi-Hung Lin[4], Yu-Chung Hsieh[4], Mien-Ming Chen[4], Masahiro Chigira[5], Chun-Yi Wu[6], Su-Chin Chen[6] (1.Faculty of Agriculture and Life Science, Hirosaki University, 2.Japan Conservation Engineers Co., Ltd., 3.Faculty of Agriculture, Shizuoka University, 4.Central Geological Survey, Taiwan, 5.Disaster Prevention Research Institute, Kyoto University, 6.College of Agriculture and Natural Resources, National Chung Hsing University)

[HDS09-11] The role of faults for the formation of uphill-facing scarps

*Osamu Yokoyama[1], Masahiro Chigira[2], Ching-Ying Tsou[3] (1.Japan Conservation Engineers & Co., Ltd., 2.Disaster Prevention Research Institute, Kyoto University, 3.Faculty of Agriculture and Life Science, Hirosaki University)

[E] Oral | H (Human Geosciences)：H-DS Disaster geosciences

[H-DS09] Landslides and related phenomena

convener:Masahiro Chigira(Disaster Prevention Research Institute, Kyoto University), Fumitoshi Imaizumi(Faculty of Agriculture, Shizuoka University), Gonghui Wang(Disaster Prevention Research Institute, Kyoto University)

[HDS09-12] The 2016-17 landslide hazard in Siorapaluk and landsliding environment in NW Greenland

*Shintaro Yamasaki[1], Tastuya Watanabe[2], Shin Sugiyama[3] (1.Disaster Prevention Research Institute, Kyoto University, 2.Kitami Institute of Technology, 3.Institute of Low Temperature Science, Hokkaido University)

[HDS09-13] Landslides of altered rhyolite induced by the Heavy Rain Event of July 2018 in the south of Hiroshima Prefecture, Japan

*Yasuto Hirata[1] (1.Central Research Institute of Electric Power Industry)

[HDS09-14] **Characterization of rainfall events that triggered landslides in different regions in Japan**

*Slim Mtibaa[1], Haruka Tsunetaka[1] (1.Forestry and Forest Products Research Institute)

[HDS09-15] Landslides and driftwoods in headwater catchments: Supply, transport, and storage

*Takashi Gomi[1] (1.Tokyo University of Agriculture and Technology)

[HDS09-16] Temporal Changes in Landslide Frequency After Forest Harvesting in Ikawa, Central Japan

*Al Nuriza Rahmadania[1], Fumitoshi Imaizumi[2] (1.Graduate School of Integrated Science and Technology, Shizuoka University, 2.Faculty of Agriculture, Shizuoka University)

[HDS09-17] **Investigating the effect of forest stand age on slope stability in terms of root reinforcement in the Ikawa Artificial Forest, central Japan**

*Vany Fadhilah[1], Fumitoshi Imaizumi[2] (1.Graduate School of Integrated Science and Technology, Shizuoka University, 2.Faculty of Agriculture, Shizuoka University)

[E] Oral | H (Human Geosciences)：H-DS Disaster geosciences

[H-DS10] Natural hazard impacts on human society, economics and technological systems

convener:ELENA PETROVA(Lomonosov Moscow State University, Faculty of Geography), Hajime Matsushima(Research Faculty of Agriculture, Hokkaido University)

[HDS10-02] Lessons Learned from Wind Turbine Failures Caused by Natural Hazards

*Jui-Sheng Chou[1] (1.National Taiwan University of Science and Technology)

[HDS10-03] Impacts of the risk of chemical release from unregistered plant triggered by a future local earthquake in Osaka

*Takehisa Ishida[1], Lisa Ito[1], Akihiro Tokai[1] (1.Graduate School of Engineering, Osaka University)

[HDS10-04] Effects of abandoned paddy field use for the conservation of threatened hydrophyte after the 2011 Tohoku-oki tsunami.

★Invited Papers

*Korehisa Kaneko[1], Hiroshi Jinguji[2] (1.Hokuso Creature Association, 2.Miyagi University)

[HDS10-05] **The influence of the construction of the seawall on the on the coastal plant community in Sendai coast**

*XIANGMEI ZHONG[1], Hajime Matsushima[2], Akira Suzuki[3], Yoshihiko Hirabuki[4], Kouji Kimura[5] (1.Graduate school of Agriculture, Hokkaido University, 2.Research Faculty of Agriculture, Hokkaido University, 3.Kita-no-satohama Hana-no-kakehashi Network, 4.Faculty of Liberal Arts, Tohoku Gakuin University, 5.Snow Brand Seed Co., Ltd.)

[HDS10-06] Japanese coastal dune crisis and future prospects

*Hajime Matsushima[1] (1.Research Faculty of Agriculture, Hokkaido University)

[E] Oral | H (Human Geosciences)：H-DS Disaster geosciences

[H-DS11] Subaqueous Landslides and Their Anthropogenic Impact for Coastal Regions

convener:Yujin Kitamura(Department of Earth and Environmental Sciences, Graduate School of Science and Engineering, Kagoshima University), Kiichiro Kawamura(Yamaguchi University)

[HDS11-01] The progressive development of microfabrics from initial deposition to slump deformation on the Nankai prism

*Kiichiro Kawamura[1] (1.Yamaguchi University)

[HDS11-02] Structure of submarine mass-transport complexes(MTCs) southern Mt.Kaimon

*Hiroto Yamaguchi[1], Mamoru Sano[2], Satoshi Shimizu[2], Hikaru Iwamaru[2], Nobukazu Seama[1,2], Tetsuo Matsuno[1,2], Yoshiyuki Tatsumi[1,2] (1.Department of Planetology, Graduate School of Science, Kobe university, 2.Kobe Ocean-bottom Exploration Center)

[HDS11-03] On generation mechanism of the tsunami due to the 1923 Great Kanto Earthquake and bathymetric change in Sagami bay

*Kazuki Murata[1], Toshikazu Ebisuzaki[2], Shigenori Maruyama[2] (1.Port and Airport Research Institute, Japan, 2.RIKEN)

[HDS11-04] What "tsunami earthquake" is?

★Invited Papers

*Toshikazu Ebisuzaki[1] (1.RIKEN)

[HDS11-05] Tsunami modeling by marine landslides and reduction of disasters

★Invited Papers

*Yuichiro Tanioka[1], Hideaki Yanagisawa[2], Kei Ioki[3], Tatsuya Nakagaki[1] (1.Hokkaido University, Institute of Seismology and Volcanology, 2.Tohoku-Gakuin University, 3.National Institute of Advanced Industrial Science and Technology)

[HDS11-06] Submarine mass transport marked by mercury-bearing sediments and tephra in active fault zone, Yatsushiro sea, Japan

*Yujin Kitamura[1], Takashi Tomiyasu[1], Daigo Ito[2], Ryoga Kimura[2], Yuki Tamachi[2], Kuniyo Kawabata[3], Yuta Ikebata[4], Ryoya Goto[5], Koki Hori[4], Hakuho-maru KH-18-3 Scientists (1.Department of Earth and Environmental Sciences, Graduate School of Science and Engineering, Kagoshima University, 2.Department of Earth and Environmental Sciences, Faculty of Science, Kagoshima University, 3.Institute for Comprehensive Education, Kagoshima University, 4.Department of Earth and Planetary Sciences, Graduate School of Science, Kyushu University, 5.Graduate School of Frontier Sciences, The University of Tokyo)

[E] Oral | H (Human Geosciences)：H-TT Technology & Techniques

[H-TT14] Geographic Information Systems and Cartography

convener:Takashi Oguchi(Center for Spatial Information Science, The University of Tokyo), Yoshiki Wakabayashi(Graduate School of Urban Environmental Sciences, Tokyo Metropolitan University), Yuei-An Liou(National Central University), Ronald C. Estoque(National Institute for Environmental Studies, Japan)

[HTT14-01] **Analysis of the Land Surface Temperature Pattern in Kathmandu, Nepal, Using Remote Sensing and GIS.**

*Siri Karunaratne Batugoda Gedara[1], Morimoto - Takehiro[2], Yuji - Murayama[3] (1.Division of Spatial Information Science,Graduate School of Life and Environmental Sciences, University of Tsukuba, 2.Division of Spatial Information Science,Faculty of Life and Environmental Sciences, University of Tsukuba, 3.Division of Spatial Information Science,Faculty of Life and Environmental Sciences, University of Tsukuba)

[HTT14-02] Detecting Heat Spot within the City using Drones

★Invited Papers

*Kotaro Iizuka[1], Yuki Akiyama[1] (1.Center for Spatial Information Science, University of Tokyo)

[HTT14-03] **Landsat 8 data for soil salinity mapping in Tra Vinh Province, Mekong Delta, Vietnam**

★Invited Papers

*Kim-Anh Nguyen[1], Yuei-An Liou[1], Ha-Phuong Tran[2] (1.National Central University, 2.Ho Chi Minh City Institute of Resources Geography, VAST)

[HTT14-04] **Geospatial Approaches to Modell the Landslide Risk: A case study for Kegalle District-Sri Lanka**

★Invited Papers

*Elibichchiralalage Nimala Chinthake Perera[1], HMDS Wijenayaka[1], DSP Kuruppuarachchi[1] (1.Faculty of Management and Finance, SANASA CAMPUS, SRI LANKA)

[HTT14-05] Permafrost environment in Kongsfjord, Svalbard, from the viewpoint of topography and vegetation change

*Jaeyong Lee[1], Takashi Oguchi[2] (1.Department of Environmental Studies, Graduate School of Frontier Sciences, The University of Tokyo, 2.Center for Spatial Information Science, The University of Tokyo)

[HTT14-06] **Responses of suspended sediment yield to topography and land use in the Yellow River Basin, China**

*Ruiqi Zhang[1], Takashi Oguchi[2], Zhiguo Meng[3], Lele Hou[3] (1.The University of Tokyo, Graduate school of Frontier Sciences, 2.The University of Tokyo, Center for Spatial Information Science, 3.The University of Jilin, College of Geoexploration Science and Technology)

[E] Oral | H (Human Geosciences)：H-TT Technology & Techniques

[H-TT14] Geographic Information Systems and Cartography

convener:Takashi Oguchi(Center for Spatial Information Science, The University of Tokyo), Yoshiki Wakabayashi(Graduate School of Urban Environmental Sciences, Tokyo Metropolitan University), Yuei-An Liou(National Central University), Ronald C. Estoque(National Institute for Environmental Studies, Japan)

[HTT14-07] **A study on the selection process of tsunami evacuation sites using qualitative GIS approaches: the case of Ishinomaki city, Miyagi prefecture**

*Yuki Iwai[1,2] (1.Graduate School, University of Tsukuba, 2.JSPS Research Fellow)

[HTT14-08] **A Comparative Analysis of the Impacts of Various Natural Disasters on Human Mobility based on Geotagged Photos**

★Invited Papers

*Ahmed Derdouri[1], Toshihiro Osaragi[1], Takuya Oki[1] (1.School of Environment and Society, Tokyo Institute of Technology)

[HTT14-09] **Impact of Curriculum Design for Disaster Risk Reduction Education Using Web GIS Technology on Student Learning Effects in Secondary Schools**

*Jiali Song[1], Takashi Oguchi[1] (1.The University of Tokyo)

[HTT14-10] **Urban Expansion and Its Impact on the Urban Flood Disaster: A Case Study of Colombo Metropolitan Area, Sri Lanka**

*Ranagalage Mahinda Manjula[1], Yuji Murayama[1], Takehiro Morimoto[1] (1.Faculty of Life and Environmental Sciences, University of Tsukuba)

[HTT14-11] Changes in the landscape pattern of the Muthurajawela Marsh and Negombo Lagoon Sri Lanka: Socio-ecological implications

*SUMUDU DARSHANA ATHUKORALA ARACHCHIGE[1], Yuji Murayama[2], Bunkei Matsushita[2], Ronald C. Estoque[3] (1.Graduate School of Life and Environmental Sciences, University of Tsukuba, Japan, 2.Faculty of Life and Environmental Sciences, University of Tsukuba, Japan, 3.National Institute for Environmental Studies, Japan)

[HTT14-12] Relationships between the locations of ancient sites and topographic factors in Japan and China to explore interactions between human and nature

*Yuan Wang[1], Takashi Oguchi[1] (1.The University of Tokyo)

[E] Oral | H (Human Geosciences)：H-TT Technology & Techniques

[H-TT14] Geographic Information Systems and Cartography

convener:Takashi Oguchi(Center for Spatial Information Science, The University of Tokyo), Yoshiki Wakabayashi(Graduate School of Urban Environmental Sciences, Tokyo Metropolitan University), Yuei-An Liou(National Central University), Ronald C. Estoque(National Institute for Environmental Studies, Japan)

[HTT14-13] Potential influence of the use of sample survey data on spatial statistical analysis

★Invited Papers

*Ikuho Yamada[1] (1.Center for Spatial Information Science, University of Tokyo)

[HTT14-15] **Modeling and Mapping the Suitability of Parcel Pick-up Points using GIS-based Multivariate Binary Logistic Regression Model: A Case Study of Guangzhou City, China**

*ZILAI ZHENG[1], Takehiro Morimoto[2] (1.Graduate School of Life and Environmental Sciences, University of Tsukuba, 2.Faculty of Life and Environmental Sciences, University of Tsukuba)

[HTT14-16] **Simulating Land Use Change with Rapid Urbanization under the Natural and Anthropogenic Driving Forces**

*BINGYU WANG[1], Takashi Oguchi[1,2] (1.Department of Natural Environment Studies, The University of Tokyo, 2.Center for Spatial Information Science, The University of Tokyo, Japan)

[HTT14-17] Visualization of the supply-demand gap in childcare services in Tokyo

*Yoshiki Wakabayashi[1], Hitoshi Miyazawa[2] (1.Graduate School of Urban Environmental Sciences, Tokyo Metropolitan University, 2.Faculty of Letters and Education, Ochanomizu University)

[HTT14-18] **Comparative analysis of spatial patterns of tourists' behavior in Japanese cities using Online Geotagged Photographs**

*Bochra Bettaieb[1], Yoshiki Wakabayashi[1] (1.Tokyo Metropolitan University)

[E] Oral | H (Human Geosciences)：H-TT Technology & Techniques

[H-TT15] Environmental Remote Sensing

convener:Wei Yang(Chiba University), Akihiko Kondoh(Center for Environmental Remote Sensing, Chiba University), Carolynne Hultquist(Columbia University), Elena Sava(US Army Corps of Engineers Geospatial Research Laboratory), Guido Cervone(Pennsylvania State University Main Campus)

[HTT15-01] **Satellite-based Regional Scale Evapotranspiration Estimation Mapping**

*Manoj Hari[1], Bhishma Tyagi[1], Mohammad Sanaulla K. Huddar[2], Harish A.[3] (1.National Institute of Technology Rourkela, Odisha, India., 2.Indian Council of Agricultural Research, New Delhi, India., 3.Karaikal, Puducherry, India.)

[HTT15-02] Remote sensing of floating macroalgae in the coastal areas based on machine learning

*Zhaoxin Li[1], Zhongfeng Qiu[2], Wei Yang[1] (1.Chiba Univ., 2.NUIST)

[HTT15-03] Update of GCOM-C/SGLI Leaf Area Index & fraction of Absorbed Photosynthetically Active Radiation products

*Toshiyuki Kobayashi[1], Hideki Kobayashi[2], Wei Yang[3], Yoshiaki HONDA[3], Yuhsaku Ono, Shin Nagai[2], Tomoko Akitsu[4], Kenlo Nasahara[4], Masahiro Hori[1], Hiroshi Murakami[1] (1.Japan Aerospace Exploration Agency, 2.Japan Agency for Marine-Earth Science and Technology, 3.Chiba University, 4.University of Tsukuba)

[HTT15-04] **Comparison of five smoothing methods for noise removal in MODIS LAI time series data**

*Bageshree K[1], Tsuyoshi Kinouchi[1] (1.Tokyo Institute of Technology)

[HTT15-05] Mapping and comparing the geomorphological environments of designated conservation area and urban city in Majuro using drone data

*Benedict Yamamura[1,2], Hayate Kimura[1], Wataru Sano[1], Soko Hirabayashi[1], Yukihiko Imai[1], Kyotak Ishiguro[2], Hironobu Kan[1] (1.Kyushu University, Integrated Sciences for Global Society - Research Center for Coastal Seafloor , 2.Marshall Islands Marine Resources Authority)

[HTT15-06] Spatial Investigations of Surface Urban Heat Islands in 10 Chinese Metropolises: A Perspective from Land Cover/Use Composition

*Fei LIU[1] (1.University of Tsukuba)

[E] Oral | H (Human Geosciences)：H-TT Technology & Techniques

[H-TT15] Environmental Remote Sensing

convener:Wei Yang(Chiba University), Akihiko Kondoh(Center for Environmental Remote Sensing, Chiba University), Carolynne Hultquist(Columbia University), Elena Sava(US Army Corps of Engineers Geospatial Research Laboratory), Guido Cervone(Pennsylvania State University Main Campus)

[HTT15-07] Landscape changes in the Cordillera Real, Andes detected from satellite images

*YILIN HUANG[1] (1.Tokyo Institute of Technology)

[HTT15-08] **Assessment of local climate zones in Tokyo (Japan) and Lyon (France) using satellite and mobile measurements**

*Florent Renard[1,2], Lucille Alonso[1,2] (1.University of Lyon, France, 2.UMR CNRS Environment City Society)

[HTT15-09] **Deep learning for atmospheric duct estimation from radar sea clutter**

*Xiaofeng Zhao[1], Huadong Du[1], Zhixian Luo[1] (1.College of Meteorology and Oceanography, National University of Defense Technology)

[HTT15-10] Verification of forest cover changes in China using multiple satellites

*Takuto Taguchi[1], Kazuhito Ichii[1], Jingfeng Xiao[2] (1.Chiba University, 2.University of New Hampshire)

[HTT15-11] High-resolution aerosol remote sensing retrieval using Chinese High-Resolution Earth Observation Satellite I (GF-1) wide-field images (WFI) and MODIS surface products

*Fangwen Bao[1] (1.Center for Oceanic and Atmospheric Science at SUSTech (COAST), Department of Ocean Sciences and Engineering, Southern University of Science and Technology)

[HTT15-12] Toward operational satellite monitoring of chlorophyll-a concentrations in turbid inland waters

*Wei Yang[1], Bunkei Matsushita[2], Akihiko Kondoh[1] (1.Chiba University, 2.University of Tsukuba)

[E] Oral | H (Human Geosciences)：H-CG Complex & General

[H-CG21] International Comparison of Landscape Appreciation

convener:yoji aoki(Open University of Japan)

[HCG21-01] “The Original Landscape” of Niigata City in the Early Meiji Era (1876): from the Viewpoint of a Russian Geographer, *A. I. Voeikov*.

★Invited Papers

*Masahiro Nakatani[1] (1.none)

[HCG21-02] Recognition Structure about Japanese Garden Identity analyzed from the Incongruity Feelings of Overseas Japanese Gardens

★Invited Papers

*Liu Ming[1], Kazuhiko Nakamura[1] (1.Graduate School of Agricultural and Life Sciences, The University of Tokyo)

[HCG21-03] Perception Differences between Managers and Visitors on Landscape Changes in Urban Woodlands' Understory: A case in suburban Tokyo

*Bao Guo[1], Toru Terada[1] (1.Graduate School of Frontier Sciences, The University of Tokyo)

[HCG21-04] Consideration on the technique of landscape formation in Japanese garden

★Invited Papers

*Masayshi Kikuchi[1] (1.Tokyo Metropolitan Park Association)

[HCG21-05] **A Study on the Gugok Distribution as Current Status in Chungcheong-do and Jeolla-do Korea**

★Invited Papers

*HyunBin Park[1,2], KeeRae Kang[3], dongpil kim[1,2] (1.The Korean Institute of Landscape Architecture, 2. Dept. of Landscape Architecture, Pusan National University, 3.Institute of Comprehensive Bio industrial, Pusan National University)

[HCG21-06] Spatial conditions related to the sublimity of the shrine forest of Meiji Jingu :Landscape evaluation of the 100-years plan forest at 100 years after afforestation

*Yusuke Mizuuchi[1], Kazuhiko W. Nakamura[1], Katsunori Furuya[2] (1.Graduate School of Agricultural and Life Sciences, The University of Tokyo, 2.Graduate School of Horticulture, Chiba University)

[E] Oral | H (Human Geosciences)：H-CG Complex & General

[H-CG23] Earth surface processes related to deposition, erosion and sediment transport

convener:Koji Seike(Geological Survey of Japan, AIST), Masayuki Ikeda(University of Tokyo), Hideko Takayanagi(Institute of Geology and Paleontology, Graduate School of Science, Tohoku University), Hajime Naruse(Department of Geology and Mineralogy, Graduate School of Science, Kyoto University)

[HCG23-01] Formation of Large Blocked-Valley Lakes by Holocene Sea Level Rise: Poyang and Dongting Lakes, China

★Invited Papers

*Gary Parker[1], Chenge An[2], Li Zhang[2], Hongwei Fang[2], Xudong Fu[2] (1.University of Illinois at Urbana Champaign, 2.Tsinghua University)

[HCG23-02] Evolution of a Mixed Bedrock-Alluvial Canyon Incising into an Uplifting Plateau and Debouching into a Subsiding Valley: Linked Knickpoint Migration and Valley Fill

Li Zhang[1], *Gary Parker[2] (1.Tsinghua University, 2.University of Illinois Urbana-Champaign)

[HCG23-04] Detrital Zircon and Provenance Analysis of Sedimentary Rock in the Nemuro and Urahoro Groups, Eastern Hokkaido, Northern Japan.

*Harisma Harisma[1], Hajime Naruse[1] (1.Department of Geology and Mineralogy, Graduate School of Science, Kyoto University)

[E] Oral | H (Human Geosciences)：H-CG Complex & General

[H-CG23] Earth surface processes related to deposition, erosion and sediment transport

convener:Koji Seike(Geological Survey of Japan, AIST), Masayuki Ikeda(University of Tokyo), Hideko Takayanagi(Institute of Geology and Paleontology, Graduate School of Science, Tohoku University), Hajime Naruse(Department of Geology and Mineralogy, Graduate School of Science, Kyoto University)

[HCG23-05] **Spatio-temporal changes in sedimentation rate and its impact on overpressure evolution in offshore Suriname**

*Nifuku Ko[1], Yuki Kobayashi[1], Yasuhiko Araki[1], Takafumi Ashida[1], Takashi Taniwaki[1] (1.INPEX Corporation)

[HCG23-06] Spatial–temporal evolution of blowout on the southeastern fringe of Otindag sandy land in recent decade

*Rina Hu[1], eerdun Hasi[1], jie Yin[1] (1.Beijing Normal university)

[HCG23-07] Can Superoxide Nanobubbles Inhibit the Release of Phosphorus from Reservoir with Stagnant Water?

*Qingqing Sun[1], Siliang Li[1], Jingfu Wang[2], Pingping Yu[3] (1.Institute of Surface-Earth System Science, Tianjin University, 2.State Key Laboratory of Environmental Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, 3.Zunyi City Drainage Limited Liability Company)

[HCG23-08] Short to long term morphological changes and migration of sand waves in a semi-enclosed sea: a case study in Okinose area of Osaka Bay

Kojima Hibiki[1], *Atsushi Tani[1], Tetsuo Matsuno[2,3], Mamoru Sano[2], Nobukazu Seama[3,2], Noritaka Endo[4], Ken'ichi Ohkushi[1], Xu Zhang[5], Yusuke Uchiyama[5] (1.Graduate School of Human Development and Environment, Kobe University, 2.Kobe Ocean Bottom Exploration Center (KOBEC), Kobe University, 3.Graduate School of Science, Kobe University, 4.School of Geoscience and Civil Engineering College of Science and Engineering, Kanazawa University, 5.Graduate School of Engineering, Kobe University)

[HCG23-09] Heavy mineral assemblage of river sands along the Kaligandaki River, central Nepal and its application for Bengal Fan sediments

*Kohki Yoshida[1], Nakajima Toru[3], Lalit Kumar Rai[2], Asako Masuda[4] (1.Department of Geology, Faculty of Science, Shinshu University, 2.Graduate School of Medicine, Science and Technology, Shinshu University, 3.Graduate School of Science, Kyoto University, 4.Graduate School of Science and Technology, Shinshu University)

[HCG23-10] Spatial variability of grain size parameters and depositional process in the coastal marshland of Orissa, India

*Koushik Saha[1,2], Subhajit Sinha[1] (1.Department of Geology, University of Calcutta, 35 Ballygunge Circular Road, Kolkata-700019, India, 2.Department of Geology, University of North Bengal,Raja Rammohunpur, West Bengal 734014, India)

[E] Oral | H (Human Geosciences)：H-CG Complex & General

[H-CG24] Enhancing Integrated Research for Sustainable Future - a human geoscience perspective

convener:Yukio Himiyama(Emeritus Professor, Hokkaido University of Education), Takeshi Sakurai(Graduate School of Agricultural and Life Sciences, The University of Tokyo), Akihiko Kondoh(Center for Environmental Remote Sensing, Chiba University)

[HCG24-01] Enhancing Integrated Research for Sustainable Future - a human geoscience perspective

*Yukio Himiyama[1] (1.Emeritus Professor, Hokkaido University of Education)

[HCG24-02] Comprehensive research for land system science towards sustainable land management in Asia

*Okuro Toshiya[1] (1.Graduate School of Agricultural and Life Sciences, The University of Tokyo)

[HCG24-03] KLaSiCa Workshop to connect rural landscape in Asia through theater

*Ken-ichi Abe[1] (1.Research Institute for Humanity and Nature)

[HCG24-04] Do the Rich Suffer Less Damage from a Natural Hazard? A Case of the 2015 Nepal Earthquake

*Sato Takeshi[1], Santosh Rayamajhi[2], Tachibana Towa[3], Takeshi Sakurai[1] (1.Graduate School of Agricultural and Life Sciences, The University of Tokyo , 2.Institute of Forestry, Tribhuvan University, 3.Graduate School of Social Sciences, Chiba University)

[HCG24-05] **Assessment of regional eco-environmental vulnerabilities - - -A case study in Mongolia**

*Qinxue Wang[1] (1.National Institute for Environmental Studies)

[E] Oral | H (Human Geosciences)：H-CG Complex & General

[H-CG25] Turbidity current: generation, morphodynamics and deposits

convener:Hajime Naruse(Department of Geology and Mineralogy, Graduate School of Science, Kyoto University), Robert Michael Dorrell(University of Hull), Miwa Yokokawa(Osaka Institute of Technology)

[HCG25-01] Autogenic foreset-bottomset transition trajectory: Experiment and theory

*Wonsuck Kim[1,2], Haein Shin[1] (1.Yonsei Univ., 2.Univ. of Texas)

[HCG25-02] Submarine topographic control on the distribution of supercritical-flow deposits: insights from the Middle Eocene deep-marine system, Ainsa-Jaca basins, Spanish Pyrenees

*Pauline H Cornard[1], Kevin Pickering[1] (1.University College London)

[HCG25-03] Flume experiments for Froude supercritical flow submarine fan: morphology and grain size distribution

*Kenya Ono[1], Hajime Naruse[2], Kazuki Kikuchi[2], Qifeng Yao[2], Zhirong Cai[2], Shunsuke Watanuki[1], Koji Ohata[2], Sojiro Fukuda[2,3], Kazushi Nakata[2], Miwa Yokokawa[4] (1.INPEX Corporation, 2.Kyoto University, 3.University of Hull, 4.Osaka Institute of Technology)

[HCG25-04] The scales and profiles of submarine cyclic steps

*Zhuyuan Wu[1], Norihiro Izumi[1] (1.Hokkaido University)

[HCG25-05] **The interplay of turbidity and contour currents: its representative products, flow dynamics, and significance**

★Invited Papers

*Chenglin Gong[1,2], Yingmin Wang[1,2], Ronald J. Steel[3], Michele Rebesco[4], Stefano Salon[4] (1.State Key Laboratory of Petroleum Resources and Prospecting (China University of Petroleum, Beijing), Beijing 102249, China, 2.College of Geosciences, China University of Petroleum (Beijing), Changping, Beijing, 102249, China, 3.Department of Geological Sciences, Jackson School of Geosciences, The University of Texas, Austin, Texas78712, USA, 4.Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS), Borgo Grotta Gigante 42/C, 34010 Sgonico, Trieste, Italy)

[E] Oral | H (Human Geosciences)：H-CG Complex & General

[H-CG25] Turbidity current: generation, morphodynamics and deposits

convener:Hajime Naruse(Department of Geology and Mineralogy, Graduate School of Science, Kyoto University), Robert Michael Dorrell(University of Hull), Miwa Yokokawa(Osaka Institute of Technology)

[HCG25-06] Critical Transitions in Particulate Density Currents

★Invited Papers

*Benjamin Charles Kneller

[HCG25-07] **Laminar-turbulent transition in saturated granular free-surface flow**

*Sakai Yuichi[1], Norifumi Hotta[1] (1.Graduate School of Agricultural and Life Sciences, The University of Tokyo)

[HCG25-08] Statistical Analyses of Vertical Flow Profile show Turbidity Currents and Open-Channel Flow are Fundamentally Different

*Sojiro Fukuda[1], Elena Bastianon[2], Bill McCaffrey[3], Hajime Naruse[4], Robert Michael Dorrell[1] (1.Center for Environmental Fluid Dynamics, University of Hull, UK, 2.Energy and Environment Institute, University of Hull, UK, 3.Institute of Applied Geoscience, School of Earth and Environment, University of Leeds, 4.Department of Geology and Mineralogy, Graduate School of Science, Kyoto University, Japan)

[HCG25-09] Quantifying suspended sediment dynamics in a large-scale turbidity currents: Direct measurements from full scale flows

★Invited Papers

*Daniel R Parsons[1] (1.University of Hull, UK)

[E] Oral | S (Solid Earth Sciences)：S-GD Geodesy

[S-GD01] Geodetic Infrastructure for Monitoring the Dynamic Earth: The Global Geodetic Observing System

convener:Basara Miyahara(GSI of Japan), Richard S Gross(NASA Jet Propulsion Laboratory)

[SGD01-01] The Global Geodetic Observing System

*Basara Miyahara[1] (1.GSI of Japan)

[SGD01-03] GGOS External Relations Update: Using United Nations Frameworks to Promote International Cooperation and Geodetic Capacity Building in support of Disaster Risk Reduction and Resiliency

★Invited Papers

*Allison Craddock[1], John Labrecque[2], John Rundle[3], Basara Miyahara[4] (1.NASA Jet Propulsion Laboratory, California Institute of Technology, USA, 2.University of Texas, Center for Space Research, USA, 3.University of California, Departments of Physics and Earth & Planetary Science, USA, 4.Geospatial Information Authority of Japan, Japan)

[SGD01-04] **GGOS Bureau of Networks and Observations: Network Infrastructure and Related Activities**

*Michael R Pearlman[1], Carey E Noll[2], Dirk Behrend[3], Allison Craddock[4], Erricos Pavlis[5], Jérôme Saunier[6], Elizabeth Bradshaw[7], Riccardo Barzaghi[8], Daniela Thaller[9], Benjamin Maennel[10], Ryan Hippenstiel Hippenstiel[11], Roland Pail[12], Nicholas Brown[13] (1.Center for Astrophysics, Cambridge MA, United States, 2.NASA Goddard Space Flight Center, Code 61A, Greenbelt MD, United States, 3.NVI, Inc./NASA Goddard Space Flight Center, Greenbelt MD, United States, 4.Jet Propulsion Laboratory/California Institute of Technology, Pasadena, CA, United States, 5.University of Maryland, Baltimore MD, United States, 6.Institut Géographique National, St. Mande, France , 7.National Oceanography Centre, Liverpool, United Kingdom, 8.Politecnico di Milano, Milan, Italy, 9.Bundesamt fuer Kartographie und Geodaesie, Frankfurt, Germany, 10.GeoForschungsZentrum, Potsdam, Germany, 11.National Geodetic Survey, Silver Spring, MD, United States, 12.Technische Universitaet Muenchen, Munich, Germany, 13.Geoscience Australia, Canberra, Australia)

[SGD01-05] Activities of WG on DOIs in GGOS and Data DOI WG in GGOS Japan

★Invited Papers

*Yusuke Yokota[1], Basara Miyahara[3], Toshimichi Otsubo[4], Yasuhiro Murayama[5], Hiroshi Munekane[3], Tadashi Ishikawa[2] (1.Institute of Industrial Science, The University of Tokyo, 2.Hydrographic and Oceanographic Department, Japan Coast Guard, 3.Geospatial Information Authority of Japan, 4.Hitotsubashi University, 5.National Institute of Information and Communications Technology)

[SGD01-06] GGOS Japan's roles and activities as a GGOS Affiliate

*Toshimichi Otsubo[1], Basara Miyahara[2], Yusuke Yokota[3], Shinobu Kurihara[2] (1.Hitotsubashi University, 2.Geospatial Information Authority of Japan, 3.Institute of Industrial Science, the University of Tokyo)

[E] Oral | S (Solid Earth Sciences)：S-GD Geodesy

[S-GD01] Geodetic Infrastructure for Monitoring the Dynamic Earth: The Global Geodetic Observing System

convener:Basara Miyahara(GSI of Japan), Richard S Gross(NASA Jet Propulsion Laboratory)

[SGD01-08] The Next Generation Lunar Retroreflector and Lunar Laser Ranging

*Douglas G Currie[1], Dennis Wellnitz[1], Chensheng Wu[1], Giovanni Delle Monache[2], Simone Dell'Agnello[2], Bradford Behr[1] (1.University of Maryland, College Park, 2.INFN-LNF, Frascati, Italy)

[SGD01-09] Determination of geopotential value over Japan for contribution to the International Height Reference Frame

*Koji Matsuo[1] (1.GSI of Japan)

[SGD01-11] Integrated Space Geodetic Study of the 2019 Typhoon Hagibis: Signatures in Troposphere, Lithosphere, and Ionosphere

★Invited Papers

*Kosuke Heki[1], Wei Zhan[2], Syachrul Arief[1] (1.Department of Earth and Planetary Sciences, Faculty of Science, Hokkaido University, 2.The First Monitoring and Application Center, China Earthquake Administration, Tianjin, China)

[SGD01-12] Accuracy evaluation of a crustal deformation model with velocity in terms of maintaining the Japanese geodetic datum

*Yu Takagi[1], Kensuke Kokado[1], Yasuhiro Koso[1], Hiromi Yamao[1], Takashi Tsutsumi[1], Masao Iwata[1] (1.GSI of Japan)

[E] Oral | S (Solid Earth Sciences)：S-SS Seismology

[S-SS03] Seismological advances in the ocean

convener:Takashi Tonegawa(Research and Development center for Earthquake and Tsunami, Japan Agency for Marine-Earth Science and Technology), Takeshi Akuhara(Earthquake Research Institute, University of Tokyo), Pascal Audet(University of Ottawa), Taka'aki Taira(Berkeley Seismological Laboratory, University of California, Berkeley)

[SSS03-01] Millimeter-scale tsunami of an M6 earthquake observed by the nearest-field pressure gauge array: a fault modeling and stress drop estimation

★Invited Papers

*Tatsuya Kubota[1], Tatsuhiko Saito[1], Wataru Suzuki[1] (1.National Research Institute for Earth Science and Disaster Resilience)

[SSS03-02] Seismic velocity structure along the Japan trench inferred from ambient noise and teleseismic surface waves observed by S-net

*Ryota Takagi[1], Akira Ishigami[1], Genti Toyokuni[1], Ryosuke Azuma[1], Mare Yamamoto[1] (1.Research Center for Prediction of Earthquakes and Volcanic Eruptions, Graduate School of Science, Tohoku University)

[SSS03-03] Seismic ambient noise interferometry applied to dense OBS array of off Ibaraki region

*Lina Yamaya[1], Kimihiro Mochizuki[1], Takeshi Akuhara[1], Kiwamu Nishida[1], Tsuyoshi Ichimura[1], Kohei Fujita[1], Takuma Yamaguchi[1], Takane Hori[2] (1.Earthquake Research Institute, University of Tokyo, 2.Japan Agency for Marine-Earth Science and Technology)

[SSS03-04] Lithospheric structure beneath the extinct Mid-Ocean-Ridge in South China Sea: Constraints from passive-source OBS data

*Ting Yang[1], Ba Manh Le[1], Chenguang Liu[3], Mei Xue[2] (1.Southern University of Science and Technology, 2.Tongji University, 3.First institute of oceanography, MNR, China)

[SSS03-05] Development of seismic inversion tool for flat and isotropic layered structures in the ocean (SEIS-FILO)

*Takeshi Akuhara[1] (1.Earthquake Research Institute, The University of Tokyo)

[SSS03-06] Inverting OBS compliance signals for oceanic crust and sediment velocity structure using mixture density neural networks

*Stephen Glenn Mosher[1], Zach Eilon[2], Pascal Audet[1] (1.University of Ottawa, 2.University of California Santa Barbara)

[E] Oral | S (Solid Earth Sciences)：S-SS Seismology

[S-SS03] Seismological advances in the ocean

convener:Takashi Tonegawa(Research and Development center for Earthquake and Tsunami, Japan Agency for Marine-Earth Science and Technology), Takeshi Akuhara(Earthquake Research Institute, University of Tokyo), Pascal Audet(University of Ottawa), Taka'aki Taira(Berkeley Seismological Laboratory, University of California, Berkeley)

[SSS03-07] Seafloor seismology with Distributed Acoustic Sensing in Monterey Bay

★Invited Papers

*Nate Lindsey[1,2], Jonathan Ajo-franklin[4,2], T. Craig Dawe[3], Lise Retailleau[1], Biondo Biondi[1], Lucia Gualtieri[1] (1.Stanford University, 2.Lawrence Berkeley National Laboratory, 3.Monterey Bay Aquarium Research Institute, 4.Rice University)

[SSS03-08] Marine seismic observation by Distributed Acoustic Sensing using seafloor cable off Sanriku for long-term monitoring

*Masanao Shinohara[1], Tomoaki Yamada[1], Takeshi Akuhara[1], Kimihiro Mochizuki[1], Takeo Kasajima[2], Takahiro Arioka[2], Masayuki Hamakawa[3], Shunsuke Kubota[4] (1.Earthquake Research Institute, University of Tokyo, 2.Fujitsu Laboratories Ltd., 3.Fujitsu Limited, 4.YK Giken Co., Ltd.)

[SSS03-09] Strain release by “rapid” aseismic slip at the Izu-Bonin trench

*Yoshio Fukao[1], Hiroko Sugioka[5], Aki Ito[1], Takashi Tonegawa[1], Mikiya Yamashita[4], Hajime Shiobara[2], Tatsuya Kubota[3], Tatsuhiko Saito[3] (1.Japan Agency for Marine-Earth Science & Technology, 2.University of Tokyo, 3.National Research Institute of Earth Science and Disaster Resillence , 4.National Institute of Advanced Industrial Science and Technology, 5.Kobe University)

[SSS03-10] Glacier tremors revealed by Ocean Bottom Seismometer in Greenland

*Evgeny A. Podolskiy[1], Yoshio Murai[2], Naoya Kanna[1], Shin Sugiyama[3] (1.Arctic Research Center, Hokkaido University, 2.Institute of Seismology and Volcanology, Hokkaido University, 3.Institute of Low Temperature Science, Hokkaido University)

[SSS03-11] Distribution of long period seismic "hum" sources following large storms in the north Pacific and their relation to infragravity waves

Satish Maurya[1,2], *Taka'aki Taira[1], Barbara Romanowicz[1,3] (1.Berkeley Seismological Laboratory, University of California, Berkeley, 2.Department of Earth Sciences, Indian Institute of Technology Bombay, 3.Collège de France, Paris)

[SSS03-12] Ambient noise field and temporal changes on ambient noise auto/cross-correlogram at the sea bottom inferred from ocean-bottom seismic and pressure arrays

*Yoshihiro Ito[1], Miyuu Uemura[1], Spahr C. Webb[2], Kimihiro Mochizuki[3], Stuart Henrys[4] (1.Disaster Prevention Research Institute, Kyoto University, 2.Lamont Doherty Earth Observatory, Columbia University, 3.Earthquake Research Institute, The University of Tokyo, 4.GNS Science)

[E] Oral | S (Solid Earth Sciences)：S-SS Seismology

[S-SS04] Strong Ground Motion and Earthquake Disaster

convener:Kazuhiro Somei(Geo-Research Institute), Yasuhiro Matsumoto(Kozo Keikaku Engineering)

[SSS04-01] Separation of High-frequency Source and Path Effects from South Africa Mine Data

*James Mori[1], Hiroshi Ogasawara[2] (1.Earthquake Hazards Division, Disaster Prevention Research Institute, Kyoto University, 2.Faculty of Science and Engineering, Ritsumeikan University)

[SSS04-02] Site effects at strong motion stations in Shizuoka prefecture, Japan, and its application for validating the underground velocity model

*Tomotaka Iwata[1], Hayato Shimazu[2], Kimiyuki Asano[1], Kazuhiro Somei[3], Shigeki Senna[4] (1.Disaster Prevention Research Institute, Kyoto University, 2.Graduate School of Science, Kyoto University, 3.Geo-Research Institute, 4.National Research Institute for Earth Science and Disaster Resilience)

[SSS04-03] Small-aperture Microtremor Array Surveys in the Southern Part of the Kyoto Basin and Northern Part of the Nara Basin, Japan

*Kimiyuki Asano[1], Tomotaka Iwata[1], Haruko Sekiguchi[1] (1.Disaster Prevention Research Institute, Kyoto University)

[SSS04-04] Microtremor observation in the tsunami inundation predicted area in Hokuriku Region: Preliminary resutls from observed data in Suzu city, Ishikawa prefecture

*Michihiro Ohori[1] (1.Research Institute of Nuclear Engineering, University of Fukui)

[SSS04-05] Subsurface velocity structure of Saga Plain and Shiroishi Plain, Kyushu, Japan, estimated by microtremor array survey

*Masayuki Yoshimi[1], Michiko Shigefuji[2], Tatsuo Kanno[2], Ryosuke Noma[2], Hiro Nimiya[1] (1.Geological Survey of Japan, AIST, 2.Faculty of Human-Environment Studies, Kyushu University)

[E] Oral | S (Solid Earth Sciences)：S-SS Seismology

[S-SS04] Strong Ground Motion and Earthquake Disaster

convener:Kazuhiro Somei(Geo-Research Institute), Yasuhiro Matsumoto(Kozo Keikaku Engineering)

[SSS04-06] Estimation of shallow 3D S-wave velocity structure by applying surface-wave tomography using MeSO-net

*Hiro Nimiya[1,2], Tatsunori Ikeda[2], Takeshi Tsuji[2] (1.National Institute of Advanced Industrial Science and Technology, 2.Kyushu University)

[SSS04-07] Comparison of subsurface models derived from different physical quantities in the inversion based on microtremors and earthquake motions

*Kentaro Motoki[1], Kenichi Kato[1] (1.Kobori Research Complex)

[SSS04-08] Impact of Seismic Velocity Change on Ground Motion Modeling

*Hiroe Miyake[1], Taka'aki Taira[2], Li-Wei Chen[2] (1.Earthquake Research Institute, University of Tokyo, 2.Berkeley Seismological Laboratory, University of California, Berkeley)

[SSS04-09] Validation of S-wave velocity structure of sedimentary layers of the Kanto basin using strong motion records applied to seismic interferometry

*Kosuke Chimoto[1], Hiroaki Yamanaka[1] (1.Tokyo Institute of Technology)

[SSS04-10] Comparison of PGA and PGV at the S-net and land stations for the 2016 Mw7 off Fukushima earthquake

*Yadab Prasad Dhakal[1], Wataru Suzuki[1], Takashi Kunugi[1], Takeshi Kimura[1], Shin Aoi[1] (1.National Research Institute for Earth Science and Disaster Resilience (NIED))

[E] Oral | S (Solid Earth Sciences)：S-SS Seismology

[S-SS04] Strong Ground Motion and Earthquake Disaster

convener:Kazuhiro Somei(Geo-Research Institute), Yasuhiro Matsumoto(Kozo Keikaku Engineering)

[SSS04-11] Source scaling and stress drop for the 2018 Hokkaido Eastern Iburi earthquake sequence estimated by the S-wave coda spectral ratio method

*Kazuhiro Somei[1], Kimiyuki Asano[2], Tomotaka Iwata[2], Ken Miyakoshi[1], Takashi Akazawa[1] (1.Geo-Research Institute, 2.Disaster Prevention Research Institute, Kyoto University)

[SSS04-12] Estimation of the strong motion generation area (SMGA) during the 2018 Hokkaido eastern Iburi earthquake

*Susumu Kurahashi[1], Kojiro Irikura[1] (1.Aichi Institute of Technology)

[SSS04-13] Strong ground motions from deep earthquakes in Hokkaido and attenuation structure of island arc

*Yasumaro Kakehi[1] (1.Graduate School of Science, Kobe University)

[SSS04-14] Simulation of near-fault ground motion for the 2016 Kumamoto earthquake (Mj7.3) considering the surface rupture geometry

*Asako Iwaki[1], Nobuyuki Morikawa[1], Hiroyuki Fujiwara[1], Takashi Kumamoto[2], Yurie Okuma[2], Hinata Kimura[3] (1.National Research Institute for Earth Science and Disaster Prevention, 2.Faculty of Science, Okayama University, 3.Graduate School of Environmental Studies, Nagoya University)

[SSS04-15] Modeling procedure of fault rupturing with detailed information of surface traces for predicting strong motions and permanent displacements

*Kazuo Dan[1], Saruul Dorjpalam[1], Atsuko Oana[2], Kensuke Arai[2], Hiroyuki Fujiwara[3], Nobuyuki Morikawa[3] (1.Ohsaki Research Institute, Inc., 2.Shimizu Corporation, 3.National Research Institute for Earth Science and Disaster Resilience)

[SSS04-16] Waveform inversion with empirical Green's functions for the source rupture process of the mainshock of the 2019 Ridgecrest earthquake sequence

*SHUANGLAN WU[1], Atsushi Nozu[1], Yosuke Nagasaka[1] (1.PORT AND AIRPORT RESEARCH INSTITUTE)

[E] Oral | S (Solid Earth Sciences)：S-SS Seismology

[S-SS04] Strong Ground Motion and Earthquake Disaster

convener:Kazuhiro Somei(Geo-Research Institute), Yasuhiro Matsumoto(Kozo Keikaku Engineering)

[SSS04-17] A point source model considering the directivity effect

*Yosuke Nagasaka[1], Atsushi Nozu[1] (1.Port and Airport Research Institute)

[SSS04-18] Supplementing Vs30 and Z1.0 with H/V Fourier Spectral Ratios and Spatial Correlation for Predicting Site Effect

*Shu-Hsien Chao[1], Che-Min Lin[1], Chun-Hsiang Kuo[1], Jyun-Yan Huang[1] (1.National Center for Research on Earthquake Engineering)

[E] Oral | S (Solid Earth Sciences)：S-SS Seismology

[S-SS05] Innovative data analysis methods for characterization of seismicity

convener:Francesco Grigoli(ETH Zurich Swiss Federal Institute of Technology Zurich), Bogdan Enescu(Department of Geophysics, Kyoto University), Aitaro Kato(Earthquake Research Institute, the University of Tokyo), Yosuke Aoki(Earthquake Research Institute, University of Tokyo)

[SSS05-01] Deep Learning for Earthquake Monitoring

★Invited Papers

*Weiqiang Zhu[1], S. Mostafa Mousavi[1], Kai Sheng Tai[2], Yongsoo Park[1], Yen Joe Tan[1], William Ellsworth[1], Gregory C. Beroza[1] (1.Department of Geophysics, Stanford University, 2.Computer Science Department, Stanford University)

[SSS05-02] Deep Learning (& classification models) performance in aftershock prediction

★Invited Papers

*Marco Broccardo[1,2], Arnaud Mignan[2,3] (1.Institute of Risk and Uncertainty, University of Liverpool , 2.Swiss Seismological Service, ETH Zürich, Switzerland, 3.Institute of Risk Analysis, Prediction and Management, Academy for Advanced Interdisciplinary Studies, Southern University of Science and Technology, Shenzhen, China)

[SSS05-03] Statistical learning and denoising for multivariate seismic data streams

*Andrey Lokhov[1] (1.Los Alamos National Laboratory)

[SSS05-04] Testing foreshock hypothesis against the ETAS model: why is it so difficult?

*Jiancang Zhuang[1] (1.Institute of Statistical Mathematics)

[SSS05-05] Analyses of the temporal change in size distribution of the earthquakes without using “moving window”

*Kohei Nagata[1] (1.Meteorological Research Institute)

[E] Oral | S (Solid Earth Sciences)：S-SS Seismology

[S-SS07] Earthquake prediction and forecast+pre-earthquake geoscientific changes(TBD)

convener:Masayuki Obayashi(Japan Agency for Marine-Earth Science and Technology), Toshitaka Baba(Graduate School of Science and Technology, Tokushima University), Chi-Yu King(Retired)

[SSS07-01] Hydrological earthquake precursors caused by slow-slip events

★Invited Papers

*Chi-Yu King[1], Chi-Yu King[1] (1.Retired)

[SSS07-02] Crustal deformations precursory to the Tohoku M9 earthquake and tsunami

*Fumihide Takeda[1,2] (1.Takeda Eng Consultant Co., 2.Earthquake Prediction Inst.)

[SSS07-03] **Nowcasting Earthquakes in Sulawesi Island, Indonesia**

*Sumanta Pasari[1], Andrean VH Simanjuntak[2] (1.Birla Institute of Technology and Science Pilani, 2.Indonesian Agency for Meteorology, Climatology and Geophysics)

[SSS07-04] Dilation of a sheared granular model experiment of earthquake to serve as a possible precursor

*Victor Simon Levy dit Vehel[1], Florine Dubourg, Loic Vanel[1], Knut Jørgen Måløy[2], Osvanny Ramos[1] (1.Institut Lumiere Matiere Lyon 1, 2.University of Oslo)

[SSS07-05] **A Mechanochemical Model of Stress-induced Charges for Generating the Electromagnetic Precursors of Earthquakes**

*Jeen-Hwa Wang[1] (1.Academia Sinica)

[SSS07-06] Likelihood model of crustal earthquakes in southwest Japan using GNSS strain rate data

*Takuya NISHIMURA[1] (1.Disaster Prevention Research Institute, Kyoto University)

[E] Oral | S (Solid Earth Sciences)：S-SS Seismology

[S-SS08] Statistical seismology and underlying physical processes

convener:Yasuhiro Yoshida(Meteorological College, Japan Meteorological Agency)

[SSS08-01] Stress state of the Earth's crust in the Korean Peninsula with reference to Japanese islands: Implication of weak faults

*Yasuto Kuwahara[1], Jin-Hyuck Choi[1], Youngbeom Cheon[1], Kazutoshi Imanishi[2] (1.Korea Institute of Geoscience and Mineral Resources, 2.Geological Survey of Japan, AIST)

[SSS08-02] **Effect of seasonal snow load on earthquake occurrence in the Pamir Mountains**

*Muhammad Usman[1,2], Kosuke Heki[2], Sigurjon Jonsson[1] (1.Department of Physical Sci. and Engineering, King Abdullah Univ. of Sci. and Tech., Thowal, Saudi Arabia, 2.Department of Natural History Sci., Hokkaido Univ. Sapporo, Japan)

[SSS08-03] The diversity of similar earthquakes in subduction zone

*Ayako Tsuchiyama[1], Junichi Nakajima[1] (1.Earth and Planetary Sciences, Tokyo Institute of Technology)

[SSS08-04] **Spatio-temporal clustering of successive earthquakes in Japan: analyses of F-net catalogue**

*Thystere Matondo Bantidi[1], Takeshi Nishimura[1] (1.Tohoku Univesity)

[SSS08-05] Foreshock Cascade to Failure in the M 6.4 July 4, 2019 Ridgecrest, California Earthquake

*William L Ellsworth[1], Andrew J Barbour[2], David R Shelly[2] (1.Stanford University, 2.U. S. Geological Survey)

[SSS08-06] Changes in stress state associated with the 2019 Ridgecrest, California, earthquakes

*Kazuyoshi Nanjo[1] (1.University of Shizuoka)

[E] Oral | S (Solid Earth Sciences)：S-SS Seismology

[S-SS09] INDUCED AND TRIGGERED SEISMICITY: CASE STUDIES, MONITORING AND MODELING TECHNIQUES

convener:Luca Urpi, Yusuke Mukuhira(Institute of Fluid Science, Tohoku University), Bogdan Enescu(Department of Geophysics, Kyoto University), Francesco Grigoli(ETH Zurich Swiss Federal Institute of Technology Zurich)

[SSS09-01] Value at Induced Risk: Managing injection-induced seismic risks based on low-probability, high-impact events

★Invited Papers

*William L Ellsworth[1], Cornelius Langenbruch[2], Jeong-Ung Woo[3], David J Wald[4] (1.Stanford University, 2.Risk Management Solutions, 3.Seoul National University, 4.U. S. Geological Survey)

[SSS09-02] Large-scale response of injection-induced seismicity modulated by geomechanics

*Matthew Weingarten[1] (1.San Diego State University)

[SSS09-03] Fast-linearized methods for hypocentre location, magnitude estimation and site amplification effects of seismic events induced in conventional and unconventional gas fields

*Germán Rodríguez-Pradilla[1,2] (1.Department of Geoscience, University of Calgary, 2.School of Earth Sciences, University of Bristol)

[SSS09-04] Seismicity induced by the Hutubi Underground Gas Storage Facility

*Hongfeng Yang[1], Pengcheng Zhou[1], Guoyan Jiang[1], Baoshan Wang[2], Jiancang Zhuang[3] (1.The Chinese University of Hong Kong, 2.University of Science and Technology of China, 3.Institute of Statistical Mathematics)

[SSS09-05] Detection and location of seismic events in continuous data of sparse monitoring network of an abandoned flooded mine

*Dalija Namjesnik[1,2], Jannes Kinscher[1], Yann Gunzburger[2], Pascal Dominique[3], Pascal Bernard[4], Isabelle Contrucci[1], Natalia Poiata[4,5], Emmanuelle Klein[1] (1.Ineris, Institut national de l'environnement industriel et des risques, France , 2.University of Lorraine, France, 3.BRGM, Bureau de recherches géologiques et minières, France, 4.IPGP, Institut de Physique du Globe de Paris, France, 5.National Institute for Earth Physics, Romania)

[E] Oral | S (Solid Earth Sciences)：S-SS Seismology

[S-SS09] INDUCED AND TRIGGERED SEISMICITY: CASE STUDIES, MONITORING AND MODELING TECHNIQUES

convener:Luca Urpi, Yusuke Mukuhira(Institute of Fluid Science, Tohoku University), Bogdan Enescu(Department of Geophysics, Kyoto University), Francesco Grigoli(ETH Zurich Swiss Federal Institute of Technology Zurich)

[SSS09-06] Monitoring anthropogenic seismicity in Italy

★Invited Papers

*Thomas Braun[1], Stefania Danesi[1], Daniela Famiani[1], Andrea Morelli[1] (1.Istituto Nazionale di Geofisica e Vulcanologia (INGV))

[SSS09-07] Examination of the finite fault model for the M_W 5.5 2017 Pohang earthquake with multi-segmented fault system

*Jeong-Ung Woo[1], Junkee Rhie[1], Eunbyeol Cho[1] (1.Seoul National University)

[SSS09-08] Revisiting triggering intensity of earthquakes in southern California using resent seismic catalogs from 2008 to 2017

*Masatoshi Miyazawa[1], Emily E Brodsky[2], Huiyun Guo[2] (1.Disaster Prevention Research Institute, Kyoto University, 2.Department of Earth & Planetary Sciences, University of California Santa Cruz)

[SSS09-09] Effective medium approach for analysis of natural fracture activation trends during hydraulic fracturing

*Nikita Dubinya[1,2], Maria Trimonova[3], Victor Nachev[1,3] (1.Moscow Institute of Physics and Technology, 2.Schmidt Institute of Physics of the Earth of the Russian Academy of Sciences, 3.Sadovsky Institute of Geospheres Dynamics of the Russian Academy of Sciences)

[E] Oral | S (Solid Earth Sciences)：S-EM Earth's Electromagnetism

[S-EM18] Paleomagnetism and rock magnetism applied to solving geological and geophysical problems

convener:Martin Chadima(Institute of Geology of the Czech Academy of Sciences), Balazs Bradak(University of Burgos, Spain), Daniel Pastor-Galan(Center for North East Asian Studies, Tohoku University), Myriam Annie Claire Kars(Center for Advanced Marine Core Research)

[SEM18-01] Implications of new Paleocene paleomagnetic data from SW Japan for the mode of early opening of the Japan Sea

★Invited Papers

*Hiroyuki Hoshi[1] (1.Department of Earth Sciences, Aichi University of Education)

[SEM18-02] **Paleomagnetic and paleointensity results from a Pliocene lava flow sequence including a transitional field record**

*Manuel Calvo-Rathert[1,2], Elisa Maria Sanchez Moreno[1], Maria Felicidad Bogalo[1], Avto Gogichaishvili[3], George Vashakidze[4], Emilio Herrero-Bervera[2], Juan Julio Morales[3] (1.Departamento de Fisica, EPS, Universidad de Burgos, 09006 Burgos, Spain, 2.Hawaii Institute of Geophysics and Planetology, University of Hawaii at Manoa, Honolulu, Hawaii, United States, 3.Servicio Arqueomagnetico Nacional – Instituto de Geofisica, Universidad Nacional Autonoma de Mexico, Morelia, Mexico , 4.Alexandre Janelidze Institute of Geology – Ivane Javakhishvili Tbilisi State University, 0171 Tbilisi, Georgia)

[SEM18-03] Paleomagnetic study of Holocene lava flow age at Nakadake volcano in Aso caldera, Kyushu Japan: Contribution to establish the Eruption history

*Chisato Anai[1], Nobutatsu Mochizuki[2], Yasuo Miyabuchi[3], Mitsuru Utsugi[1], Hidetoshi Shibuya[2], Takahiro Ohkura[1] (1.Aso Volcanological Laboratory, Institute for Geothermal Sciences, Graduate School of Science, Kyoto University, 2.Earth and Environmental Science, Division of Natural Science, Faculty of Advanced Science and Technology, Kumamoto University, 3.Center for Water Cycle, Marine Environment and Disaster Management, Kumamoto University)

[SEM18-04] **Magnetic mineral change during thermal demagnetization monitored by principle component analysis of FORC: Sediments from Boso Peninsula recording geomagnetic reversals**

*Hirokuni Oda[1], Hiroomi Nakazato[2], Futoshi Nanayama[1] (1.Institute of Geology and Geoinformation, Geological Survey of Japan, AIST, 2.National Agriculture and Food Research Organization)

[SEM18-05] **Eocene global cooling event registered in the red clay sequence near Tibet**

*Vadim A Kravchinsky[1,2], Rui Zhang[2], Lioudmila P Koukhar[1] (1.Geophysics, Department of Physics, University of Alberta, Edmonton, Alberta T6G 2E1, Canada, 2.Institute of Cenozoic Geology and Environment, State Key Laboratory of Continental Dynamics, Department of Geology, Northwest University, Xi'an 710069, China)

[SEM18-06] Analyze the early 19th century's geomagnetic declination in Japanese archipelago from Tadataka Inoh's 67 volumes magnetic survey azimuth ledger Santou-Houi-Ki national treasure of Japan (The 14th report)

*Motohiro Tsujimoto[1], Akitoshi Omotani[2] (1.none, 2.San-in.System Consultant Co.Ltd)

[E] Oral | S (Solid Earth Sciences)：S-EM Earth's Electromagnetism

[S-EM19] Earth and planetary magnetism: Observations, modeling, and implications on dynamics and evolution

convener:Hirokuni Oda(Institute of Geology and Geoinformation, Geological Survey of Japan, AIST), Futoshi Takahashi(Faculty of Sciences, Kyushu University), Courtney Jean Sprain(University of Florida), Yoichi Usui(Japan Agency for Marine-Earth Science and Technology)

[SEM19-01] Interpretation techniques for crustal magnetic fields in the presence of solar fields, instrument or mission challenges

★Invited Papers

*Michael E Purucker[1], Dhananjay Ravat[2], Benoit Langlais[5], Alexander Michels[3], Jack Connerney[4], Suzanne McEnroe[3] (1.NASA/GSFC, Greenbelt, MD, USA, 2.Univ.Kentucky, Lexington, KY, USA, 3.NTNU, Trondheim, Norway, 4.ADNET/NASA, Greenbelt, MD USA, 5.CNRS, U.Nantes, Nantes, France)

[SEM19-02] Constraints on the Source of the Martian Magnetic Anomalies Inferred From Relaxation Time of Remanent Magnetization

★Invited Papers

*Masahiko Sato[1], Yuhji Yamamoto[2], Takashi Nishioka[2], Kazuto KODAMA[3], Nobutatsu Mochizuki[4], Masashi Ushioda[5], Ryoichi Nakada[6], Hideo Tsunakawa[7] (1.The University of Tokyo, 2.Kochi University, 3.Doshisha University, 4.Kumamoto University, 5.National Institute of Advanced Industrial Science and Technology, 6.Japan Agency for Marine-Earth Science and Technology, 7.Japan Aerospace Exploration Agency)

[SEM19-04] Anelastic torsional oscillations in Jupiter's metallic hydrogen region

*Kumiko Hori[1,2], Robert J Teed[3], Chris A Jones[2] (1.Graduate School of System Informatics, Kobe University, 2.Department of Applied Mathematics, University of Leeds, 3.School of Mathematics and Statistics, University of Glasgow)

[SEM19-05] Quantitative evaluation of the convection structure in the core with reference to a compositionally-driven lunar dynamo

*Fumi Hyodo[1], Futoshi Takahashi[2], Satoshi Kaneshima[2], Hisayoshi Shimizu[3], Hideo Tsunakawa[4] (1.Department of Earth and Planetary Sciences, Graduate School of Science, Kyushu University, 2.Department of Earth and Planetary Sciences, Faculty of Science, Kyushu University, 3.Earthquake Research Institute, University of Tokyo, 4.Japan Aerospace Exploration Agency)

[SEM19-06] Effects of thermal boundary conditions on geodynamo with various Rayleigh numbers and inner core radii

*Yuki Nishida[1], Yuto Katoh[1], Hiroaki Matsui[2], Masaki Matsushima[3], Atsushi Kumamoto[1] (1.Department of Geophysics, Graduate School of Science, Tohoku University, 2.Dept. of Earth and Planetary Sciences, University of California, Davis, 3.Department of Earth and Planetary Sciences, School of Science, Tokyo Institute of Technology)

[E] Oral | S (Solid Earth Sciences)：S-EM Earth's Electromagnetism

[S-EM19] Earth and planetary magnetism: Observations, modeling, and implications on dynamics and evolution

convener:Hirokuni Oda(Institute of Geology and Geoinformation, Geological Survey of Japan, AIST), Futoshi Takahashi(Faculty of Sciences, Kyushu University), Courtney Jean Sprain(University of Florida), Yoichi Usui(Japan Agency for Marine-Earth Science and Technology)

[SEM19-07] **Origin, Diversity and Evolution of Magnetotctic Bacteria: Implication for Earth's Magnetic Field**

★Invited Papers

*Yongxin Pan[1], Wei Lin[1] (1.Biogeomagnetism Group, Key Laboratory of Earth and Planetary Physics, Institute of Geology and Geophysics, Chinese Academy of Sciences)

[SEM19-08] Hints of 3.4 billion-year-old magnetofossils: Possible early coevolution of life and the geodynamo

*John Anthony Tarduno[1,2], Axel Hofmann[3], Rory D Cottrell[1] (1.University of Rochester, Department of Earth and Environmental Sciences, Rochester, New York, United States, 2.University of Rochester, Department of Physics and Astronomy, Rochester, New York, United States, 3.University of Johannesburg, Department of Geology, Johannesburg, South Africa)

[SEM19-09] Shallow water MHD waves trapped near the poles in a stably stratified outermost Earth's core

*Ryosuke Nakashima[1], Shigeo Yoshida[2] (1.Faculty of Sciences, Kyushu University, 2.Department of Earth and Planetary Sciences, Faculty of Science, Kyushu University)

[SEM19-10] Contribution to IGRF-13 from Japan: A secular variation model using a numerical dynamo model and 4DEnVar data assimilation

*Takuto Minami[1], Shin ya Nakano[2], Futoshi Takahashi[3], Masaki Matsushima[4], Ryosuke Nakashima[3], Hisayoshi Shimizu[5], Hinami Taniguchi[3], Hiroaki TOH[6] (1. Kobe University, 2.The Institute of Statistical Mathematics, 3.Kyushu University, 4.Tokyo Institute of Technology, 5.The University of Tokyo, 6.Kyoto University)

[SEM19-11] **Estimating rates of change in the geomagnetic field**

★Invited Papers

*Catherine Constable[1], Christopher J Davies[2] (1.Scripps Institution of Oceanography, University of California San Diego, USA, 2.School of Earth and Environment, University of Leeds, UK)

[E] Oral | S (Solid Earth Sciences)：S-EM Earth's Electromagnetism

[S-EM20] Electric and Electromagnetic survey technologies and the scientific achievements: Recent advances

convener:Kiyoshi Baba(Earthquake Research Institute, The University of Tokyo), Tada-nori Goto(Graduate School of Life Science, University of Hyogo), Toshihiro Uchida(National Institute of Advanced Industrial Science and Technology), Toru Mogi(Faculty of Science, Tokyo Institute of Technology)

[SEM20-01] Case studies on ERT monitoring in Taiwan

★Invited Papers

*Chien-Chih Chen[1,2] (1.Department of Earth Sciences, National Central University, Taoyuan, Taiwan, 2.Earthquake-Disaster and Risk Evaluation and Management Center, National Central University, Taoyuan, Taiwan)

[SEM20-02] Carbonate Imaging with Magnetotellurics in a Shallow-Water Environment, South Yellow Sea, China

*Shuangmin Duan[1], Yuguo Li[1], Jianxin Pei[1], Tiehu Zhao[2], Zhiqiang Wu[2], Bo Han[3], Xinsheng Yu[1], Lanjun Liu[1], Jialin Chen[1] (1.Ocean Univ. of China, 2.Qingdao Inst. of Marine Geology, 3.China Univ. of Geosciences (Wuhan))

[SEM20-03] Three-dimensional Electrical Resistivity Structure of Tokachidake Volcano Revealed by GREATEM Survey Data

*Sabry Abdallah[1], Toru Mogi[1], Yusuke Yamaya[2], Takashi Hashimoto[2], Makoto Murakami[2], Akira Jomori[3], Youichi Yuuki[4], Hideshi Kaieda[5], Hisatoshi Ito[5] (1.Earthquake and Volcano Research Center Graduate School of Environmental Studies, Nagoya University, 2.Institute of Seismology and Volcanology, Hokkaido Univ., 3.Neoscience co., 4.Oyo,Co., 5.CRIEPI)

[SEM20-04] Anatomy of Active Volcanic Edifice at the Kusatsu-Shirane Volcano, Japan, by Magnetotellurics: Hydrothermal Implications for Volcanic Unrests

Kuo Hsuan Tseng[1], *Yasuo Ogawa[1], Nurhasan Nurhasan[1], Sabri Bülent Tank[1], Yoshimori Honkura[1], Naoto Ujihara[1], Akihiko Terada[1], Yoshiya Usui[1], Wataru Kanda[1] (1.Volcanic Fluid Research Center, School of Science, Tokyo Institute of Technology)

[SEM20-05] Global electrical conductivity model of Miyake-jima: insights into its hydrothermal and magmatic system

*Marceau Gresse[1], Takao Koyama[1], Makoto Ueshima[1], Yuichi Morita[1], Yoichi Sasai[2], Jacques Zlotnicki[3], Tsuneo Ishido[4], Hideaki Hase[5], Wataru Kanda[6], Koki Aizawa[7], Derek Weller[1], Tawat Rung-Arunwan[8], Yasuo Matsunaga[6], Hideki Ueda[9], Maki Hata[1], Yusuke Yamaya[10] (1.Earthquake Research Institute, The University of Tokyo, Tokyo, Japan, 2.Earthquake Prediction Research Centre, Tokai University, Shizuoka, Japan, 3.CNRS, OPGC-UMR6524, Aubière, France, 4.Geological Survey of Japan, AIST, Tsukuba Ibaraki, Japan, 5.Geothermal Energy Research & Development Co., Ltd., Tokyo, Japan, 6.Tokyo Institute of Technology School of Science, Tokyo, Japan, 7.Institute of Seismology and Volcanology, Faculty of Science, Kyushu University, Fukuoka, Japan, 8.Curl-E Geophysics Co., Ltd., Thailand, 9.National Research Institute for Earth Science and Disaster Resilience, Tsukuba, Japan, 10.Renewable Energy Research Center, National Institute of Advanced Industrial Science and Technology (AIST), Fukushima, Japan)

[E] Oral | S (Solid Earth Sciences)：S-EM Earth's Electromagnetism

[S-EM20] Electric and Electromagnetic survey technologies and the scientific achievements: Recent advances

convener:Kiyoshi Baba(Earthquake Research Institute, The University of Tokyo), Tada-nori Goto(Graduate School of Life Science, University of Hyogo), Toshihiro Uchida(National Institute of Advanced Industrial Science and Technology), Toru Mogi(Faculty of Science, Tokyo Institute of Technology)

[SEM20-06] Advances in Marine Electromagnetic Instruments and Data Processing Techniques

★Invited Papers

*Yuguo Li[1,2] (1.Ocean Univ. of China, 2.Key Lab of Submarine Geosciences and Prospecting Techniques of Ministry of Education)

[SEM20-07] Ocean bottom electromagnetometers of Earthquake Research institute

*Kiyoshi Baba[1] (1.Earthquake Research Institute, The University of Tokyo)

[SEM20-09] Effecitive combination of MT and GDS survey for three-dimensional imaging of geothermal resovoir

*Tada-nori Goto[1], Yuji Yamada[2] (1.Graduate School of Life Science, University of Hyogo, 2.Graduate School of Engineering, Kyoto University)

[SEM20-10] Estimation of electrical conducitivity in the mantle transition zone by using the Sq source model GAIA

*Takao Koyama[1], Shigeru Fujita[2], Ikuko Fujii[2], Kiyoshi Baba[1] (1.Earthquake Research Institute, The University of Tokyo, 2.Meteorological College)

[E] Oral | S (Solid Earth Sciences)：S-IT Science of the Earth's Interior & Techtonophysics

[S-IT23] Property and role of liquids inside terrestrial planets

convener:Tatsuya Sakamaki(Department of Earth Science, Tohoku University), Yoichi Nakajima(Kumamoto University, Priority Organization for Innovation and Excellence)

[SIT23-01] A multifaceted experimental approach to studying silicate liquids under high pressure

★Invited Papers

Young Jay Ryu[1], *Yanbin Wang[1], Tony Yu[1], Vitali Prakapenka[1], Zhicheng Jing[6], Man Xu[5], Clemens Prescher[2], Eran Greenberg[1], Sergey Tkachev[1], Heather Watson[3], Yoshio Kono[4], Peter Eng[1], Joanne Stubbs[1] (1.Center for Advanced Radiation Sources, University of Chicago, Chicago, IL, USA, 2.DESY, FS-PS, Hamburg, Germany, 3.Union College, NY, USA, 4.Geodynamics Research Center, Ehime University, Matsuyama, Japan, 5.Case Western Reserve University, OH, USA, 6.Southern University of Science and technology, Guangdong, China)

[SIT23-05] X-ray diffraction measurements on aluminosilicate glasses at ultrahigh-pressure conditions

*Itaru Ohira[1,2], Yoshio Kono[1,2], Yu Shu[3], Yuki Shibazaki[4,5], Curtis Kenney-Benson[3], Rostislav Hrubiak[3], Atsunobu Masuno[6], Guoyin Shen[3] (1.Geodynamics Research Center, Ehime University, 2.Geophysical Laboratory, Carnegie Institution of Washington, 3.High Pressure Collaborative Access Team (HPCAT), X-ray Science Division, Argonne National Laboratory, 4.Frontier Research Institute for Interdisciplinary Sciences (FRIS), Tohoku University, 5.International Center for Young Scientists (ICYS), National Institute for Materials Science (NIMS), 6.Graduate School of Science and Technology, Hirosaki University)

[SIT23-06] Equation of State for Liquid Iron under Extreme Conditions

★Invited Papers

*Yasuhiro Kuwayama[1], Guillaume Morard[2], Yoichi Nakajima[3,4], Kei Hirose[1,5], Alfred Q. R. Baron[4], Saori I Kawaguchi[6], Taku Tsuchiya[7], Daisuke Ishikawa[6,4], Naohisa Hirao[6], Yasuo Ohishi[6] (1.The University of Tokyo, 2.Laboratoire ISTERRE, Université Grenoble Alpes, 3.Kumamoto University, 4.RIKEN MDR, 5.Tokyo Institute of Technology, 6.JASRI, 7.Ehime University)

[E] Oral | S (Solid Earth Sciences)：S-IT Science of the Earth's Interior & Techtonophysics

[S-IT24] MAGMA AND FLUID TRANSPORT IN THE EARTH'S INTERIOR

convener:Bjorn Mysen(Geophysical Laboratory, Carnegie Inst. Washington), Eiji Ohtani(Department of Earth and Planetary Materials Science, Graduate School of Science, Tohoku University), Dapeng Zhao(Department of Geophysics, Tohoku University), Michihiko Nakamura(Division of Earth and Planetary Materials Science, Department of Earth Science, Graduate School of Science, Tohoku University)

[SIT24-01] Searching for the deep roots of arc volcanoes: seismic imaging in the Washington Cascades (Invited)

★Invited Papers

*Geoffrey A Abers[1], Michael E Mann[1], Kayla J Crosbie[1], Roque Soto Castaneda[1], Carl Ulberg[2], Kenneth C Creager[2] (1.Cornell University, 2.University of Washington)

[SIT24-02] **Combining InSAR and GNSS to model magma transport during the May 2016 eruption of Piton de la Fournaise Volcano (La Réunion Island**

*Valerie Cayol[1], Delphine Smittarello[2], Virginie Pinel[2], Aline Peltier[3], Jean-Luc Froger[1] (1.CNRS, UCA, LMV, OPGC, IRD, Clermont-Ferrand, France, 2.ISTerre, IRD, CNRS, USMB, Le Bourget du Lac, France, 3.OVPF, IPGP, UP, CNRS, La Réunion, France.)

[SIT24-03] Salinity map of subduction-zones fluids recorded in fluid inclusions

★Invited Papers

*Tatsuhiko Kawamoto[1] (1.Department of Geoscience, Faculty of Science, Shizuoka University)

[SIT24-04] Developing a laboratory technique to probe volatile transport in the deep mantle

★Invited Papers

*Catherine McCammon[1], Serena Dominijanni[1], Leonid Dubrovinsky[1], Nobuyoshi Miyajima[1], Egor Gennadievich Koemets[1], Dan Frost[1] (1.Bayerisches Geoinstitut, University of Bayreuth)

[SIT24-05] Temperature dependence on nitrogen solubility in bridgmanite under lower mantle conditions: its role in formation of deep nitrogen reservoir through solidification of magma ocean.

*Ko Fukuyama[1], Hiroyuki Kagi[1], Toru Inoue[2,3], Sho Kakizawa[1], Toru Shinmei[3], Yuji Sano[4,5], Cécile Deligny[6], Evelyn Füri[6] (1.Geochemical Research Center, Graduate School of Science, The University of Tokyo, 2.Department of Earth and Planetary Systems Science, Graduate School of Science, 3.Geodynamics Research Center, Ehime University, 4.Division of Ocean and Earth Systems, Atmosphere and Ocean Research Institute, University of Tokyo, 5.Institute of Surface-Earth System Science, Tianjin University, 6.Centre de Recherches Pétrographiques et Géochimiques)

[SIT24-06] Effect of Spin transition of iron in physical properties of hydrous phase δ-(Al,Fe)OOH under the lower mantle conditions

*Eiji Ohtani[1], Wen-pin Hsieh[2], Takayuki Ishii[3], Itaru Ohira[4] (1.Department of Earth and Planetary Materials Science, Graduate School of Science, Tohoku University, 2.Institute of Earth Science, Academia Sinica, 3.Bayeriches Geoinstitute, University of Bayreuth, 4.Geodynamics Research Center, Ehime University)

[E] Oral | S (Solid Earth Sciences)：S-IT Science of the Earth's Interior & Techtonophysics

[S-IT25] Structure and Dynamics of Earth and Planetary Mantles

convener:Takashi Yoshino(Institute for Planetary Materials, Okayama University), Takashi Nakagawa(Department of Earth Sciences, The University of Hong Kong), Dapeng Zhao(Department of Geophysics, Tohoku University)

[SIT25-01] Application of the mixed length theory to assess the generation of melt in internally heated systems

*Kenny Vilella[1], Shunichi Kamata[1] (1.Hokkaido University)

[SIT25-02] **New insights into structural elements of the upper mantle below the contiguous United States from S-to-P converted seismic waves**

Rainer Kind[2], *Walter D Mooney[1], Xiaohui Yuan[2] (1.USGS Western Regional Offices Menlo Park, 2.Helmholtz Center Potsdam GFZ)

[SIT25-03] **The effect of water on seismic attenuation of upper mantle olivine and its implications for origin of the sharp lithosphere-asthenosphere boundary**

*Chao Liu[1], Takashi Yoshino[1] (1.Institute for Planetary Materials, Okayama University)

[SIT25-06] **Source stacking followed by cross-correlation: the first application to real long period data for full-waveform inversion at the global scale**

*Li-Wei Chen[1], Barbara Romanowicz[1,2,3] (1.University of California, Berkeley, 2.Institut de Physique du Globe de Paris, 3.Collège de France, Paris)

[E] Oral | S (Solid Earth Sciences)：S-IT Science of the Earth's Interior & Techtonophysics

[S-IT25] Structure and Dynamics of Earth and Planetary Mantles

convener:Takashi Yoshino(Institute for Planetary Materials, Okayama University), Takashi Nakagawa(Department of Earth Sciences, The University of Hong Kong), Dapeng Zhao(Department of Geophysics, Tohoku University)

[SIT25-07] Numerical experiments on stagnation and avalanche of subducting slabs: Important roles of trench migration and its temporal change

*Mana Tsuchida[1], Masanori Kameyama[1] (1.Geodynamics Research Center, Ehime University)

[SIT25-08] Topography on the mantle discontinuities beneath the Ontong Java Plateau

*Daisuke Suetsugu[1], Hajime Shiobara[2], Hiroko Sugioka[3], Aki Ito[1], Takehi Isse[2], Yasushi Ishihara[1], Satoru Tanaka[1], Masayuki Obayashi[1], Takashi Tonegawa[1], Junko Yoshimitsu[1], Takumi Kobayashi[3] (1.institute for Marine Geodynamics, Japan Agency for Marine-Earth Science and Technology, 2.Earthquake Research Institute, the University of Tokyo, 3.Department of Planetrology, Graduate School of Science Kobe University)

[SIT25-10] **Iron content induced pressure- and temperature-dependency change of thermal conductivity of ferropericlase: implications for mantle dynamics**

*Youyue Zhang[1], Takashi Yoshino[1], Masahiro Osako[2] (1.Institute for Planetary Materials, Okayama University, 2.National Museum of Nature and Science)

[SIT25-11] Shear localization and shear instability induced by the olivine-spinel transformation of fayalite at 8 GPa

*Yuichiro Mori[1], Tomoaki Kubo[1], Takuya Iwasato[2], Yuji Higo[3], Yoshinori Tange[3] (1.Kyushu University, 2.Shin-Nippon Nondestructive Inspection Co., Ltd, 3.JASRI)

[SIT25-12] Volatile cycle across the Earth-like planet – Impact to plate tectonics and climate

*Takashi Nakagawa[1] (1.Department of Earth Sciences, The University of Hong Kong)

[E] Oral | S (Solid Earth Sciences)：S-IT Science of the Earth's Interior & Techtonophysics

[S-IT26] Interaction and Coevolution of the Core and Mantle in the Earth and Planets

convener:Kenji Ohta(Department of Earth and Planetary Sciences, Tokyo Institute of Technology), Tsuyoshi Iizuka(University of Tokyo), Kenji Kawai(Department of Earth and Planetary Science, School of Science, University of Tokyo), Taku Tsuchiya(Geodynamics Research Center, Ehime University)

[SIT26-01] Thermal and Chemical Interactions between the Core and Mantle

*Taku Tsuchiya[1], Haruhiko Dekura[1], Zhihua Xiong[1], Atsuroh Ohba[1] (1.Geodynamics Research Center, Ehime University)

[SIT26-02] Martian Core Heat Flux: Electrical Resistivity and Thermal Conductivity of Liquid Fe at Martian Core P-T Conditions

*Innocent Ezenwa[1], Takashi Yoshino[1] (1.Institute for Planetary Materials, Okayama University)

[SIT26-03] **Advances in a high pressure-temperature experiment for understanding thermal transport property of the Earth's core**

*Kenji Ohta[1], Sho Suehiro[1], Hayato Inoue[1], Akira Hasegawa[1] (1.Department of Earth and Planetary Sciences, Tokyo Institute of Technology)

[SIT26-04] Iron diffusion in ε-iron

*Daisuke Yamazaki[1], Naoya Sakamoto[2], Hisayoshi Yurimoto[2] (1.Institute for Planetary Materials, Okayama University, 2.Hokkaido University)

[SIT26-05] Determination of noble gas partition coefficients between metal and silicate melts under high-pressure and high-temperature conditions

*Hirochika Sumino[1], Tomotaka Tanaka[1], Hideharu Kuwahara[2], Satoshi Kishi[1], Kenji Mibe[4], Ryuichi Nomura[3], Hiroyuki Kagi[5] (1.Department of Basic Science, Graduate School of Arts and Sciences, University of Tokyo, 2.Geodynamics Research Center, Ehime University, 3.Graduate School of Human and Environmental Studies, Kyoto University, 4.Earthquake Research Institute, University of Tokyo, 5.Geochemical Research Center, Graduate School of Science, University of Tokyo)

[E] Oral | S (Solid Earth Sciences)：S-IT Science of the Earth's Interior & Techtonophysics

[S-IT26] Interaction and Coevolution of the Core and Mantle in the Earth and Planets

convener:Kenji Ohta(Department of Earth and Planetary Sciences, Tokyo Institute of Technology), Tsuyoshi Iizuka(University of Tokyo), Kenji Kawai(Department of Earth and Planetary Science, School of Science, University of Tokyo), Taku Tsuchiya(Geodynamics Research Center, Ehime University)

[SIT26-06] Tungsten isotopic compositions of Ethiopian and Aden Bay basalts and the Samoan ocean island: implications for core-mantle interaction in their source

*Katsuhiko Suzuki[1], Asako Takamasa[2,1], Yusuke Fukami[3,1], Tsuyoshi Iizuka[4], Yuji Orihashi[5], Ryuichi Shinjo[6], Takeshi Hanyu[7] (1.Submarine Resources Research Center, JAMSTEC, 2.JAPAN NUS CO., Ltd, 3.Department of Chemistry, Gakushuin University, 4.Department of Earth and Planetary Science, The University of Tokyo, 5.Department of Earth and Environmental Sciences, Hirosaki University, 6.Department of Physics and Earth Sciences, University of the Ryukyus , 7.Volcanoes and Earth's Interior Research Center, JAMSTEC)

[SIT26-07] Ultrasonic velocity measurement of deep Earth hydrous phase (Al-bearing phase D) under high pressure and high temperature

*Toru Inoue[1,2], Chaowen Xu[2], Steeve Gre'aux[2], Masamichi Noda[1], Wei Sun[2], Hideharu Kuwahara[2], Yuji Higo[3] (1.Department of Earth and Planetary Systems Science, Graduate School of Science, Hiroshima University, 2.Geodynamics Research Center, Ehime University, 3.Japan Synchrotron Radiation Research Institute)

[SIT26-08] Mantle flows in the lowermost mantle beneath the Northern Pacific inferred by 3-D waveform inversion for radially anisotropic structure

*Yuki Suzuki[1], Kenji Kawai[1], Robert J. Geller[1] (1.Department of Earth and Planetary Sciences, Graduate School of Science,The University of Tokyo)

[SIT26-09] Spin transition in (Mg,Fe)O tilt grain boundaries across the Earth's lower mantle

*Sebastian Ritterbex[1], Taku Tsuchiya[1] (1.Geodynamics Research Center, Ehime University)

[SIT26-10] **First principles study of the lattice thermal conductivity of ferropericlase**

★Invited Papers

*Kaihua He[1] (1.China University of Geosciences)

[E] Oral | S (Solid Earth Sciences)：S-IT Science of the Earth's Interior & Techtonophysics

[S-IT26] Interaction and Coevolution of the Core and Mantle in the Earth and Planets

convener:Kenji Ohta(Department of Earth and Planetary Sciences, Tokyo Institute of Technology), Tsuyoshi Iizuka(University of Tokyo), Kenji Kawai(Department of Earth and Planetary Science, School of Science, University of Tokyo), Taku Tsuchiya(Geodynamics Research Center, Ehime University)

[SIT26-11] Assessment and implication on the thermal and chemical state of the Earth's core in the 1-D radial convective structure tracking over 4 billion years

*Takashi Nakagawa[1] (1.Department of Earth Sciences, The University of Hong Kong)

[SIT26-12] Elastic wave velocity of Al-bearing anhydrous bridgmanites under high pressure and high temperature

*Masamichi Noda[1], Toru Inoue[1], Steeve GREAUX[2], Chaowen Xu[3], Hideharu Kuwahara[2], Wei Sun[2], Yuji Higo[4] (1.Graduate School of Science, Hiroshima University, 2.Geodynamics Research Center, Ehime University, 3.Institute of earthquake forecasting, CEA, 4.JASRI)

[SIT26-13] **Detector study for geo-neutrino directional measurement**

*Naoya Maemura[1], Hiroko Watanabe[1] (1.Tohoku University)

[SIT26-14] Ratest results of geo-neutrino measurement with KamLAND

*Hiroko Watanabe[1] (1.Research Center for Neutrino Science, Tohoku University)

[SIT26-15] Is there primordial reservoir in lower mantle?

*Takashi Yoshino[1] (1.Institute for Planetary Materials, Okayama University)

[E] Oral | S (Solid Earth Sciences)：S-IT Science of the Earth's Interior & Techtonophysics

[S-IT27] Oceanic lithosphere and asthenosphere

convener:Nozomu Takeuchi(Earthquake Research Institute, University of Tokyo), Ban-Yuan Kuo(Institute of Earth Sciences, Academia Sinica), Rob L Evans(Woods Hole Oceanographic Institution), Younghee Kim(Seoul National University)

[SIT27-01] *Pacific Array* update 2020

*Hitoshi Kawakatsu[1], - the international Pacific Array team (1.Earthquake Research Institute, The University of Tokyo)

[SIT27-02] Olivine fabric development during Newtonian (diffusion creep) corner flow.

*NAHYEON KIM[1], Takehiko Hiraga[1] (1.Earthquake Research Institute, University of Tokyo)

[SIT27-03] The seismic structure of the oldest Pacific: Preliminary results from the broadband Rayleigh-wave dispersion analysis of the Pacific Array, Oldest-1

*Yuki Kawano[1], Takehi Isse[1], Akiko Takeo[1], Hitoshi Kawakatsu[1], Hajime Shiobara[1], Nozomu Takeuchi[1], Hiroko Sugioka[2], YoungHee Kim[3], Hisashi Utada[1], Sang-Mook Lee[3] (1.Earthquake Research Institute, The University of Tokyo, 2.Kobe University, 3.Seoul National University)

[SIT27-05] A peridotite xenolith from garnet-stability field beneath Aitutaki (Cook islands): an implication for small-scale convection

*Norikatsu Akizawa[1], Kazuhito Ozawa[2], Simon Richard Wallis[2], Akihiro Tamura[3], Akira Ishikawa[4], Tetsu Kogiso[5] (1.Atmosphere and Ocean Research Institute, The University of Tokyo, 2.Department of Earth and Planetary Science, The University of Tokyo, 3.Faculty of Geosciences and Civil Engineering, Kanazawa University, 4.Department of Earth and Planetary Sciences, Tokyo Institute and Technology, 5.Graduate School of Human and Environmental Studies, Kyoto University)

[SIT27-06] Three dimensional shear wave structure in the upper mantle beneath the oldest Pacific plate

*Takehi Isse[1], Hitoshi Kawakatsu[1], Hajime Shiobara[1], Nozomu Takeuchi[1], Hiroko Sugioka[2], Younghee Kim[3], Hisashi Utada[1], Sang-Mook Lee[3], Kazunori Yoshizawa[4] (1.Earthquake Research Institute, the University of Tokyo, 2.Department of Planetology, Kobe University, 3.Seoul National University, 4.Faculty of Science, Hokkaido University)

[E] Oral | S (Solid Earth Sciences)：S-IT Science of the Earth's Interior & Techtonophysics

[S-IT27] Oceanic lithosphere and asthenosphere

convener:Nozomu Takeuchi(Earthquake Research Institute, University of Tokyo), Ban-Yuan Kuo(Institute of Earth Sciences, Academia Sinica), Rob L Evans(Woods Hole Oceanographic Institution), Younghee Kim(Seoul National University)

[SIT27-07] A comprehensive portrait of the central Pacific lithosphere-asthenosphere system from NoMelt seafloor geophysical observations

James Gaherty[2], Joshua Russell[3], Hannah Mark[4], Zhitu Ma[5], Colleen Dalton[5], Daniel Lizarralde[1], Greg Hirth[5], John Collins[1], *Rob L Evans[1] (1.Dept of Geology and Geophysics, Woods Hole Oceanographic Institution, 2.School of Earth and Sustainability, Northern Arizona University, 3.Columbia Univ., Lamont Doherty Earth Observatory, 4.Dept. of Earth and Planetary Sciences, Washington University, St. Louis, 5.Dept. of Earth, Environmental, and Planetary Sciences, Brown Univ)

[SIT27-08] Seismic discontinuity at lithosphere-asthenosphere boundary predicted from laboratory-based anelasticity model

Hatsuki Yamauchi[1], *Yasuko Takei[1] (1.Earthquake Research Institute, University of Tokyo)

[SIT27-09] Shear attenuation and anelastic mechanisms in the central Pacific upper mantle

★Invited Papers

*Zhitu Ma[1], Colleen A Dalton[2], Joshua B Russell[3], James B Gaherty[3], Greg Hirth[2], Donald W Forsyth[2] (1.State Key Laboratory of Marine Geology, Tongji University, Shanghai, China, 2.Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI, USA, 3.Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY, USA)

[SIT27-10] Viscosity-depth profiles of the oceanic upper mantle deforming by grain-boundary diffusion creep

*Kosuke Yabe[1], Takehiko Hiraga[1] (1.School of Science, The University of Tokyo)

[SIT27-11] **Upper mantle velocity structure beneath the northern Ryukyu subduction zone revealed from multiscale finite-frequency traveltime tomography**

★Invited Papers

*Shu-Huei Hung[1], Ban-Yuan Kuo[2], Pei-Ying Patty Lin[3], Yuancheng Gung[1], Eh Tan[2], Kate Huihsuan Chen[3], Ching-Ren Lin[2], Chau-Chang Wang[5,4], Shuichi Kodaira[6], Yasushi Ishihara[6], Mamoru Nakamura[7] (1.National Taiwan University, Taipei, Taiwan, 2.Academia Sinica, Taipei, Taiwan, 3.National Taiwan Normal University, Taipei, Taiwan, 4.Taiwan Ocean Research Institute, National Applied Research Laboratories, Kaohsiung, Taiwan , 5.National Sun Yat-sen University, Kaohsiung, Taiwan, 6.Japan Agency for Marine-Earth Science and Technology, Yokohama, Japan, 7.University of the Ryukyus, Okinawa, Japan)

[SIT27-12] Future geophysical observation on oceanic lithosphere and asthenosphere study: Hawaii-Emperor Bend (HEB) Project

*Kiyoshi Baba[1], Bernhard Steinberger[2,3], Marion Jegen[4], Max Moorkamp[5], Takehi Isse[1], Akiko Takeo[1], Antje Schlömer[5], HEB Research group (1.Earthquake Research Institute, The University of Tokyo, 2.GFZ, Helmholtz Centre, Potsdam, 3.CEED, University of Oslo, 4.GEOMAR, Helmholtz Centre of Ocean Research Kiel, 5.Munich University)

[E] Oral | S (Solid Earth Sciences)：S-IT Science of the Earth's Interior & Techtonophysics

[S-IT29] New perspectives on East Asia geodynamics

convener:Jonny Wu(University of Houston), Asuka Yamaguchi(Atomosphere and Ocean Research Institute, The University of Tokyo), Kyoko Okino(Atmosphere and Ocean Research Institute, The University of Tokyo), Timothy B Byrne(University of Connecticut)

[SIT29-01] New insights into East Asian mantle structure and dynamics

★Invited Papers

*Dapeng Zhao[1] (1.Department of Geophysics, Tohoku University)

[SIT29-02] **NE Asian arc magmatic tempos and their relationship to Western Pacific-Izanagi plate tectonics since Cretaceous times**

*Jonny Wu[1], Tsung-Jui Wu[1] (1.University of Houston)

[SIT29-03] Mesozoic island arc rocks in Hokkaido: potential keys to reconstruct ancient oceanic plates offshore East Asia.

★Invited Papers

*Hayato Ueda[1], Ryusei KOTA[1], Mitsuhiko Ishino[1], Minato Munakata[1], Komei Nara[1], Yuta Akutsu[1], Yusuke Sugiyama[1], Nozomu Suzuki[1] (1.Department of Geology, Niigata University)

[SIT29-04] Mid-Cretaceous Tectonics of the Ryukyu arc reconstructed by geology of Kerama Islands, Okinawa

*Ippei Yamamoto[1], Kenichiro Tani[2], Yui Kouketsu[3], Asuka Yamaguchi[1] (1.Atmosphere and Ocean Research Institute, The University of Tokyo, 2.National Museum of Nature and Science, 3.Nagoya University)

[SIT29-05] The last unknown pieces of the Proto-Philippine Sea Plate: Huatung Basin and Gagua Ridge

★Invited Papers

*Kenichiro Tani[1], Osamu Ishizuka[2], Kyoko Okino[3], Hayato Ueda[4] (1.Department of Geology and Paleontology, National Museum of Nature and Science, 2.Geological Survey of Japan/AIST, 3.Atmosphere and Ocean Research Institute, The University of Tokyo, 4.Faculty of Science, Niigata University)

[SIT29-06] **Maturation of incipient island arcs: New insights from the southern Mariana arc**

★Invited Papers

*Julia Ribeiro[1], Osamu Ishizuka[2], Cin-Ty Lee[3], Guillaume Girard[4] (1.Guangzhou Institute of Geochemistry, the Chinese Academy of Sciences, Guangzhou, China, 2.Geological Survey of Japan, AIST, Ibaraki, Japan, 3.Rice University, Earth Science Department, Houston, Tx, USA, 4.Northern Illinois University, DeKalb, Illinois, USA.)

[E] Oral | S (Solid Earth Sciences)：S-IT Science of the Earth's Interior & Techtonophysics

[S-IT29] New perspectives on East Asia geodynamics

convener:Jonny Wu(University of Houston), Asuka Yamaguchi(Atomosphere and Ocean Research Institute, The University of Tokyo), Kyoko Okino(Atmosphere and Ocean Research Institute, The University of Tokyo), Timothy B Byrne(University of Connecticut)

[SIT29-07] Post-back-arc spreading magmatism: an example of the Seifu Seamount in the Sea of Japan
★Invited Papers

*Tomoaki Morishita[1,2,3], Naoto Hirano[4], Hirochika Sumino[5], Hiroshi Sato[6], Tomoyuki Shibata[7], Masako Yoshikawa[7], Shoji Arai[1], Akihiro Tamura[1] (1.Kanazawa University, 2.JAMSTEC, 3.Columbia University, 4.Tohoku University, 5.University of Tokyo, 6.Senshu University, 7.Hiroshima University)

[SIT29-08] Tectonics in the Median Tectonic Line and surrounding areas, southwest Japan during the Late Cretaceous to Paleogene periods

*Toru Takeshita[1], Yasuuchi Kubota[2] (1.Department of Natural History Sciences, Graduate School of Science, Hokkaido University, 2.Oyo Co., Ltd.)

[SIT29-09] **Doming induced by rapid exhumed serpentinite bodies in the subduction mélange and the associated structures: a case study of the Yuli Belt in eastern Taiwan**

*Jian-Cheng Lee[1,6], Gong-Ruei Ho[1,6], Kai-Hsiang Yang[1,6], Yuan-Hsi Lee[2,6], En-Chao Yeh[3,6], Wei Lo[4,6], Ching-Ho Tsai[5,6] (1.Academia Sinica, 2.National Chung Cheng University, 3.National Taiwan Normal University, 4.National Taipei University of Technology, 5.National Dung Hwa University, 6.The Yuli Exhumation Study team (YES Team))

[SIT29-10] A high strain shear zone in the metamorphic core of Central Range, Taiwan: A possible Plio-Pleistocene transform fault

*Gong-Ruei Ho[1], Jian-Cheng Lee[1], Timothy B Byrne[2] (1.Institute of Earth Sciences, Academia Sinica, 2.Department of Geography, University of Connecticut)

[SIT29-11] Exhumation and deformation partitioning in an arc-continent collision during highly oblique plate convergence ~6 to ~2 Ma, Taiwan

*Timothy B Byrne[1], Gong-Ruei Ho[2], Yuan-Hsi Lee[3], Chase J. Shyu[2] (1.University of Connecticut, 2.Institute of Earth Sciences, 3.National Chung Cheng University)

[SIT29-12] Two steps of onset of the modern geodynamic framework; ~6Ma and ~2.5Ma in east Asia and western Pacific margin

*Gaku Kimura[1], Takeshi Tsuji[2], Asuka Yamaguchi[3] (1.Tokyo University of Marine Science and Technology, 2.Dept. Earth Resources Engineering, Kyushu University, 3.Atmosphere and Ocean Research Institute, The University of Tokyo)

[E] Oral | S (Solid Earth Sciences)：S-IT Science of the Earth's Interior & Techtonophysics

[S-IT30] Tectonic collision systems in continents and oceans

convener:Ling Bai(ITP Institute of Tibetan Plateau Research, Chinese Academy of Sciences), James Mori(Earthquake Hazards Division, Disaster Prevention Research Institute, Kyoto University), Xiaodong Song(University of Illinois at Urbana-Champaign), Yuzo Ishikawa(The National Institute of Advanced Industrial Science and Technology)

[SIT30-01] **Seismic recordings of ice collapses along Yarlung Tsangpo Grand Canyon**

*Ling Bai[1], Yong Jiang[1], James Mori[2] (1.ITP Institute of Tibetan Plateau Research, Chinese Academy of Sciences, 2.Disaster Prevention Research Institute, Kyoto University)

[SIT30-02] Mountain height at convergent plate boundaries is controlled by the megathrust shear force

★Invited Papers

*Armin Dielforder[1], Ralf Hetzel[2], Onno Oncken[1] (1.Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences, Germany, 2.Institute of Geology and Paleontology, University of Muenster, Germany)

[SIT30-03] **Episodic Lithospheric Deformation in Eastern Tibet Inferred from Seismic Anisotropy**

★Invited Papers

*Xuewei Bao[1], Xiaodong Song[2,3], David Eaton[4], Yixian Xu[1], Hanlin Chen[1] (1.Key Laboratory of Geoscience Big Data and Deep Resource of Zhejiang Province, School of Earth Sciences, Zhejiang University, Hangzhou 310027, China, 2.Institute of Theoretical and Applied Geophysics, School of Earth and Space Sciences, Peking University, China, 3.Department of Geology, University of Illinois at Urbana-Champaign, USA, 4.Department of Geoscience, University of Calgary, Canada)

[SIT30-04] **Deformation of Tibetan plateau from recent seismic images: “thin skinned” or lithospheric tectonics?**

*Xiaodong Song[1,2], Jiangtao Li[3] (1.Peking University, China , 2.University of Illinois at Urbana-Champaign, USA, 3.Wuhan University, China)

[SIT30-05] **Subduction thermal regime, slab metamorphism and interplate earthquakes beneath Mariana based on 3-D numerical simulation**

*Yingfeng Ji[1] (1.Institute of Tibetan Plateau Research, Chinese Academy of Sciences)

[SIT30-06] Structural variation along the Main Himalayan Thrust in the source region of 2015 Gorkha earthquake, Nepal

*Chintan Timsina[1], James Mori[2], Masumi Yamada[2] (1.Department of Geophysics, Graduate School of Science, Kyoto University, 2.Disaster Prevention Research Institute, Kyoto University)

[E] Oral | S (Solid Earth Sciences)：S-IT Science of the Earth's Interior & Techtonophysics

[S-IT31] Planetary cores: Structure, formation, and evolution

convener:Hidenori Terasaki(Faculty of Science, Okayama University), Eiji Ohtani(Department of Earth and Planetary Materials Science, Graduate School of Science, Tohoku University), Gerd Steinle-Neumann(Bayerisches Geoinstitut, Universitaet Bayreuth), William F McDonough(Department of Earth Science and Research Center for Neutrino Science, Tohoku University, Sendai, Miyagi 980-8578, Japan)

[SIT31-01] Compositional model for the terrestrial planets

*William F McDonough[1,2], Takashi Yoshizaki[3] (1.Department of Earth Science and Research Center for Neutrino Science, Tohoku University, Sendai, Miyagi 980-8578, Japan, 2.Department of Geology, University of Maryland, College Park, MD 20742, USA, 3.Department of Earth Science, Graduate School of Science, Tohoku University, Sendai, Miyagi 980-8578, Japan)

[SIT31-02] Anomalous is normal in planetary dynamos: A case of Mercury

★Invited Papers

*Futoshi Takahashi[1], Hisayoshi Shimizu[2], Hideo Tsunakawa[3] (1.Faculty of Sciences, Kyushu University, 2.Earthquake Research Institute, University of Tokyo, 3.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency)

[SIT31-03] Liquid Iron Alloys with Light Elements at Outer Core Conditions by First Principles

★Invited Papers

*Koichiro Umemoto[1], Kei Hirose[1,2] (1.Earth-Life Science Institute, Tokyo Institute of Technology, 2.Department of Earth and Planetary Science, The University of Tokyo)

[SIT31-04] **High-pressure melting experiments on Fe-Si-C; Implications for Si in the core**

*Masahiro Hasegawa[1], Kei Hirose[2], Kenta Oka[1] (1.Department of Earth and Planetary Science, The University of Tokyo, 2.Earth-Life Science Institute, Tokyo Institute of Technology)

[SIT31-05] Sound velocity of B2-FeNiSi alloy at high pressure determined with inelastic X-ray scattering: Implications for the composition of the Earth's inner core

Serena Dominijanni[1], *Eiji Ohtani[2], Daijo Ikuta[2], Tatsuya Sakamaki[2], Hiroshi Fukui[3], Catherine McCammon[1], Leonid Dubrovinsky[1], Hiroshi Uchiyama[4], Alfred Q.R. Baron[5] (1.Bayeriches Geoinstitit, University of Bayreuth, 2.Department of Earth and Planetary Materials Science, Graduate School of Science, Tohoku University, 3.University of Hyogo, 4.Japan Synchrotron Radiation Research Institute, 5.RIKEN)

[E] Oral | S (Solid Earth Sciences)：S-IT Science of the Earth's Interior & Techtonophysics

[S-IT31] Planetary cores: Structure, formation, and evolution

convener:Hidenori Terasaki(Faculty of Science, Okayama University), Eiji Ohtani(Department of Earth and Planetary Materials Science, Graduate School of Science, Tohoku University), Gerd Steinle-Neumann(Bayerisches Geoinstitut, Universitaet Bayreuth), William F McDonough(Department of Earth Science and Research Center for Neutrino Science, Tohoku University, Sendai, Miyagi 980-8578, Japan)

[SIT31-06] Rising or falling snow: Constraints on core composition from the F-layer

*Irene Bonati[1], Marine Lasbleis[2], John W Hernlund[1], Kei Hirose[1] (1.Earth-Life Science Institute,Tokyo Institute of Technology, 2.LPG Nantes)

[SIT31-07] **Fe alloy snow and fractional solidification at the lowermost outer core**

*Youjun Zhang[1], Peter Nelson[2], Nick Dygert[3], Jung-Fu Lin[2] (1.Sichuan University, China, 2.The University of Texas at Austin, USA, 3.University of Tennessee, USA)

[SIT31-08] Light elements in iron-hydrous silicate system: Searching for core formation process using in-situ high-pressure and high-temperature neutron and X-ray observations

★Invited Papers

*Riko Iizuka-Oku[1], Hirotada Gotou[2], Chikara Shito[1], Hiroyuki Kagi[1], Akio Suzuki[3] (1.Geochemical Research Center, Graduate School of Science, The University of Tokyo, 2.The Institute for Solid State Physics, The University of Tokyo, 3.Department of Earth Science, Graduate School of Science, Tohoku University)

[SIT31-09] Mass Transport and Structural Properties of Liquid Iron Alloys at high pressure from *ab-initio* simulations

*Gerd Steinle-Neumann[1], Esther S. Posner[1] (1.Bayerisches Geoinstitut, Universitaet Bayreuth)

[SIT31-10] Experimental examination of self-diffusion coefficient of iron under high pressure and its implication to the viscosity of the Earth’s inner core: a preliminary result

*Yohan Park[1], Kenji Ohta[1], Shoichi Itoh[2], Kei Hirose[3] (1.Tokyo institute of technology, 2.Kyoto University, 3.University of Tokyo)

[E] Oral | S (Solid Earth Sciences)：S-GL Geology

[S-GL33] Geologic structure and tectonic history of East Asia and Japanese Islands

convener:Jun Hosoi(Geological Survey of Japan, Institute of Geology and Geoinformation, AIST), Makoto Otsubo(Geological Survey of Japan, Research Institute of Earthquake and Volcano Geology)

[SGL33-01] **Sedimentary History of the Ryukyu Group on Okinawa Island, southwestern Japan**

*SHUYIN CHENG[1], Yasufumi Iryu[2], J Bruce H Shyu[1] (1.National Taiwan Univ., 2.Tohoku Univ.)

[SGL33-03] Temporal changes of Cenozoic volcanic rock petrochemistry in Oki-Dogo, SW Japan

*Masataka Aizawa[1], Ryuichi Shinjo[2], Satoshi Okamura[3,4] (1.Graduate School of Engineering and Sience, University of the Ryukyus, 2.Faculty of Science, University of the Ryukyus, 3.Hokkaido Education University, 4.Hokkaido Soil-Research Co-op.)

[SGL33-04] Highly scattered paleomagnetic directions of middle Miocene volcanic rocks in the Inase area in Northeast Japan: vertical-axis rotations?

*Hiroyuki Hoshi[1], Miki Ohashi[2] (1.Department of Earth Sciences, Aichi University of Education, 2.Graduate, Aichi University of Education)

[SGL33-05] Stratigraphy and sedimentary facies of the Late Jurassic Nakanosawa Formation, Somanakamura Group: Facies changes from wave-dominated siliciclastic facies to lagoonal carbonate facies and their significance

*Hisao Ando[1], Shota Taguchi[2], Yoshihiro Morino[3] (1.Department of Earth Sciences, College of Science, Ibaraki University, 2.Graduate School of Science and Engineering, Ibaraki University, 3.Osaka Headquarters, Pacific Consultant Co. Ltd.)

[SGL33-06] Origin of alkali basalts in Late Jurassic to Early Cretaceous accretionary complex in Amami–Oshima Island, Ryukyu Arc

*Ginta Motohashi[1], Kohtaro Ujiie[1], Takashi Sano[2] (1.University of Tsukuba, 2.Department of Geology and Paleontology, National Museum of Nature and Science)

[E] Oral | S (Solid Earth Sciences)：S-GL Geology

[S-GL33] Geologic structure and tectonic history of East Asia and Japanese Islands

convener:Jun Hosoi(Geological Survey of Japan, Institute of Geology and Geoinformation, AIST), Makoto Otsubo(Geological Survey of Japan, Research Institute of Earthquake and Volcano Geology)

[SGL33-07] Cretaceous Amur sedimentary complex in the Kiselevka area, Far East Russia: Cretaceous history of accretion and rearrangement

*Shigeru Otoh[1], Yuko Miyake[2], Mitsuhiro Nagata[2], Alexei Didenko[3], Alexander Kudymov[3], Mikhail Arkhipov[3], Koshi Yamamoto[4] (1.Academic Assembly, Faculty of Sustainable Design, University of Toyama, 2.Graduate School of Science and Engineering, University of Toyama, 3.Kosygin Institute of Tectonics and Geophysics, FEB, Russian Academy of Science, 4.Graduate School of Environmental Studies, Nagoya University)

[SGL33-08] Geological and thermal structures along the Butsuzo Tectonic Line in the eastern Kyushu

*Hiroki Goto[1], Keita Nakano[1], Tomohiro Tsuji[1] (1.Division of Earth Science The Graduate School of Science and Technology for Innovation Yamaguchi University)

[SGL33-09] Early Paleozoic zircon U-Pb age for high P/T-type metagabbro from western Tokyo

*Hikaru Sawada[1], Yukio Isozaki[2], Shuhei Sakata[2] (1.Japan Marine Science and Technology Center, 2.The University of Tokyo)

[SGL33-11] **3-D magnetic imaging of Taiwan region**

*Qiang Zu[1], Chun-Rong Chen[2], Chieh-Hung Chen[1] (1.China University of Geosciences, 2.National Central University)

[E] Oral | S (Solid Earth Sciences)：S-RD Resources, Mineral Deposit & Resource Exploration

[S-RD35] Mineral Resources for Society: Ore deposit formation and exploration

convener:Yasushi Watanabe(Faculty of International Resource Sciences, Akita University), Kotaro Yonezu(Deaprtment of Earth Resources Engineering, Faculty of Engineering, Kyushu University)

[SRD35-01] **Hydrothermal Mineralization and Alteration of the Sediment-Hosted Fe-Cu-Co Target H Prospect, Mumbwa Iron-Oxide Copper-Gold District, Zambia**

*Mukuka Simusokwe[1], Yasushi Watanabe[1], Takuya Echigo[1] (1.Graduate School of International Resource Sciences, Akita University)

[SRD35-02] **Multi-stage mineralization of the sediment-hosted stratabound Zone 5 copper-silver deposit, Kalahari Copperbelt, NW Botswana**

*Mpho Keeditse[1], Yasushi Watanabe[1], Antonio Arribas[2] (1.Akita Univ., 2.Univ. of Texas at El Paso)

[SRD35-03] Variations in mineral assemblages and oxygen and hydrogen isotopes of wall rock alteration in the Hishikari epithermal gold deposit, Japan

*Yuji Gonoi[1], Akira Imai[1], Kotaro Yonezu[1], Thomas Tindell[1], Koichiro Watanabe[1] (1.Kyushu University)

[SRD35-04] Calcium: Trigger of porphyry Cu and peralkaline granite REE mineralization

*Yasushi Watanabe[1] (1.Graduate School of International Resource Sciences, Akita University)

[SRD35-05] Differentiated sedimentary models and inner architectural characteristics of wave-dominated shoreface deposits: a case of Devonian 'Donghe sandstones' deposits in Tarim Basin, China

*Weilu Li[1] (1.National Marine Data and Information Service)

[SRD35-06] **A new orogenic gold belt in mainland SE Asia: The Vangtat gold deposit in southern Laos**

*Patthana Bounliyong[1], Antonio Arribas[1], Yasushi Watanabe[1], Takuya Echigo[1], Tetsumaru Itaya[2], Henry Wong[3] (1.Akita Univ, Japan, 2.Okayama Univ of Science, Japan, 3.JADE Co., Ltd)

[E] Oral | S (Solid Earth Sciences)：S-MP Mineralogy & Petrology

[S-MP36] Physics and Chemistry of Minerals

convener:Seiji Kamada(Frontier Research Institute for Interdisciplinary Sciences, Tohoku University), Masahiro KAYAMA(Department of General Systems Studies, Graduate School of Arts and Sciences, The University of Tokyo)

[SMP36-01] Synthesis and structural characterization of a new zinc silicate phase A ($Zn_7Si_2O_8(OH)_6$) by ^{1}H and ^{29}Si NMR and synchrotron powder X-ray diffraction

*Xianyu Xue[1], Masami Kanzaki[1], Jianjun Jiang[1,2] (1.Institute for Planetary Materials, Okayama University, 2.Department of Geosciences, Princeton University)

[SMP36-02] Pressure-induced structural changes in hemimorphite and dehydrated hemimorphite: first-principles calculation

*Masami Kanzaki[1] (1.Institute for Planetary Matereials, Okayama University)

[SMP36-03] Molecular Dynamics Simulations of Sodium Water Glass

*Fumiya Noritake[1] (1.Graduate Faculty of interdisciplinary Research, University of Yamanashi)

[SMP36-04] Structural change processes of iron sulfide nanoparticle under hydrothermal conditions

Yoshinari Sano[1], *Atsushi Kyono[1], Yasuhiro Yoneda[2], Sota Takagi[1], Gen-ichiro Yamamoto[1] (1.Division of Earth Evolution Sciences, Faculty of Life and Environmental Sciences, University of Tsukuba, 2.Japan Atomic Energy Agency)

[SMP36-05] **Crystal structure of nesquehonite, $MgCO_3 \cdot 3(H,D)_2O$ by neutron diffraction, Raman spectroscopy, and thermal analysis**

*Gen-ichiro Yamamoto[1], Atsushi Kyono[1], Jun Abe[2], Asami Sano-Furukawa[3], Takanori Hattori[3] (1.University of Tsukuba, 2.CROSS, 3.JAEA)

[SMP36-06] High-*PT* neutron diffraction experiments on guyanaite: Pressure-temperature dependence of hydrogen bonding in hydrous minerals

*Chikara Shito[1], Hiroyuki Kagi[1], Asami Sano-Furukawa[2], Sho Kakizawa[1], Kazuki Komatsu[1], Katsutoshi Aoki[1], Riko Iizuka-Oku[1], Shinichi Machida[3], Noboru Furukawa[4], Akio Suzuki[5] (1.Geochemical Research Center, Graduate School of Science, The University of Tokyo, 2.Japan Atomic Energy Agency, 3.Comprehensive Research Organization for Science and Society, 4.Graduate School of Science, Chiba University, 5.Graduate School of Science, Tohoku University)

[E] Oral | S (Solid Earth Sciences)：S-MP Mineralogy & Petrology

[S-MP36] Physics and Chemistry of Minerals

convener:Seiji Kamada(Frontier Research Institute for Interdisciplinary Sciences, Tohoku University), Masahiro KAYAMA(Department of General Systems Studies, Graduate School of Arts and Sciences, The University of Tokyo)

[SMP36-07] Single crystal elasticity of minerals under high-pressure conditions determined by inelastic x-ray scattering

★Invited Papers

*Hiroshi Fukui[1], Akira Yoneda[2], Seiji Kamada[3], Alfred Baron[4] (1.University of Hyogo, 2.Osaka University, 3.Tohoku University, 4.RIKEN)

[SMP36-08] Redetermination of enthalpy and reassessment of thermodynamic data set for SiO_2 stishovite

*Hiroshi Kojitani[1], Masaki Akaogi[1] (1.Department of Chemistry, Faculty of Science, Gakushuin University)

[SMP36-09] Generalized Theory of Brillouin Scattering Toward Multi-Grain Analyses

*Miaki Ishii[1], Raymond Jeanloz[2] (1.Department of Earth & Planetary Sciences, Harvard University, 2.Department of Earth & Planetary Science, University of California, Berkeley)

[SMP36-10] GHz ultrasonic velocity measurements of iron beyond the bcc-hcp transition

*Akira Yoneda[1], Ryo Tsuruoka[2], Seiji Kamada[3], Hidenori Terasaki[2] (1.Institute for Planetary Materials, Okayama University, 2.Graduate school of Science, Osaka Univ., 3.Frontier Research Institute for Interdisciplinary Sciences, Tohoku Univ.)

[SMP36-11] Density measurements of Fe up to 25 GPa based on X-ray absorption

*Seiji Kamada[1,2], Fumiya Maeda[2], Hidenori Terasaki[3,4], Ryo Tsuruoka[3], Yusaku Takubo[3], Saori I Kawaguchi[5], Naohisa Hirao[5], Akihiko Machida[6] (1.Frontier Research Institute for Interdisciplinary Sciences, Tohoku University, 2.Dept. Earth Science, Tohoku University, 3.Osaka University, 4.Okayama University, 5.JASRI, 6.QST)

[E] Oral | S (Solid Earth Sciences)：S-MP Mineralogy & Petrology

[S-MP37] Supercontinents and crustal evolution

convener:Madhusoodhan Satish-Kumar(Department of Geology, Faculty of Science, Niigata University), Krishnan Sajeev(Centre for Earth Sciences, Indian Institute of Science), Tomokazu Hokada(National Institute of Polar Research), Yasuhito Osanai(Division of Evolution of Earth Environments, Faculty of Social and Cultural Studies, Kyushu University)

[SMP37-01] **Magma activities in Sør Rondane, eastern Dronning Maud Land, East Antarctica: Implications for amalgamation of the Gondwana supercontinent**

★Invited Papers

*Masaaki Owada[1], Atsushi Kamei[2], Yasuhito Osanai[3], Nobuhiko Nakano[3], Ippei Kitano[3] (1.Yamaguchi University, 2.Shimane University, 3.Kyushu University)

[SMP37-02] Thermal gap between UH *T* granulite and surrounding pelitic gneiss from Rundvågshetta in the Lützow-Holm Complex, East Antarctica

*Kota Suzuki[1], Tetsuo Kawakami[1] (1.Department of Geology and Mineralogy, Graduate School of Science, Kyoto University)

[SMP37-03] **Spinel+quartz assemblage in granulites from the Southeastern Madurai Block- Southern Granulite Terrain, India: Implications for ultrahigh-temperature Metamorphism**

*Rajkumar Perumal[1], Krishnan Sajeev[1], KUMAR R. S.[2], Vinod Samuel[3], Kim S. W.[3], Justin K Antony[2] (1.Indian Institute of Science, Bangalore India, 2.Department of earth sciences, Annamalai University, Annamalai nagar, India, 3.Yonsei University, Department of Earth Sciences, South Korea)

[SMP37-04] **Neoproterozoic fayalite-bearing charnockite from south-eastern India—its genesis and metamorphism**

*Krishnan Sajeev[1], P Rajkumar[1], - Durgalakshmi[2], Ian S Williams[2] (1.Centre for Earth Sciences, Indian Institute of Science, Bengaluru 560 012, India, 2.Research School of Earth Sciences, Australian National University, Acton, ACT, 2601, Australia)

[SMP37-05] **C-O-Sr-Nd-Pb isotope geochemistry of metacarbonate rocks in continental collision zones as proxies for estimating the sedimentation age and understanding the tectonic setting of deposition**

*Madhusoodhan Satish-Kumar[1], A. Imura[1], M. Shirakawa[1], Gen Shimoda[2], Kosuke T. Goto[2], M A Sanjeewa P K Malaviarachchi[3] (1.Department of Geology, Faculty of Science, Niigata University, 2.Geological Survey of Japan, AIST, 3.Department of Geology, Peradeniya University, Peradeniya 20400, Sri Lanka.)

[E] Oral | S (Solid Earth Sciences)：S-MP Mineralogy & Petrology

[S-MP37] Supercontinents and crustal evolution

convener:Madhusoodhan Satish-Kumar(Department of Geology, Faculty of Science, Niigata University), Krishnan Sajeev(Centre for Earth Sciences, Indian Institute of Science), Tomokazu Hokada(National Institute of Polar Research), Yasuhito Osanai(Division of Evolution of Earth Environments, Faculty of Social and Cultural Studies, Kyushu University)

[SMP37-06] **Bulk rock Nd-Sr and multiple-sulfur isotope compositions of carbonatites from the Phalaborwa complex, South Africa**

★Invited Papers

*Anupam Banerjee[1], Madhusoodhan Satish-Kumar[1] (1.Niigata University)

[SMP37-07] Circum-Indian ca. 800 Ma tectonothermal activities: A review of imprints of Rodinia growth and dispersal at Indian Archean cratonic margin

*Kaushik Das[1] (1.Hiroshima University)

[SMP37-08] **Tectonics and crustal evolution of Shevaroy Block, Southern India: Insights from petrology, geochemistry and U-Pb zircon geochronology**

*Sam Uthup[1], Tsunogae Toshiaki[1,2], Rajesh VJ[3], Tsutsumi Yukiyasu[4] (1.Graduate School of Life and Environmental Sciences, University of Tsukuba, Japan, 2.Department of Geology, University of Johannesburg, Auckland Park 2006, South Africa, 3.Department of Earth and Space Sciences, Indian Institute of Space Science and Technology, Trivandrum, India, 4.Department of Geology and Paleontology, National Museum of Nature and Science, Ibaraki 305-0005, Japan.)

[SMP37-09] Multiple sulfur isotope characteristics of felsic-mafic-ultramafic granulites from the Nilgiri Block, southern India

*VINOD O SAMUEL[1], Madhusoodhan Satish-Kumar[2] (1.Department of Earth System Sciences, Yonsei University, Seoul 03722, Republic of Korea, 2.Faculty of Science, Niigata University, Niigata, Japan)

[E] Oral | S (Solid Earth Sciences)：S-MP Mineralogy & Petrology

[S-MP38] Deformed rocks, Metamorphic rocks and Tectonics

convener:Yoshihiro Nakamura(Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology), Yumiko Harigane(Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (AIST))

[SMP38-01] Pure shear deformation experiments of polycrystalline olivine : Relationship between grain shape and crystallographic preferred orientation during diffusion creep

*AKIHIRO ANDO[1], Takehiko Hiraga[1], Kosuke Yabe[1] (1.Earthquake Research Institute, University of Tokyo)

[SMP38-02] Olivine-plagioclase assemblage in orogenic peridotites: Proxy for the extent of lithosphere thinning and asthenosphere shallowing

*Kazuhito Ozawa[1], Carlos J. Garrido[2], Karoly Hidas[3], Jean-Louis Bodinier[4], Tomo Aoki[1], Françoise Boudier[5] (1.Department of Earth and Planetary Science, Graduate School of Science, University of Tokyo, 2.Instituto Andaluz de Ciencias de la Tierra (IACT), CSIC – UGR, Armilla, Granada, Spain, 3.Instituto Geológico y Minero de España (IGME), Tres Cantos, Madrid, Spain, 4.Geosciences Montpellier, Montpellier, France, 5.University of Montpellier, Faculté des Sciences de Montpellier, Place E. Bataillon, 34095 Montpellier, France)

[SMP38-03] Early subduction processes recorded by the metamorphic sole of the Palawan Ophiolite, Philippines

*Gabriel Theophilus Vinalay Valera[1], Tetsuo Kawakami[1], Betchaida Duetes Payot[2] (1.Department of Geology and Mineralogy, Graduate School of Science, Kyoto University, 2.National Institute of Geological Sciences, University of the Philippines)

[SMP38-04] **Transition of melt-fluid infiltration along detachment fault sampled from deformed gabbroic rocks and amphibolites of initial and final stages on the Godzilla Megamullion, Parece Vela Basin, Philippine Sea**

*Yumiko Harigane[1], Jonathan Snow[2], Yasuhiko Ohara[3,4,5] (1.Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (AIST), 2.Louisiana State University, 3.Hydrographic and Oceanographic Department of Japan, 4.JAMSTEC, 5.Nagoya University)

[E] Oral | S (Solid Earth Sciences)：S-MP Mineralogy & Petrology

[S-MP38] Deformed rocks, Metamorphic rocks and Tectonics

convener:Yoshihiro Nakamura(Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology), Yumiko Harigane(Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (AIST))

[SMP38-06] **Fault zone structure and deformation in pelagic sedimentary rocks in the Jurassic chert-clastic complex, Central Japan**

*Wang Ding[1], Kohtaro Ujiie[1] (1.University of Tsukuba)

[SMP38-07] Energy based normalized brittleness index and its relationship with mineralogical composition of shale rock

*Nikita Dubinya[1,2], Kirill Ezhov[3], Aleksander Kolomytsev[3], Daria Petrova[3] (1.Moscow Institute of Physics and Technology, 2.Schmidt Institute of Physics of the Earth of the Russian Academy of Sciences, 3.Center of integrated engineering for e&p of unconventional resources, Gazprom neft)

[SMP38-08] Banded marbles and pseudotachylyte-like veins from the Higo Metamorphic Rocks:Indication of deep earthquake?

*Tadao Nishiyama[1], Ryuraro Nishida[1] (1.Department of Earth and Environmental Sciences, School of Science, Graduate School of Science and Technology, Kumamoto University)

[SMP38-09] Estimating volume change in metamorphic rocks using deformed vein sets example of the Del Puerto canyon region, in the Franciscan belt, W USA

*Shogo Soejima[1], Simon Richard Wallis[1] (1.Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo)

[SMP38-10] Petrologic evidence for ultrahigh-temperature metamorphism in lower crustal granulite xenoliths from Siberian kimberlite pipes

*Shunsuke Fukuhara[1], Tatsuki Tsujimori[1], Shogo Aoki[2], Kazumasa Aoki[2], Vladimir Malkovets[3], Ludmila Pokhilenko[3] (1.Tohoku University, 2.Okayama University of Science, 3.S.V. Sobolev Institute of Geology and Mineralogy)

[SMP38-11] Petrology and metamorphism of pelitic rocks from the internal zone of the Pan-African Lufilian belt, Copperbelt, Zambia

*Kabangu Grace Sakuwaha[1], Toru Takeshita[1] (1.Hokkaido Univ.)

[E] Oral | S (Solid Earth Sciences)：S-MP Mineralogy & Petrology

[S-MP38] Deformed rocks, Metamorphic rocks and Tectonics

convener:Yoshihiro Nakamura(Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology), Yumiko Harigane(Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (AIST))

[SMP38-13] Single-shot laser ablation ICP-MS U-Pb dating of invisible outer-rim of zircon

*Hideki Iwano[1], Takafumi Hirata[2], Yuji Orihashi[3], Tohru Danhara[1], Harutaka Sakai[4] (1.Kyoto Fission-Track Co., Ltd., 2.Geochemical Research Center, University of Tokyo, 3.Hirosaki University, 4.Kyoto University)

[SMP38-14] **Detection of zircon growth pulses and thermal evolution of Ryoke complex**

*Kazuhiro Miyazaki[1], Takeshi Ikeda[2], Hideki Iwano[3], Takafumi Hirata[4], Tohru Danhara[3] (1.Orogenic Processes Research Group, Institute of Geology and Geoinformation, Geological Survey of Japan/National Institute of Advanced Industrial Science and Technology, 2.Kyushu Univ., 3.Kyoto FT, 4.Tokyo Univ.)

[SMP38-15] Dating ductile deformation in a high-temperature/low-pressure type metamorphic terrane (Ryoke belt, Japan)

*Tetsuo Kawakami[1], Tomoe Ichino[1], Shuhei Sakata[2] (1.Graduate School of Science, Kyoto University, 2.Earthquake Research Institute, The University of Tokyo)

[SMP38-16] **Does the Median Tectonic Line in the Chubu district, Japan preserve a subduction interface? Implication for a paired metamorphism in subduction zone**

*Yoshihiro Nakamura[1], Kazuhiro Miyazaki[1], Yutaka Takahashi[1] (1.Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology)

[E] Oral | S (Solid Earth Sciences)：S-MP Mineralogy & Petrology

[S-MP38] Deformed rocks, Metamorphic rocks and Tectonics

convener:Yoshihiro Nakamura(Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology), Yumiko Harigane(Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (AIST))

[SMP38-18] Hydrologic properties evolution during magmatic fluid activity in the middle-crustal conditions estimated from metamorphic fluid-rock reaction zones, Sør Rondane Mountains, East Antarctica.

*Diana Mindaleva[1], Masaoki Uno[1], Atsushi Okamoto[1], Noriyoshi Tsuchiya[1] (1.Graduate school of environmental studies, Tohoku University)

[SMP38-19] Mass transport during carbonate–silicate rock interaction in a collisional orogen: C-O-Sr isotope study of drill core samples from the Hida Belt, Japan.

*Hironobu Harada[1], Tatsuki Tsujimori[1], Keitaro Kunugiza[2], Katsuyuki Yamashita[3], Hideko Takayanagi[1], Yasufumi Iryu[1] (1.Tohoku Univesity, 2.Toyama University, 3.Okayama University)

[SMP38-20] **The formation of micro- to nano-pores in feldspars induced by fluid infiltration within the crust**

*Astin Nurdiana[1], Atsushi Okamoto[1], Masaoki Uno[1], Kenta Yoshida[2], Takayoshi Nagaya[3], Noriyoshi Tsuchiya[1] (1.Tohoku University, 2.Japan Agency for Marine-earth Science and Technology (JAMSTEC), 3.The University of Tokyo)

[SMP38-21] An integrated study of prograde-zoned garnets in low-temperature eclogites: Reappraisal of omphacite antiphase domain geospeedometry and new insights in fluid-induced metamorphic crystal growths

*Ryo Fukushima[1], Tatsuki Tsujimori[1], Nobuyoshi Miyajima[2], Kazumasa Aoki[3] (1.Tohoku University, 2.Bayerisches Geoinstitut, University of Bayreuth, 3.Okayama University of Science)

[SMP38-22] Migration of Albite and Chlorite Rhythmic Bands with Temperature and Pressure Change in the Metamorphic Rocks.

*mitsuhiro toriumi[1] (1.Japan agency of marine science and technology)

[E] Oral | S (Solid Earth Sciences)：S-MP Mineralogy & Petrology

[S-MP39] Oceanic and Continental Subduction Processes

convener:REHMAN Hafiz Ur(Department of Earth and Environmental Sciences, Graduate School of Science and Engineering, Kagoshima University), Tatsuki Tsujimori(Tohoku University), Kazuaki Okamoto(Faculty of Education, Saitama University)

[SMP39-01] **Models for Seismic slip and Fluid Flow along the Subduction Interface**

*Donald M Fisher[1], John N Hooker[1] (1.Pennsylvania State University)

[SMP39-02] Geological records related to ridge subduction in the back-arc basin: a case study from East China Sea Shelf Basin

*Shunli Gao[1], Jun Zhao[1], Senqing Hu[1], Xiaowei Fu[2] (1.China National Offshore Oil Corporation (CNOOC), China Limited-Shanghai, 2.State Key Laboratory of Marine Geology, Tongji University)

[SMP39-03] Slab breakoff tectonics: constraints from temporal changes of melting conditions recorded in geochemical stratigraphy of the Cumulate Member and ultramafic dikes of the Hayachine-Miyamori ophiolite, northeast Japan

*Takafumi Kimura[1], Kazuhito Ozawa[1] (1.Department of Earth and Planetary Science, The University of Tokyo)

[SMP39-04] **Boninites and related tholeiites from the southernmost of West Mariana Arc: geochemical evidence for subduction initiation**

*Ji Zhang[1,2], Guoliang Zhang[1] (1.Institute of Oceanology, Chinese Academy of Sciences, 2.University of Chinese Academy of Sciences)

[SMP39-06] A new scheme of diffusion-limited REE-uptake model for prograde-zoned garnets in low-temperature eclogites: Principle and application

*Ryo Fukushima[1], Tatsuki Tsujimori[1] (1.Tohoku University)

[E] Oral | S (Solid Earth Sciences)：S-MP Mineralogy & Petrology

[S-MP39] Oceanic and Continental Subduction Processes

convener:REHMAN Hafiz Ur(Department of Earth and Environmental Sciences, Graduate School of Science and Engineering, Kagoshima University), Tatsuki Tsujimori(Tohoku University), Kazuaki Okamoto(Faculty of Education, Saitama University)

[SMP39-07] Push out and Phase Transition of Mantle under the Izu Slab, recorded on CMT solutions of JMA

*Nobuaki Niitsuma[1] (1.Institute of Geosciences,Shizuoka University)

[SMP39-08] **Variations in Frictional Properties Depending on Temperature in Tectonic Mélanges of Ancient Accretionary Prisms**

*Tsai-Wei Chen[1], Donald M Fisher[1], Andrew J Smye[1], Chris J Marone[1], Yoshitaka Hashimoto[2] (1.Pennsylvania State University , 2.Kochi University)

[E] Oral | S (Solid Earth Sciences)：S-MP Mineralogy & Petrology

[S-MP40] Thermal structure of subduction zones: modeling and the rock record

convener:Simon Richard Wallis(The University of Tokyo), Takayoshi Nagaya(Graduate School of Science, The University of Tokyo), Shoichi Yoshioka(Research Center for Urban Safety and Security, Kobe University)

[SMP40-01] Bayesian inference of model parameters controlling the thermal structure of subduction zones

*Manabu Morishige[1], Tatsu Kuwatani[1] (1.Japan Agency for Marine-Earth Science and Technology)

[SMP40-02] A holistic view of the thermal structure of subduction zones

★Invited Papers

*Peter E Van Keken[1], Geoff Abers[2], Cian Wilson[1] (1.Carnegie Institution for Science, Washington DC, USA, 2.Cornell University, Ithaca, NY, USA)

[SMP40-03] Subduction zone processes with fluid and melt: numerical model and observations

★Invited Papers

*Hikaru Iwamori[1] (1.Earthquake Research Institute, The University of Tokyo)

[SMP40-04] Low and high stress subduction zones recognized from metamorphic P-T paths

*Simon Richard Wallis[1], Kazuhiko Ishii[2] (1.The University of Tokyo, 2.Osaka Prefecture University)

[SMP40-05] Constraining the temperature conditions of paleo-subduction plate interfaces: Combining petrology and geodynamics

★Invited Papers

*Sarah Penniston-Dorland[1], Kayleigh Harvey[1], Xin Zhou[2], Ikuko Wada[2], Besim Dragovic[3], Peter E Van Keken[4] (1.University of Maryland College Park, 2.University of Minnesota, 3.University of South Carolina, 4.Carnegie Institution for Science)

[SMP40-06] Thermal structure near the continental Moho of subduction zone: Natural example of the Asemigawa region of the Sanbagawa metamorphic belt, SW Japan

*Yui Kouketsu[1], Kazushi Sadamoto[1], Hayato Umeda[2], Hirokazu Kawahara[3], Takayoshi Nagaya[4], Tomoki Taguchi[5], Hiroshi Mori[6], Simon Richard Wallis[4], Masaki Enami[7] (1.Department of Earth & Planetary Sciences, Graduate School of Environmental Studies, Nagoya University, 2.DOWA Metals & Mining Co., Ltd., 3.Japan Oil, Gas and Metals National Corporation (JOGMEC), 4.Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, 5.Department of Geology and Mineralogy, Graduate School of Science, Kyoto University, 6.Faculty of Science, Shinshu University, 7.Nagoya University)

[E] Oral | S (Solid Earth Sciences)：S-VC Volcanology

[S-VC41] Timescales of magmatism: from genesis to eruption

convener:Chamberlain Katy Jane(University of Derby), Iona McIntosh(Japan Agency for Marine-Earth Science and Technology), Kenichiro Tani(Department of Geology and Paleontology, National Museum of Nature and Science), Akihiko Tomiya(Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology)

[SVC41-01] Degassing processes of silicic magma estimated from multivolatile analysis of obsidian pyroclast

★Invited Papers

*Shumpei Yoshimura[1] (1.Department of Earth and Planetary Sciences, Hokkaido University)

[SVC41-02] Decoding the pre-eruptive process by crystal clots: A case study of Unzen 1991-95 eruption

*Kurumi Iwahashi[1], ATSUSHI YASUDA[1], Hidemi Ishibashi[2] (1.Earthquake Research Institute,The University of Tokyo, 2.Shizuoka University)

[SVC41-03] ***Crystal archives of the Havre 2012 submarine rhyolite eruption: Understanding the origin of crystal-poor rhyolites***

*Joseph Knafelc[1], Scott E. Bryan[1], Henrietta Cathey[1], David Gust[2] (1.School of Earth, Environmental and Biological Sciences, Queensland University of Technology, Brisbane, Australia, 2.Institute of Future Environments, Central Analytical Research Facility, Queensland University of Technology, Brisbane, Australia)

[SVC41-04] **Extent of late Holocene volcanic activity in Southern Patagonia**

*Maximillian Van Wyk de Vries[1], Emi Ito[1], Mark Shapley[1], Guido Brignone[2], Shanti Penprase[1], Alexander Schmies[1] (1.University of Minnesota, Twin Cities, 2.University of Cordoba)

[SVC41-05] **Time constraints on magma ascent from volatile element diffusion in apatite**

★Invited Papers

*Weiran Li[1], Fidel Costa[1,2], Sumit Chakraborty[3], Kazuhide Nagashima[4] (1.Earth Observatory of Singapore, Nanyang Technological Univ, 2.Asian School of Environment, Nanyang Technological Univ, 3.Ruhr Universität Bochum, Germany, 4.Univ. of Hawai‘i at Mānoa)

[SVC41-06] Plagioclase and biotite in holocrystalline composite dike record pre-solidification chemical diffusion in melt

*Ayu Yamazaki[1], Tetsuo Kawakami[1], Fumiko Higashino[2] (1.Department of Geology and Mineralogy, Graduate school of Science, Kyoto University , 2.Faculty of Science, Okayama University of Science)

[E] Oral | S (Solid Earth Sciences)：S-VC Volcanology

[S-VC42] Dynamics of volcanic eruptions and their physical and chemical processes

convener:Atsuko Namiki(Graduate School of Integrated Arts and Sciences, Hiroshima University), Christian Huber(Brown University), Michael Manga(University of California Berkeley), Yujiro Suzuki(Earthquake Research Institute, The University of Tokyo)

[SVC42-01] Magma flow style based on deformed bubble structure of pumice

*Masatoshi Ohashi[1], Mie Ichihara[2] (1.Department of Earth and Planetary Sciences, Graduate School of Science, Kyushu University, 2.Earthquake Research Institute, the University of Tokyo)

[SVC42-03] **The dynamics of buoyancy driven fragmentation in a deep subaqueous volcanic eruption, observations of the 2009 eruption of West Mata**

*Arran Peter Murch[1], Ryan A. Portner[2], Kenneth H. Rubin[3], David A. Clague[4] (1.Department of Geology and Paleontology, National Museum of Nature and Science, Tsukuba, Japan , 2.Geology Department, San Jose State University, USA, 3.SOEST, University of Hawaii at Manoa, USA, 4.Monterey Bay Aquarium Research, Moss Landing, USA)

[SVC42-04] Eruption mechanics of the 2012 eruption of Mount Tongariro, NZ: Revealed by temporal Magnetotellurics

*Graham Hill[1,2], Hugh Bibby[3], Jared Peacock[4], Erin Wallin[5], Yasuo Ogawa[6], Luca Caricchi[7], Harry Keys[8], Stewart Bennie[3], Yann Avram[9] (1.Institute of Geophysics, Czech Academy of Science, Prague, Czech Republic, 2.Gateway Antarctica, University of Canterbury, Christchurch, New Zealand, 3.GNS Science, Lower Hutt, New Zealand, 4.United States Geological Survey, Menlo Park CA, USA, 5.United States Army Corps of Engineers, Huntsville AL, USA, 6.Volcanic Fluid Research Centre, Tokyo Institute of Technology, Tokyo, Japan, 7.Department of Earth Sciences, University of Geneva, Geneva, Switzerland, 8.Department of Conservation, Turangi, New Zealand, 9.Phoenix Geophysics, Toronto, Canada)

[SVC42-05] Fluid ascent dynamics of the Onikobe geyser, NE Japan: Insight from the thermal infrared imagery

*Noriko Teshima[1], Takeshi Nishimura[1], Hiroshi Aoyama[2], Ayuta Tsuge[2] (1.Department of Geophysics, Graduate School of Science, Tohoku University, 2.Institute of Seismology and Volcanology, Faculty of Science, Hokkaido University)

[E] Oral | S (Solid Earth Sciences)：S-VC Volcanology

[S-VC42] Dynamics of volcanic eruptions and their physical and chemical processes

convener:Atsuko Namiki(Graduate School of Integrated Arts and Sciences, Hiroshima University), Christian Huber(Brown University), Michael Manga(University of California Berkeley), Yujiro Suzuki(Earthquake Research Institute, The University of Tokyo)

[SVC42-07] An analysis of the relationship between mass eruption rate and runout distance of pyroclastic density currents

★Invited Papers

*Olivier Roche[1], Nourddine Azzaoui[2], Arnaud Guillin[2] (1.Laboratoire Magmas et Volcans, Université Clermont Auvergne-CNRS-IRD, OPGC, Clermont-Ferrand, France, 2.Laboratoire de Mathématiques Blaise Pascal, Université Clermont Auvergne-CNRS, Clermont-Ferrand, France)

[SVC42-08] 3D numerical simulations of volcanic jets inside a crater during explosive volcanic eruptions

*Fiodar Perakozhau[1], Takehiro Koyaguchi[1] (1.Earthquake Research Institute, the University of Tokyo)

[SVC42-09] Simulating tephra fall deposit from a bending eruption plume: development of a new code and its validation using inversion

*Kazutaka Mannen[1] (1.Hot Springs Research Institute of Kanagawa Prefecture)

[SVC42-10] Dynamics of ballistic projectiles based on Trashcano experiment

*Saruta Shusaku[1], Kae Tsunematsu[1], Isao Motoyama[1] (1.Yamagata University)

[SVC42-12] **ERUPTION DYNAMICS AND CONDUIT PROCESS OF THE 52-ka MANINJAU CALDERA FORMING ERUPTION, WEST SUMATRA, INDONESIA**

*Indranova Suhendro[1], Atsushi Toramaru[1], Agung Harijoko[2,3], Haryo Edi Wibowo[2,3] (1.Department of Earth and Planetary Sciences, Graduate School of Sciences, Kyushu University, 2.Department of Geological Engineering, Faculty of Engineering, Universitas Gadjah Mada, Jl. Grafika no. 2, Yogyakarta, 3.Center for Disaster Studies Universitas Gadjah Mada, Jl. Mahoni C-16 Bulaksumur, Yogyakarta)

[E] Oral | S (Solid Earth Sciences)：S-VC Volcanology

[S-VC43] Magma crystallization, fragmentation, and their roles on volcanic eruption

convener:Takahiro Miwa(National research institute for earth science and disaster prevention), Satoshi Okumura(Division of Earth and Planetary Materials Science, Department of Earth Science, Graduate School of Science, Tohoku University), Pranabendu Moitra(University of Arizona)

[SVC43-01] **Highly explosive basaltic eruptions: magma fragmentation induced by rapid crystallisation**

★Invited Papers

*Mike Burton[1], Fabio Arzilli[1], Giuseppe La Spina[1], Margherita Polacci[1], Nolwenn Le Gall[2], Margaret Hartley[1], Danilo Di Genova[3], Biao Cai[4], Nghia Vo[5], Sara Nonni[1], Robert Atwood[5], Edward Llewellin[6], Richard Brooker[7], Heidy Mader[7], Peter Lee[2] (1.Department of Earth and Environmental Sciences, University of Manchester, Manchester M13 9PL, UK, 2.Department of Mechanical Engineering, University College London, London, UK, 3.Institute of Non-Metallic Materials, Clausthal University of Technology, Zehntner Str. 2a, 38678 Clausthal-Zellerfeld, Germany, 4.School of Metallurgy and Materials, University of Birmingham, Birmingham B15 2TT, UK, 5.Diamond Light Source, Harwell Science and Innovation Campus, Didcot OX11 0DE, UK, 6.Department of Earth Sciences, Durham University, Durham DH1 3LE, UK, 7.School of Earth Sciences, University of Bristol, Bristol BS8 1RJ, UK)

[SVC43-02] Petrological Constraints on the Magma Fragmentation Pressure on the Hoei Eruption (AD 1707) of Fuji Volcano - Implications for the dynamics of Basaltic Plinian Eruptions

*Kyungmin Kim[1], Michihiko Nakamura[1], Tomofumi Kozono[2], Mitsuhiro Yoshimoto[3] (1.Department of Earth Science, Graduate School of Science, Tohoku University, Sendai, Japan, 2.Department of Geophysics, Graduate School of Science, Tohoku University, Sendai, Japan, 3.Mount Fuji Research Institute, Yamanashi Prefecture Government, Japan)

[SVC43-03] Role of crystallization and conduit structure on small transitions of Strombolian eruption at Suwanosejima volcano, SW Japan

*Taketo Shimano[1], Atsushi Yasuda[2], Masato Iguchi[3] (1.Graduate School of Environment and Disaster Research, Tokoha University, 2.Earthquake Research Institute, University of Tokyo, 3.Disaster Prevention Research Institute, Kyoto University)

[SVC43-04] Importance of Q as a measure of the fragmentation potential

★Invited Papers

*Atsuko Namiki[1], Yukie Tanaka[1], Satoshi Okumura[2], Osamu Sasaki[2], Kyohei Sano[3], Shingo Takeuchi[4] (1.Hiroshima University, 2.Tohoku University, 3.University of Hyogo, 4.Central Research Institute of Electric Power Industry)

[SVC43-05] **Heterogeneities in Crystal from YTT (74 ka) and the Implications for Toba Magma Chamber Systems**

*Gabriela Nogo Retnaningtyas Bunga Naen[1], Atsushi Toramaru[1], Tomoharu Miyamoto[1], Haryo Edi Wibowo[2] (1.Department Earth and Planetary Sciences, Kyushu University, Fukuoka, Japan, 2.Geological Engineering Departement, Universitas Gadjah Mada, Yogyakarta, Indonesia)

[SVC43-06] Crystal-size distribution and micro-textural variation of Holocene volcanic products from the last 2000 years eruption of Kelud Volcano, Indonesia: an approach to understand the conduit dynamics.

*Jananda Nuralam Indriyanto[1], Tsukasa Ohba[1], Takashi Hoshide[1], Mirzam Abdurrachman[2] (1.Faculty of International Resource Sciences, Akita University, 2.Department of Geological Engineering, Bandung Institute of Technology)

[E] Oral | S (Solid Earth Sciences)：S-GC Geochemistry

[S-GC48] Volatiles in the Earth - from Surface to Deep Mantle

convener:Takeshi Hanyu(Japan Agency for Marine-Earth Science and Technology, Research Institute for Marine Geodynamics), Gray E Bebout(Lehigh University), Hirochika Sumino(Department of Basic Science, Graduate School of Arts and Sciences, The University of Tokyo), Yuji Sano(Division of Ocean and Earth Systems, Atmosphere and Ocean Research Institute, University of Tokyo)

[SGC48-01] Spatial distribution of halogen compositions near the paleo slab-mantle wedge boundary, example from the Sanbagawa metamorphic belt

*JIE REN[1], Hirochika Sumino[1], Yui Kouketsu[2], Simon Richard Wallis[3] (1.Graduate School of Arts and Sciences, The University of Tokyo , 2.Graduate School of Enviromental Studies, Nagoya University, 3.Graduate School of Science, The University of Tokyo)

[SGC48-02] Multiple halogen components in subcontinental lithospheric mantle revealed by single-grain analysis of mantle-derived xenoliths

*Hirochika Sumino[1], Sota Niki[2], Ray Burgess[3], Masahiro Kobayashi[4], Hiroyuki Kagi[2] (1.Department of Basic Science, Graduate School of Arts and Sciences, The University of Tokyo, 2.Geochemical Research Center, Graduate School of Science, University of Tokyo, 3.School of Earth and Environmental Sciences, University of Manchester, 4.Tokyo Metropolitan Industrial Technology Research Institute)

[SGC48-03] **C-N-He-Ar Cycling at the Hikurangi Subduction Margin, New Zealand**

Gabe S Epstein[1], *Gray E Bebout[1,2], Bruce W Christenson[3], Hirochika Sumino[4], Ikuko Wada[5], Cynthia A Werner[6], David R Hilton[7] (1.Dept. Earth and Environmental Sciences, Lehigh University, USA, 2.Okayama University, Institute for Planetary Materials, 3.National Isotope Center, GNS Science, New Zealand, 4.Dept. of Basic Science, University of Tokyo, 5.Dept. of Earth Sciences, University of Minnesota, USA, 6.USGS-Contractor, USA, 7.Scripps Institution of Oceanography, USA)

[SGC48-04] Helium and carbon characteristics in forearc fluids of Central America

★Invited Papers

*Peter H Barry[1], J. M. de Moor[2], M. Nakagawa[3], D. Giovannelli[4], M. Schrenk[5], A. M. Selzer[1], K. G. Lloyd[6] (1.Woods Hole Oceanographic Institution, 2.Observatorio Volcanológico y Sismológico de Costa Rica (OVSICORI), Universidad Nacional, Costa Rica, 3.Earth-Life Science Institute, Tokyo Institute for Technology, Tokyo, Japan, 4.Department of Biology, University of Naples “Federico II”, Naples, Italy, 5.Department of Earth and Environmental Sciences, Michigan State University, MI, USA, 6.Department of Microbiology, University of Tennessee, TN, USA)

[SGC48-05] Evidence for volatile-rich mantle transition zone beneath NE China: implication from the geochemistry of melt inclusions from Wudalianchi basalts

*Tetsuya Sakuyama[1], Yuma Hayashi[1], Kenji Shimizu[2], Takayuki Ushikubo[2], Takeshi Hanyu[3], Jun-Ichi Kimura[3], Wei Tian[4] (1.Faculty of Science, Osaka City University, 2.Kochi Institute for Core Sample Research, JAMSTEC, 3.JAMSTEC, Yokosuka, 4.Peking University)

[SGC48-06] **Crustal and mantle degassing in continental China**

★Invited Papers

*Maoliang Zhang[1], Zhengfu Guo[2], Sheng Xu[1], Yuji Sano[3,1], Peter H. Barry[4] (1.Tianjin University, 2.Institute of Geology and Geophysics, Chinese Academy of Sciences, 3.The University of Tokyo, 4.Woods Hole Oceanographic Institution)

[E] Oral | S (Solid Earth Sciences)：S-GC Geochemistry

[S-GC48] Volatiles in the Earth - from Surface to Deep Mantle

convener:Takeshi Hanyu(Japan Agency for Marine-Earth Science and Technology, Research Institute for Marine Geodynamics), Gray E Bebout(Lehigh University), Hirochika Sumino(Department of Basic Science, Graduate School of Arts and Sciences, The University of Tokyo), Yuji Sano(Division of Ocean and Earth Systems, Atmosphere and Ocean Research Institute, University of Tokyo)

[SGC48-08] **Investigating past eruptive activity of a silicic submarine volcano using FTIR volatile analyses**

*Iona McIntosh[1], Kenichiro Tani[2], Alexander Robert Lee Nichols[3], Qing Chang[1], Jun-Ichi Kimura[1] (1.Japan Agency for Marine-Earth Science and Technology, Yokosuka, Japan, 2.National Museum of Nature and Science, Tsukuba, Japan, 3.University of Canterbury, Christchurch, New Zealand)

[SGC48-09] **Reactive evolution of carbonated silicate melt in the mantle lithosphere**

*Guoliang Zhang[1,3], Shuai Wang[1,2], Ji Zhang[1,2], Ming-Jun Zhan[1,2], Zhi-Hua Zhao[1,2] (1.Institute of Oceanology, Chinese Academy of Sciences, 2.University of Chinese Academy of Sciences, 3.Center for Ocean Mega-Science, Chinese Academy of Sciences)

[SGC48-10] **.** ***The conditions of sub-lithospheric diamond formation constrained from ferric iron-rich exsolution in ferropericlase inclusions in diamond*** **.**

*Caterina Melai[1], Daniel Frost [1], Tiziana Boffa Ballaran[1], Catherine McCammon[1], Katharina Marquardt [2] (1.Bayerisches Geoinstitut, Universitaet Bayreuth, 2.Imperial College, London)

[SGC48-11] **The effects of carbon concentration and silicate melt structure on the metal-silicate partitioning of carbon in a shallow magma ocean**

*Hideharu Kuwahara[1], Akimasa Suzumura[2], Shoichi Itoh[2], Ryoichi Nakada[3], Tetsuo Irifune[1,4] (1.Geodynamics Research Center, Ehime University, 2.Graduate School of Science, Kyoto University, 3.Kochi Institute for Core Sample Research, Japan Agency for Marine-Earth Science and Technology (JAMSTEC), 4.Earth-Life Science Institute, Tokyo Institute of Technology)

[SGC48-12] Subduction barrier for argon

★Invited Papers

*Shigeaki Ono[1] (1.Japan Agency for Marine-Earth Science and Technology)

[E] Oral | S (Solid Earth Sciences)：S-TT Technology & Techniques

[S-TT50] Synthetic Aperture Radar and its application

convener:Yohei Kinoshita(University of Tsukuba), Yu Morishita(Geospatial Information Authority of Japan), Shoko Kobayashi(Tamagawa University), Takahiro Abe(Earth Observation Research Center, Japan Aerospace Exploration Agency)

[STT50-01] Trial of deforestation detection accuracies improvement for JJ-FAST algorithm by using deep learning.

*Manabu Watanabe[1], Christian Naohide koyama[1], Masato Hayashi[2], Isumi Nagatani[2], Takeo Tadono[2], Masanobu Shimada[1] (1.School of Science and Engineering, Tokyo denki university, 2.JAXA/EORC)

[STT50-02] **Changes in surface conditions and permafrost environment of a summit area of the Daisetsu Mountains, Hokkaido, Japan**

*Go Iwahana[1], Toshio Sone[2], Masao Uchida[3], Tokuta Yokohata[3] (1.International Arctic Research Center, University of Alaska Fairbanks, 2.Institute of Low Temperature Science, Hokkaido University, 3.National Institute for Environmental Studies)

[STT50-03] **Determination of the dipping direction of a blind reverse fault from InSAR: Case study on the 2017 Sefid Sang earthquake, Northeastern Iran**

*Nematollah Ghayournajarkar[1], Yo Fukushima[2] (1.Graduate School of Science, Tohoku University, 2.International Research Institute of Disaster Science, Tohoku University)

[STT50-04] **DefVolc: Interface and web service for fast computation of volcano displacement**

*Valerie Cayol[1], Farshid Dabaghi[2], Yo Fukushima[3], Marine Tridon[1], Delphine Smittarello[4], Olivier Bodart[2], Jean-Luc Froger[1] (1.CNRS, UCA, LMV, OPGC, IRD, Clermont-Ferrand, France, 2.UdL, ICJ, Saint-Etienne, France, 3.IRIDeS, TU, Tohoku, Japan, 4.UGA, USMB, CNRS, IRD,IFSTTAR, ISTerre, Grenoble, France)

[E] Oral | S (Solid Earth Sciences)：S-TT Technology & Techniques

[S-TT50] Synthetic Aperture Radar and its application

convener:Yohei Kinoshita(University of Tsukuba), Yu Morishita(Geospatial Information Authority of Japan), Shoko Kobayashi(Tamagawa University), Takahiro Abe(Earth Observation Research Center, Japan Aerospace Exploration Agency)

[STT50-05] Ups and downs in the Osaka metropolitan area, Japan, detected by LiCSBAS InSAR time-series analysis

*Yo Fukushima[1] (1.International Research Institute of Disaster Science, Tohoku University)

[STT50-06] Time-series surface displacements in Taiwan using Sentinel-1 wide-swath SAR data

*Shoki Hiranaka[1], Kazuya Ishitsuka[1], Weiren Lin[1] (1.Kyoto University)

[STT50-07] Deep learning InSAR: atmospheric noise removal and small deformation signal extraction from InSAR time series using a convolutional autoencoder

*Bertrand Rouet-Leduc[1], Manon Dalaison[2], Claudia Hulbert[2], Paul Johnson[1], Romain Jolivet[2] (1.Los Alamos National Laboratory, USA, 2.Ecole Normale Superieure, France)

[STT50-08] Mitigation of ionospheric noise in azimuth pixel offset based on the split-spectrum method

*Tatsuya Yamashita[1], Tomokazu Kobayashi[1], Yu Morishita[1] (1.GSI of Japan)

[STT50-09] Detection of huge deformation by SAR interferometry with split-spectrum method

*Taku Ozawa[1], Yuji Himematsu[1] (1.National Research Institute for Earth Science and Disaster Resilience)

[E] Oral | S (Solid Earth Sciences)：S-TT Technology & Techniques

[S-TT51] seismic monitoring and processing system

convener:Takahiro Maeda(National Research Institute for Earth Science and Disaster Resilience)

[STT51-01] Automatic identification of airgun signals observed by ocean bottom seismic network

*Koji Tamaribuchi[1] (1.Meteorological Research Institute)

[STT51-02] Processing the Deep-towed Autonomous Continous System (ACS) Data in Joetsu Basin, Niigata Prefecture, Japan

*Fernando Lawrens Hutapea[1,2,3], Takeshi Tsuji[1,2,4], Eiichi Asakawa[5], Masafumi Kato[6] (1.Department Earth Resources Engineering, Kyushu University, Japan, 2.International Institute for Carbon-Neutral Energy Research (WPI-I2CNER), Kyushu University, Japan, 3.Exploration and Engineering Seismology Research Group, Institute Technology of Bandung (ITB), Indonesia, 4.Disaster Prevention Research Institute, Kyoto University, Japan, 5.JGI, Inc. Japan, 6.Japan Oil Gas and Metals National Corporation (JOGMEC), Japan)

[STT51-03] Performance evaluation of seismic observation system using phase-shifted optical interferometry

*Yoshiharu Hirayama[1], Minemori Sato[1], Atsushi Takahara[1], Toshiharu Ikeda[1], Keiji Takeuchi[1], Taiichi Taniguchi[1], Yoshihiro Sawada[2] (1.Hakusan Corporation, 2.Association for the Development of Earthquake Prediction)

[STT51-04] Extracting Noise-Correlation Functions from Analogue Seismograms

Thomas Lee[1], *Miaki Ishii[1], Paul Okubo (1.Department of Earth & Planetary Sciences, Harvard University)

[STT51-05] Crustal Thickness Behind the Tonga Arc Measured by Stacking of pP Precursors

*Lauren McLeod[1], Larry D Brown[1] (1.Cornell Univ.)

[STT51-06] Investigation on the traceable calibration of sensors for monitoring the seismic activities based on the international metrology system

*Wan-Ho Cho[1], Yong-Bong Lee[1], Sung-Soo Jung[1], Byeng-Su Jeon[1] (1.Korea Research Institute of Standards and Science)

[E] Oral | S (Solid Earth Sciences)：S-TT Technology & Techniques

[S-TT52] Seismic Big Data Analysis Based on the State-of-the-Art of Bayesian Statistics

convener:Hiromichi Nagao(Earthquake Research Institute, The University of Tokyo), Aitaro Kato(Earthquake Research Institute, the University of Tokyo), Keisuke Yano(The University of Tokyo, Graduate School of Information Science and Technology), Takahiro Shiina(Earthquake Research Institute, The University of Tokyo)

[STT52-01] Multiple classes of non-tectonic emergent and impulsive seismic noise identified in continuous waveforms

★Invited Papers

*Christopher W Johnson[1,2], Yehuda Ben-Zion[3] (1.Scripps Institution of Oceanography, 2.Los Alamos National Lab, 3.University of Southern California)

[STT52-02] Uncertainty Quantification for Inhomogeneous Frictional Features in a Slow-Slipping Fault Based on a Large-Scale Four-Dimensional Variational Data Assimilation

*Shin-ichi Ito[1], Masayuki Kano[2], Hiromichi Nagao[1] (1.The University of Tokyo, 2.Tohoku University)

[STT52-03] A hidden Markov model for overlapping of seismic waves

*Sumito Kurata[1], Keisuke Yano[1], Fumiyasu Komaki[1] (1.Graduate School of Information Science and Technology, The University of Tokyo)

[STT52-04] Prediction of Aftershocks With Gaussian Process Regression: Application to the 2004 Chuetsu Earthquake

*Kosuke Morikawa[1], Hiromichi Nagao[2], Shin-ichi Ito[2], Yoshikazu Terada[1,3], Shin'ichi Sakai[2], Naoshi Hirata[2] (1.Osaka University, 2.The University of Tokyo, 3.RIKEN AIP)

[STT52-05] On statistical declustering of global earthquake catalogue

★Invited Papers

*Debashis Mondal[1], Suhas Sastry[1] (1.Oregon State University)

[E] Oral | S (Solid Earth Sciences)：S-TT Technology & Techniques

[S-TT53] Airborne surveys and monitoring of the Earth

convener:Shigekazu Kusumoto(Graduate School of Science and Engineering for Research, University of Toyama), Takao Koyama(Earthquake Research Institute, The University of Tokyo), Yuji Mitsuhata(AdvancedIndustrial Science and Technology), Shigeo Okuma(Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (AIST))

[STT53-01] Compute environment agnostic scientific research platform for exploration geophysics

★Invited Papers

*Pavel Golodoniuc[1], Davis Aaron[1], Samuel Bradley[1], Shane Mule[1], John Hille[1] (1.CSIRO)

[STT53-02] Investigation of geological structure using airborne electromagnetic survey method in which transmitter and receiver are towed by drone.

★Invited Papers

*Youichi Yuuki[1], akira shinsei[1], satoshi tomimori[1], Zenshiro Saito[1], akira jomori[2], atsuyoshi jomori[2] (1.Oyo corporation, 2.Neo Science)

[STT53-03] Special Techniques for Airborne Survey Technologies Using Unmanned Helicopters in Noboribetsu Volcano

*Tomoya Hayakawa[1], Keitaro Yoshikawa[2], Takeshi hashimoto[3] (1.NIPPON KOEI CO., LTD., 2.Hokkaido Regional Development Bureau, 3.Hokkaido University Institute of Seismology and Volcanology)

[STT53-04] Repeated aeromagnetic survey of Noboribetsu volcano

Akinori Satoh[1], *Takeshi Hashimoto[1], Tomoya Hayakawa[2], Keitaro Yoshikawa[3], Takao Koyama[4] (1.Institute of Seismology and Volcanology, Graduate School of Science, Hokkaido University, 2.Nippon Koei Co.,Ltd, 3.Hokkaido Regional Development Bureau, 4.Earthquake Research Institute, The University of Tokyo)

[STT53-05] Evaluation of a UAV-enabled Magnetometer for Geophysical Survey in Volcanic Areas

*Shigeo Okuma[1], Masahiko Makino[2], Ayumu Miyakawa[1], Tadashi Nakatsuka[1], Shogo Komori[3], Yoshiki Sugino[1], makoto yanagida[4], Atsushi Oshida[5] (1.Insititute of Geology and Geoinformation, National Institute of Advanced Industrial Science and Technology (AIST), 2.Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (AIST), 3.Research Institute for Geo-Resources and Environment, National Institute of Advanced Industrial Science and Technology (AIST), 4.Hanshin Consultants Co., Ltd., 5.Kawasaki Geological Engineering Co., Ltd.)

[STT53-06] The initial report of aeromagnetic studies for Nishinoshima

*Noriko Tada[1], Hiroshi Ichihara[2], Takao Koyama[3], Kiyoshi Baba[3], Akimichi Takagi[4], Fukashi Maeno[3], Minoru Takeo[3] (1.Japan Agency for Marine-Earth Science and Technology, 2.Nagoya University, 3.Earthquake Research Institute, The University of Tokyo, 4.Japan Meteorological Agency)

[E] Oral | S (Solid Earth Sciences)：S-TT Technology & Techniques

[S-TT54] Creating future of solid Earth science with high performance computing (HPC)

convener:Takane Hori(R&D Center for Earthquake and Tsunami, Japan Agency for Marine-Earth Science and Technology), Yuji Yagi(Graduate School of Life and Environmental Sciences, University of Tsukuba, Tsukuba), Katsuhiko Shiomi(National Research Institute for Earth Science and Disaster Resilience)

[STT54-01] Exploiting exascale computing to unravel multi-physics and multi-scale earthquake dynamics and seismic wave propagation

★Invited Papers

*Alice-Agnes Gabriel[1], Bo Li[1], Duo Li[1], Thomas Ulrich[1], Carsten Uphoff[1] (1.Department of Earth and Environment Sciences, Ludwig-Maximilians-Universitat Munchen)

[STT54-02] Development and application of large scale numerical simulations for earthquake generation, ground motion and non-linear soil amplification

*Takane Hori[1], Tsuyoshi Ichimura[2], Kohei Fujita[2], Ryoichiro Agata[1] (1.Research Institute for Marine Geodynamics, Japan Agency for Marine-Earth Science and Technology, 2.Earthquake Research Institute, The University of Tokyo)

[STT54-03] **Computing 3-D Viscoelastic Earthquake Cycle Models for Cascadia Using Large-Scale, High-Fidelity Finite Element Methods**

*Kaj M Johnson[1], Takane Hori[2], Tsuyoshi Ichimura[3], Kohei Fujita[3] (1.Indiana University Bloomington, 2.Research Institute for Marine Geodynamics, JAMSTEC , 3.Earthquake Research Institute & Department of Civil Engineering, The University of Tokyo)

[STT54-04] Fast and scalable finite-element solvers for three-dimensional urban earthquake simulation

*Kohei Fujita[1], Tsuyoshi Ichimura[1], Takuma Yamaguchi[1], Muneo Hori[2], Lalith Wijerathne[1] (1.Earthquake Research Institute, The University of Tokyo, 2.Japan Agency for Marine-Earth Science and Technology)

[STT54-05] Finite element solver for large-scale three-dimensional soil liquefaction analysis

★Invited Papers

*Ryota Kusakabe[1], Tsuyoshi Ichimura[1], Kohei Fujita[1], Muneo Hori[2], Lalith Wijerathne[1] (1.Earthquake Research Institute, The University of Tokyo, 2.Japan Agency for Marine-Earth Science and Technology)

[STT54-06] Large-scale finite element simulation of earthquake ground motion and its numerical verification aiming for enhanced earthquake damage estimation

*Ryoichiro Agata[1], Kohei Fujita[2,3], Tsuyoshi Ichimura[2,3,4], Takane Hori[1] (1.Japan Agency for Marine-Earth Science and Technology, 2.Earthquake Research Institute, The University of Tokyo, 3.RIKEN Center for Computational Science, 4.RIKEN Center for Advanced Intelligence Project)

[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG55] Petrology, Mineralogy & Resource Geology

convener:Yu Nishihara(Geodynamics Research Center Ehime University), Koichi Momma(National Museum of Nature and Science), Tatsuo Nozaki(Submarine Resources Research Center, Research Institute for Marine Resources Utilization, Japan Agency for Marine-Earth Science and Technology), Nobutaka Tsuchiya(Department of Geology, Faculty of Education, Iwate University)

[SCG55-01] The relationship between the morphology of entablature and the magma cooling process in the Genbudo lava, Iwate Prefecture

*Takashi Hoshide[1], Nao Ishibashi[1] (1.Faculty of International Resource Sciences, Akita University)

[SCG55-02] Preliminary paleomagnetic results from the manganese wad deposit at the Sanbe hot springs, Shimane.

*Kazuo Kawasaki[1], Sunao Kobayashi[2] (1.School of Sustainable Design, University of Toyama, 2.Department of Earth Sciences, University of Toyama)

[SCG55-03] Geochemistry of Middle Permian Tavantolgoi sandstone: Implications for paleoclimate and provenance

*Bat-Orshikh Erdenetsogt[1], Enkhbayar Bolormaa[1], Dashpuntsag Nansalmaa[1], Baigalmaa Norov[1], Bat Bold[1], Luvsanchultem Jargal[1] (1.National University of Mongolia)

[SCG55-04] Proposal for novel quantitative classification method of below the hundred-micron particle in soils using a microscope Raman spectroscopy combined with an automated image analysis.

*Daisuke Sasakura[1], Aiko Hayauchi[1] (1.Malvern Japan ,Div of Spectris Co.Ltd,.)

[SCG55-05] High-pressure phase relations of K-bearing NAL phase with implications to aluminosilicate inclusions in superdeep diamonds in kimberlites

*Masaki Akaogi[1], Fumiya Kimura[1], Hiroshi Kojitani[1] (1.Department of Chemistry, Faculty of Science, Gakushuin University)

[SCG55-06] Rheology of bcc-iron at high-pressure and -temperature

*Yu Nishihara[1], Yuji Higo[2], Yoshinori Tange[2] (1.Geodynamics Research Center, Ehime University, 2.Japan Synchrotron Radiation Research Institute)

[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG56] ICDP Oman Drilling Project: Oman to Oceanic Lithosphere to Island Arc Formation and Beyond

convener:Eiichi TAKAZAWA(Department of Geology, Faculty of Science, Niigata University), Katsuyoshi Michibayashi(Department of Earth and Planetary Sciences, Nagoya University), Sayantani Chatterjee(Niigata University, Department of Geology, Faculty of Science)

[SCG56-01] Feedback between melt percolation and deformation at Oman crust-mantle transition zone: ICDP_ Exp. 807 Holes CM1A and CM2B

★Invited Papers

*Fatma Kourim[1], Katsuyoshi Michibayashi[2], Kou-Lung Wang[1,3], Jürgen Koepke[4], Mathieu Rospabé[5], Mary-Alix Kaczmarek[6], Eiichi Takazawa[7], Damon A-H Teagle[8], Marguerite Godard[9], Mathieu Benoit[6], Peter Kelemen[10], Yuki Kakihata[2], Oman Drilling Project Phase 2 Science Party (1.Institute of Earth Sciences, Academia Sinica, 2.Nagoya University, 3.National Taiwan University, 4.Hannover University, 5.Research Institute for Marine Geodynamics, JAMSTEC, 6.Toulouse university, 7.Nigata University, 8.Southampton University, 9.University of Montpellier, 10.Columbia University)

[SCG56-02] Important role of the ultramafic layers in the lower oceanic crust and Moho

*Natsue Abe[1,2], Keishi Okazaki[3], Kohei Hatakeyama[4], Yuya Akamatsu[4], Ikuo Katayama[4], Benoit Ildefonse[5], Katsuyoshi Michibayashi[6], Eiichi TAKAZAWA[7], Damon A H Teagle[8], Peter B Kelemen[9], Science Party The Oman Drilling Project (1.Mantle Drilling Promotion Office, MarE3, Japan Agency for Marine-Earth Science and Technology , 2.Graduate School of Natural Science & Technology, Kanazawa University, 3.KCC, X-star, Japan Agency for Marine-Earth Science and Technology , 4.Hiroshima University, 5.University of Montpellier, 6.Nagoya University, 7.Niigata University, 8.University of Southampton, 9.LDEO, Columbia University)

[SCG56-03] An idea of borehole measurements at Mantle drilling: insights from the OmanDP

★Invited Papers

*Yasuhiro Yamada[1,2,3], KYAW MOE[1], Kazuya Shiraishi[1] (1.Japan Agency for Marine-Earth Science and Technology (JAMSTEC), 2.Kochi University, Japan, 3.Royal Holloway University of London, UK)

[SCG56-04] Strontium isotopic compositions of mantle peridotites in the Oman ophiolite

*Jiwon Eom[1], Shigeyuki Wakaki[2], Norikatsu Akizawa[1], Tsuyoshi Ishikawa[2], Kyoko Yamaoka[3], Eiichi TAKAZAWA[4], Hodaka Kawahata[1] (1.Atmosphere and Ocean Research Institute, The University of Tokyo, 2.Kochi Institute for Core Sample Research, JAMSTEC, 3.Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology, 4.Department of Geology, Faculty of Science, Niigata University)

[SCG56-05] Reconstruction of peridotite textures preserved within serpentinites from BA site of Oman Drilling Project Phase II

*Kakihata Yuki[1], Katsuyoshi Michibayashi[1], Laura Crispini[2], Oman Drilling Project Phase2 Science Party (1.Nagoya University Graduate School of Environmental Studies, 2.University of Genova)

[SCG56-06] Rock Magnetic Properties of Oman Drilling Project Cores BA1B, BA3A, BA4A and Its Implications on Iron Oxide Alteration

*Gilbert Hong[1], Jessica Lynn Till[2], Annika Greve[3], Sang-Mook Lee[1], Oman Drilling Project Phase 2 Science Party - (1.Seoul National University, 2.University of Iceland, 3.Utrecht University)

[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG56] ICDP Oman Drilling Project: Oman to Oceanic Lithosphere to Island Arc Formation and Beyond

convener:Eiichi TAKAZAWA(Department of Geology, Faculty of Science, Niigata University), Katsuyoshi Michibayashi(Department of Earth and Planetary Sciences, Nagoya University), Sayantani Chatterjee(Niigata University, Department of Geology, Faculty of Science)

[SCG56-07] Melt-rock interaction processes inferred from spinel-bearing layered gabbros in the Hess deep rift, East Pacific Rise

*Keita Kondo[1], Takashi Hoshide[1] (1.Faculty of International Resource Science, Akita University)

[SCG56-08] **Petrography and geochemistry of lower crustal gabbros at Oman ophiolite: Insight from Oman Drilling Project Phase 1 & 2**

*Sayantani Chatterjee[1], Eiichi Takazawa[1,2], Katsuyoshi Michibayashi[3], Oman Drilling Project Science Party (1.Department of Geology, Faculty of Science, Niigata University, 2.Volcanoes and Earth's Interior Research Center, Research Institute for Marine Geodynamics, JAMSTEC , 3.Department of Earth and Environmental Sciences, Nagoya University, Japan)

[SCG56-09] Velocity gradient in the oceanic crust layer 3 based on seismic velocity of cores drilled from the Oman ophiolite

*Kohei Hatakeyama[1], Ikuo Katayama[1], Natsue Abe[2], Keishi Okazaki[3], Katsuyoshi Michibayashi[4], The Oman Drilling Project Science Party (1.Department of earth and planetary systems science, Hiroshima University , 2.Japan Agency for Marine-Earth Science and Technology, 3.Kochi Institute for Core Sample Research, Japan Agency for Marine-Earth Science and Technology, 4.Nagoya University)

[SCG56-10] Synthesis of Oceanic Crustal Structure from Two-Dimensional Seismic Profiles

★Invited Papers

*Gail Lynn Christeson[1], John Goff[1], Robert Reece[2] (1.University of Texas at Austin, 2.Texas A&M University)

[SCG56-11] **Petrographical and chemical evolution of a troctolites rich section of oceanic crust located directly above a spreading centre, example from Wadi Mahram, Oman ophiolite**

★Invited Papers

*Marie Python[1], Mathieu Rospabe[2], Claire Charles[3], Georges Ceuleneer[4], Shoji Arai[5] (1.Hokkaido University Department of Natural History Science Division of Earth and Planetary Systems Sciences, 2.Japan Agency for Marine-Earth Science and Technology, 3.IFREMER, Université de Bretagne Loire, Brest, France, 4.Université Paul Sabatier, GET, OMP, Toulouse, 5.Department of Earth Sciences, Faculty of Science, Kanazawa University)

[SCG56-12] **The PGE and Os isotope variations of the mantle derived rocks from the ICDP Cores of the Oman Drilling Project at the Samail Ophiolite, Oman**

*Ryoko Senda[1,2], Katsuhiko Suzuki[2], Tomoaki Morishita[3], Eiichi TAKAZAWA[4], The Oman Drilling Project Science Party (1.Faculty of Social and Cultural Studies, Kyushu University, 2.Submarine Resources Research Center, Japan Agency for Marine-Earth Science and Technology, 3.School of Geoscience and Civil Engineering, College of Science and Technology, Kanazawa University, 4.Department of Geology, Faculty of Science, Niigata University)

[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG56] ICDP Oman Drilling Project: Oman to Oceanic Lithosphere to Island Arc Formation and Beyond

convener:Eiichi TAKAZAWA(Department of Geology, Faculty of Science, Niigata University), Katsuyoshi Michibayashi(Department of Earth and Planetary Sciences, Nagoya University), Sayantani Chatterjee(Niigata University, Department of Geology, Faculty of Science)

[SCG56-13] Knockout seawater –basalt experiments and its implications to hydrothermal alteration in midocean ridges

★Invited Papers

*Atsushi Okamoto[1], Yusuke Netsu[1], Masaoki Uno[1], Noriyoshi Tsuchiya[1] (1.Graduate School of Environmental Studies)

[SCG56-14] Petrology of Oman listvenite (carbonated ultramafic rocks) and related serpentinite from the Hole BT1B of the Oman Drilling Project

*Toma Takahashi[1], Tomoaki Morishita[1], Akihiro Tamura[1], Yumiko Harigane[3], Tatsuhiko Kawamoto[2] (1.Kanazawa university, 2.Shizuoka university, 3.Geological survey of Japan ,National Institute of Advanced Industrial Science and Technology (AIST))

[SCG56-15] Major mineral mode of listvenite from ICDP Oman Drilling Project Hole BT1B inferred from X-ray CT core images

★Invited Papers

*Keishi Okazaki[1], Katsuyoshi Michibayashi[2], Kohei Hatakeyama[3], Natsue Abe[4], Kevin T.M. Johnson[5], Peter B Kelemen[6], Oman Drilling Project Phase I Science Party (1.Kochi Institute for Core Sample Research, Japan Agency for Marine-Earth Science and Technology, 2.Department of Earth and Planetary Sciences, Nagoya University, 3.Department of Earth and Planetary Systems Sciences, Hiroshima University, 4.Mantle Drilling Promotion Office (MDP), Japan Agency for Marine-Earth Science and Technology, 5.Department of Earth Sciences, University of Hawai‘i at Mānoa, 6.Lamont Doherty Earth Observatory, Columbia University)

[SCG56-16] Crustal structure, ophiolites and flexure beneath the Oman-UAE mountains

*Mohammed Ali[1], Anthony Watts[2], Michael Searle[2], Brook Keats[2], Simone Pilia[3], Tyler Ambrose[2] (1.Khalifa University of Science and Technology, 2.University of Oxford, 3.University of Cambridge)

[SCG56-17] *Clues to Cretaceous subduction initiation in South-East Asia - A geochronological and geochemical perspective from the Andaman Ophiolite*

*Debaditya Bandyopadhyay[1,2], Douwe J.J. van Hinsbergen[3], Alexis Plunder[3,4], Biswajit Ghosh[1], Fernando Corfu[5], Carl Guilmette[6], Eldert L. Advokaat[3,7], Pinaki C. Bandopadhyay[1] (1.Department of Geology, University of Calcutta, 35 Ballygunge Circular Road, Kolkata-700019, India, 2.Department of Geology, University of North Bengal, Darjeeling-734013, India, 3.Department of Earth Sciences, Utrecht University, Princetonlaan 8A, 3584 CB Utrecht, The Netherlands, 4.BRGM, 3 avenue Claude Guillemin, BP 36009, 45060 Orléans Cedex 2, France, 5.Department of Geosciences and CEED, University of Oslo, Oslo, Norway, 6.E4m, Département de Géologie et de Génie Géologique, Université Laval, Québec, Québec, Canada, 7.Department of Physical Geography, Utrecht University, Princetonlaan 8A, 3584 CD Utrecht, The Netherlands)

[SCG56-18] Comparison of olivine crystal-fabrics between Oman ophiolite peridotites and Supra-subduction zone peridoitites

*Katsuyoshi Michibayashi[1] (1.Department of Earth and Planetary Sciences, Graduate School of Environmental Studies, Nagoya University)

[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG57] New perspectives of subduction zone earthquake dynamics through experiments across-scales

convener:Masataka Kinoshita(Earthquake Research Institute, University of Tokyo), Yoshio Kono(Geodynamics Research Center, Ehime University), Eiichiro Araki(Japan Agency for Marine-Earth Science and Technology), Hiroko Kitajima(Texas A&M University College Station)

[SCG57-01] Combined X-ray microtomography and elastic wave velocity measurements of porous material at in situ high pressures

*Yoshio Kono[1], Brendan Anzures[2], Heather Watson[3], Tony Yu[4], Yanbin Wang[4] (1.Geodynamics Research Center, Ehime University, 2.Brown University, 3.Union College, 4.University of Chicago)

[SCG57-02] A consideration on friction experiments with synchrotron radiation towards unveiling earthquake generation processes

*Takehiro Hirose[1], Yoshio Kono[2] (1.Kochi Institute for Core Sample Research, Japan Agency for Marine-Earth Science and Technology, 2.Geodynamics Research Center, Ehime, University)

[SCG57-03] Riserless contingency operations during IODP NanTroSEIZE Expedition 358

*Asuka Yamaguchi[1], Matt Ikari[2], Gaku Kimura[3], Lena Maeda[4], Toczko Sean[4], Scientists IODP Expedition 358 (1.Atomosphere and Ocean Research Institute, The University of Tokyo, 2.Marum, University of Bremen, 3.Tokyo University of Marine Science and Technology, 4.JAMSTEC)

[SCG57-04] Overpressured underthrust sediment in the Nankai Trough forearc revealed by high-frequency receiver function inversion

*Takeshi Akuhara[1], Takeshi Tsuji[2], Takashi Tonegawa[3] (1.Earthquake Research Institute, The University of Tokyo, 2.Kyushu University, 3.Research and Development center for Earthquake and Tsunami, JAMSTEC)

[SCG57-05] **Regional imaging of the Nankai subduction zone from decades' worth of active and passive seismic data.**

★Invited Papers

*Adrien F Arnulf[1], Dan Bassett[2], Alistair Harding[3], Shuichi Kodaira[4], Ayako Nakanishi[4] (1.Institute for Geophysics, University of Texas at Austin, 2.GNS Science, 3.IGPP, Scripps Institution of Oceanography, University of California San Diego, 4.Japan Agency for Marine-Earth Science and Technology)

[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG57] New perspectives of subduction zone earthquake dynamics through experiments across-scales

convener:Masataka Kinoshita(Earthquake Research Institute, University of Tokyo), Yoshio Kono(Geodynamics Research Center, Ehime University), Eiichiro Araki(Japan Agency for Marine-Earth Science and Technology), Hiroko Kitajima(Texas A&M University College Station)

[SCG57-06] Thermal conductivity under high-pressure conditions of core samples from IODP NanTroSEIZE input site C0012

*Weiren Lin[1], Osamu Tadai[2], Takehiro Hirose[3], Wataru Tanikawa[3], Xiaoqiu Yang[4] (1.Graduate School of Engineering, Kyoto University, 2.Marin Works Japan LTD, 3.Kochi Institute for Core Sample research, Japan Agency for Marine-Earth Science and Technology, 4.South China Sea Institute of Oceanology, Chinese Academy of Sciences)

[SCG57-07] Pilot seafloor borehole tilt observation in the Nankai Trough seismogenic zone: development for future array network observation for slow slip events.

*Eiichiro Araki[1], Takashi Yokobiki[1], Toshinori Kimura[1], Shuhei Nishida[1], Shuichi Kodaira[1] (1.Japan Agency for Marine-Earth Science and Technology)

[SCG57-08] Comparison of active seismic signals collected from DAS along seafloor cable and conventional OBS

*Toshinori Kimura[1], Eiichiro Araki[1], Hiroyuki Matsumoto[1], Takashi Yokobiki[1], Gou Fujie[1], Shuichi Kodaira[1], Takashi Tonegawa[1], Kazuya Shiraishi[1], Koichiro Obana[1], Ryuta Arai[1], Yuka Kaiho[1], Yasuyuki Nakamura[1], Martin Horst Karrenbach[2], Robert Ellwood[2], Victor Yartsev[2] (1.Japan Agency for Marine-Earth Science and Technology, 2.Optasense)

[SCG57-09] Seafloor geodetic observation network using seafloor pressure gauges for monitoring of real-time plate coupling strength in the Nankai trough seismogenic zone

*Yuya Machida[1], Shuhei Nishida[1], Toshinori Kimura[1], Hiroyuki Matsumoto[1], Eiichiro Araki[1] (1.Japan Agency for Marine-Earth Science and Technology)

[SCG57-10] Hydroacoustic signals detected by distributed acoustic sensing (DAS) using submarine cable

*Hiroyuki Matsumoto[1], Eiichiro Araki[1], Toshinori Kimura[1], Takashi Yokobiki[1], Gou Fujie[1], Shuichi Kodaira[1], Takashi Tonegawa[1], Kazuya Shiraishi[1], Koichiro Obana[1], Ryuta Arai[1], Yuka Kaiho[1], Yasuyuki Nakamura[1], Narumi Takahashi[1,2], Martin Karrenbach[3], Robert Ellwood[3], Victor Yartsev[3] (1.Japan Agency for Marine-Earth Science and Technology, 2.National Research Institute for Earth Science and Disaster Resilience, 3.OptaSense Ltd.)

[SCG57-11] Crustal deformation observations and monitoring using a seafloor optical fiber strainmeter on the DONET seafloor cabled network

*Matthew James Cook[1], Eiichiro Araki[1], Mark Zumberge[2], Takashi Yokobiki[1], Toshinori Kimura[1], Shuhei Nishida[1], Shuichi Kodaira[1] (1.JAMSTEC Japan Agency for Marine-Earth Science and Technology, 2.University of California San Diego)

[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG58] Science of slow earthquakes: Toward unified understandings of whole earthquake process

convener:Satoshi Ide(Department of Earth an Planetary Science, University of Tokyo), Hitoshi Hirose(Research Center for Urban Safety and Security, Kobe University), Kohtaro Ujiie(Graduate School of Life and Environmental Sciences, University of Tsukuba), Takahiro Hatano(Department of Earth and Space Science, Osaka University)

[SCG58-01] Characteristic activities of deep low frequency tremor in Cascadia and southwest Japan based on energy information

*Kazushige Obara[1], Kenneth C. Creager[2] (1.Earthquake Research Institute, The University of Tokyo, 2.University of Washington)

[SCG58-02] Seismic energy estimation for shallow tremors in the Nankai trough and Japan trench

*Suguru Yabe[1], Masaru Nakano[2], Takashi Tonegawa[2], Satoru Baba[3], Shunsuke Takemura[3] (1.National Institute of Advanced Industrial Science and Technology, 2.Japan Agency for Marine-Earth Science and Technology, 3.Earthquake Research Institute, UTokyo)

[SCG58-03] Triggering of deep low-frequency earthquakes along the Parkfield-Cholame section of the San Andreas Fault by local and regional earthquakes

★Invited Papers

*Zhigang Peng[1], David R Shelly[2], Taka'aki Taira[3] (1.Georgia Institute of Technology Main Campus, 2.United States Geological Survey, 3.University of California Berkeley)

[SCG58-04] Characteristics of tectonic tremors in the northern Mexican subduction zone remotely triggered by the 2017 Mw8.2 Tehuantepec earthquake

*Masatoshi Miyazawa[1], Miguel A Santoyo[2] (1.Disaster Prevention Research Institute, Kyoto University, 2.Instituto de Geofísica, Universidad Nacional Autónoma de México)

[SCG58-05] **Tectonic tremors in southern Chile, observed in three space-time windows**

*Satoshi Ide[1], Miguel Sáez[2], Sergio Ruiz[2], Hiroko Sugioka[3], Matthew Miller[4] (1.Department of Earth an Planetary Science, University of Tokyo, 2.Department of Geophysics, University of Chile, Chile, 3.Department of Planetology, Kobe University, 4.Department of Geophysics, University of Concepción, Chile)

[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG58] Science of slow earthquakes: Toward unified understandings of whole earthquake process

convener:Satoshi Ide(Department of Earth an Planetary Science, University of Tokyo), Hitoshi Hirose(Research Center for Urban Safety and Security, Kobe University), Kohtaro Ujiie(Graduate School of Life and Environmental Sciences, University of Tsukuba), Takahiro Hatano(Department of Earth and Space Science, Osaka University)

[SCG58-06] Calibration of portable relative gravimeters toward the detection of gravity signals accompanied by slow slip events

*Yoshiyuki Tanaka[1], Chikara Shibata[1], Yoshiaki Tamura[2], Akio Kobayashi[3] (1.Earth and Planetary Science, UTokyo, 2.Mizusawa VLBI Observatory, NAOJ, 3.Meteorologocal Research Institute, JMA)

[SCG58-07] Long-lasting afterslip associated with the 2016 moderate earthquakes along the Chaman fault, Pakistan

Fumiko Matsumoto[1], *Masato Furuya[1] (1.Department of Earth and Planetary Sciences Hokkaido University)

[SCG58-08] Detection of short-term slow slip events and estimation of their duration by using three components of GNSS data in the Nankai subduction zone, southwest Japan

*Yutaro Okada[1], Takuya NISHIMURA[2], Takao Tabei[3], Takeshi Matsushima[4], Hitoshi Hirose[5] (1.Graduate School of Science, Kyoto University, 2.Disaster Prevention Research Institute, Kyoto University, 3.Department of Global Environment and Disaster Prevention, Faculty of Science and Technology, Kochi University , 4.Institute of Seismology and Volcanology, Faculty of Science, Kyushu University, 5.Research Center for Urban Safety and Security, Kobe University)

[SCG58-09] Slow slip events in the Kanto region, central Japan detected from 25-years-long GNSS data

*Takuya NISHIMURA[1] (1.Disaster Prevention Research Institute, Kyoto University)

[SCG58-10] Afterslip in the ETS zone at Nankai trough, SW Japan, and implications for rheology

★Invited Papers

*Kaj M Johnson[1] (1.Indiana University Bloomington)

[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG58] Science of slow earthquakes: Toward unified understandings of whole earthquake process

convener:Satoshi Ide(Department of Earth an Planetary Science, University of Tokyo), Hitoshi Hirose(Research Center for Urban Safety and Security, Kobe University), Kohtaro Ujiie(Graduate School of Life and Environmental Sciences, University of Tsukuba), Takahiro Hatano(Department of Earth and Space Science, Osaka University)

[SCG58-11] Slow slip events and temporal changes of coupling condition on the shallow side of the Nankai Trough

★Invited Papers

*Yusuke Yokota[1], Tadashi Ishikawa[2], Shun-ichi Watanabe[2], Yuto Nakamura[2] (1.Institute of Industrial Science, The University of Tokyo, 2.Hydrographic and Oceanographic Department, Japan Coast Guard)

[SCG58-12] Slow slips with durations between VLF and short-term SSE

*Akio Katsumata[1], Kazuki Miyaoka[2], Takahiro Tsuyuki[1], Satoshi Itaba[4], Masayuki Tanaka[1], Takeo Ito[5], Akiteru Takamori[3], Akito Araya[3] (1.Meteorological Research Institute, Japan Meteorological Agency, 2.Seismology and Volcanology Department, Japan Meteorological Agency, 3.Earthquake Research Institute, The University of Tokyo, 4.The National Institute of Advanced Industrial Science and Technology, 5.Nagoya University)

[SCG58-13] Seismic heterogeneity changes before and during slow earthquakes

*Takashi Tonegawa[1], Shunsuke Takemura[2], Suguru Yabe[3], Kiyoshi Yomogida[4] (1.Research and Development center for Earthquake and Tsunami, Japan Agency for Marine-Earth Science and Technology, 2.Earthquake Research Institute, The University of Tokyo, 3.National Institute of Advanced Industrial Science and Technology, 4.Hokkaido University)

[SCG58-14] Multi-band Receiver Function Analysis Including Local Deep-focus Events in Northeastern Kii

*Yasunori Sawaki[1], Yoshihiro Ito[2], Kazuaki Ohta[3], Takuo Shibutani[2], Tomotaka Iwata[2] (1.Graduate School of Science, Kyoto University , 2.Disaster Prevention Research Institute, Kyoto University, 3.National Research Institute for Earth Science and Disaster Resilience)

[SCG58-15] The relationship between slow earthquake activity and frictional property on the plate boundaries around Japan islands

*Satoru Baba[1], Shunsuke Takemura[1], Kazushige Obara[1], Akemi Noda[2] (1.Earthquake Research Institute, The University of Tokyo, 2.National Research Institute for Earth Science and Disaster Resilience)

[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG58] Science of slow earthquakes: Toward unified understandings of whole earthquake process

convener:Satoshi Ide(Department of Earth an Planetary Science, University of Tokyo), Hitoshi Hirose(Research Center for Urban Safety and Security, Kobe University), Kohtaro Ujiie(Graduate School of Life and Environmental Sciences, University of Tsukuba), Takahiro Hatano(Department of Earth and Space Science, Osaka University)

[SCG58-17] Seismic evidence for fault-bound anisotropy and its implications on fault structure in the northern Hikurangi subduction zone

*Ryuta Arai[1], Shuichi Kodaira[1], Stuart Henrys[2], Nathan Bangs[3], Koichiro Obana[1], Gou Fujie[1], Seiichi Miura[1], Dan Barker[2], Dan Bassett[2], Rebecca Bell[4], Kimihiro Mochizuki[5], Richard Kellett[2], Valerie Stucker[2], Fry Bill[2], NZ3D Team (1.Japan Agency Marine-Earth Science and Technology, 2.GNS Science, 3.University of Texas, Institute for Geophysics, 4.Imperial College London, 5.Earthquake Research Institute, University of Tokyo)

[SCG58-18] Marine observations of slow earthquakes using ocean bottom seismometers in the northern part of the Hikurangi subduction zone, NZ

*Kimihiro Mochizuki[1], Yusuke Yamashita[2], Martha K Savage[3], Emily Warren-Smith[4], Katie Jacobs[3], Laura M Wallace[4] (1.Earthquake Prediction Research Center, Earthquake Research Institute, University of Tokyo, 2.Disaster Prevention Institute, Kyoto University, 3.Veictoria University of Wellington, 4.GNS Science)

[SCG58-19] **Seismic evidence for megathrust fault-valve behavior during episodic tremor and slip**

★Invited Papers

Jeremy M Gosselin[1], *Pascal Audet[1], Clement Esteve[1], Morgan McLellan[1], Stephen G Mosher[1], Andrew J Schaeffer[2] (1.University of Ottawa, 2.Geological Survey of Canada)

[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG58] Science of slow earthquakes: Toward unified understandings of whole earthquake process

convener:Satoshi Ide(Department of Earth an Planetary Science, University of Tokyo), Hitoshi Hirose(Research Center for Urban Safety and Security, Kobe University), Kohtaro Ujiie(Graduate School of Life and Environmental Sciences, University of Tsukuba), Takahiro Hatano(Department of Earth and Space Science, Osaka University)

[SCG58-20] Deformation of antigorite serpentinite in the base of the shallow wedge mantle and relationship to slow earthquakes

*Kazuyuki Yoshida[1], Takayoshi Nagaya[1], Simon Richard Wallis[1] (1.Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo)

[SCG58-21] Serpentinized shear zones with low frictional strength by grain-boundary sliding of antigorite at the depth of deep SSEs

*Takayoshi Nagaya[1], Simon Richard Wallis[1] (1.Graduate School of Science, The University of Tokyo)

[SCG58-23] Role of metasomatic reactions on plate-boundary shear localization near mantle wedge corner

*Naoki Nishiyama[1], Kohtaro Ujiie[1], Kazuya Noro[1], Yasushi Mori[2], Haruna MASUYAMA[1] (1.University of Tsukuba, 2.Kitakyusyu Museum of Natural History & Human History)

[SCG58-24] Stress heterogeneity on shallow decollement controls property of sediments and Very Low Frequency Earthquakes in Nankai Trough

*Yoshitaka Hashimoto[1], Haruki Kuchimoto[1], Shigeyuki Sato[1], Gaku Kimura[2], Masataka Kinoshita[3], Ayumu Miyakawa[4], Gregory F Moore[5], Masaru Nakano[6], Kazuya Shiraishi[6], Yasuhiro Yamada[6] (1.Kochi University, 2.TUMSAT, 3.ERI, University of Tokyo, 4.AIST, 5.Hawaii University, 6.JAMSTEC)

[SCG58-25] Rheology of the fluid oversaturated simulated quartz shear zone at the brittle-ductile transition

*Keishi Okazaki[1], Eric Burdette[2], Greg Hirth[2] (1.Kochi Insutitute for Core Sample Research, Japan Agency for Marine-Earth Science and Technology, 2.Department of Earth, Environmental and Planetary Sciences, Brown University)

[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG58] Science of slow earthquakes: Toward unified understandings of whole earthquake process

convener:Satoshi Ide(Department of Earth an Planetary Science, University of Tokyo), Hitoshi Hirose(Research Center for Urban Safety and Security, Kobe University), Kohtaro Ujiie(Graduate School of Life and Environmental Sciences, University of Tsukuba), Takahiro Hatano(Department of Earth and Space Science, Osaka University)

[SCG58-26] Slow slip prior to runaway slip in laboratory

*Miki Takahashi[1] (1.Institute of Earthquake and Volcano Geology, Geological Survey of Japan, AIST)

[SCG58-28] Slow slip and transition to fast rupture in friction of gels

*Tetsuo Yamaguchi[1] (1.Graduate school of Engineering, Kyushu University)

[SCG58-29] Experiments simulating the subduction of seamounts beneath a viscoelastic crust

*Atsuko Namiki[1] (1. School of Integrated Arts and Sciences, Hiroshima University)

[SCG58-30] Episodic fluid pressure cycling controls the interplay between Slow Slip Events and Large Megathrust Earthquakes

★Invited Papers

*Luca Dal Zilio[1], Claudio Petrini[2], Taras Gerya[2] (1.Seismological Laboratory, California Institute of Technology, Pasadena, CA, 2.Department of Earth Sciences, ETH Zürich, Zürich, Switzerland)

[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG58] Science of slow earthquakes: Toward unified understandings of whole earthquake process

convener:Satoshi Ide(Department of Earth an Planetary Science, University of Tokyo), Hitoshi Hirose(Research Center for Urban Safety and Security, Kobe University), Kohtaro Ujiie(Graduate School of Life and Environmental Sciences, University of Tsukuba), Takahiro Hatano(Department of Earth and Space Science, Osaka University)

[SCG58-31] Slip-front-propagation velocity with non-vanishing friction stress at infinitely large slip velocity

*Takehito Suzuki[1], Hiroshi Matsukawa [1] (1.Department of Physics and Mathematics, Aoyama Gakuin University)

[SCG58-32] Modeling tremor with cellular automaton

*Kota Fukuda[1], Takahiro Hatano[2], Kimihiro Mochizuki[1] (1.Earthquake Research Institute The University of Tokyo, 2.Department of Earth and Space Science The Osaka University)

[SCG58-33] **Continuum model for interacting many faults: emergence of main fault and Gutenberg-Richter's law**

*Akio ISHII[1], Takahiro Hatano[1], Tomoaki Niiyama[2] (1.Osaka University, 2.Kanazawa Univesity)

[SCG58-34] New atomistic mechanism for velocity-weakening friction

*Takahiro Hatano[1], Akio Ishii[2], Tomoaki Niiyama[3], Tomotsugu Shimokawa[3], Shigenobu Ogata[2] (1.Department of Earth and Space Science, Osaka University, 2.Department of Mechanical Science and Bioengineering, Osaka University, 3.Department of Mechanical Engineering, Kanazawa University)

[SCG58-35] Reduction of mathematical model for slip behavior of one dimensional elastic layer with rate and state friction

*Yutaka Sumino[1], Takuya Saito[2], Tetsuo Yamaguchi[3], Takahiro Hatano[4], Satoshi Ide[5] (1.Tokyo University of Science, 2.Aoyama Gakuin University, 3.Graduate School of Engneering, Kyushu University, 4.Department of Earth and Space Science, Osaka University, 5.Department of Earth and Planetary Science, Tokyo University of Science)

[SCG58-36] Effects of periodic stress perturbations on earthquake nucleation

*Takuya Saito[1], Takahiro Hatano[2] (1.Aoyama Gakuin University, 2.Osaka University)

[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG59] Evolution and movement of the crustal surface and application of geo- and thermochronology

convener:Noriko Hasebe(Institute of Nature and Environmental Technology, Kanazawa University), Shigeru Sueoka(Japan Atomic Energy Agency), Frederic Herman(University of Lausanne), Takahiro Tagami(Graduate School of Science, Kyoto University)

[SCG59-01] Overview of geo- and thermo-chronology applicable to unravel the earth's surface evolution

*Takahiro Tagami[1], Shigeru Sueoka[2], Noriko Hasebe[3], Frederic Herman[4] (1.Graduate School of Science, Kyoto University, 2.Japan Atomic Energy Agency, 3.Institute of Nature and Environmental Technology, Kanazawa University, 4.University of Lausanne)

[SCG59-02] **Direct dating of faults by luminescence and ESR: Case studies from Japan and Switzerland**

★Invited Papers

*Sumiko Tsukamoto[1], Benny Guralnik[2], Kiyokazu Oohashi[3], Makoto Otsubo[4], David Colin Tanner[1], Christian Brandes[5], Christoph von Hagke[6] (1.Leibniz Institute for Applied Geophysics , 2.Technical University of Denmark, 3.Yamaguchi University, 4.Geological Survey of Japan, AIST, 5.Leiniz University of Hannover, 6.RWTH Aachen University)

[SCG59-03] Thermal characteristics of slab fluid in Hongu area, southwest Japan: Insights form thermochronology and fluid inclusion analyses

*Shigeru Sueoka[1], Mizuho Kanno[1], Makoto Kawamura[1], Masakazu Niwa[1], Hideki Iwano[2], Tohru Danhara[2] (1.Japan Atomic Energy Agency, 2.Kyoto Fission-Track Co., Ltd.)

[SCG59-04] Tectono–thermal history of the Lesser Himalaya in eastern Nepal: Insights from multi-thermochronological study and thermo-kinematic modeling

*Nakajima Toru[1], Hideki Iwano[2], Tohru Danhara[2], Harutaka Sakai[1] (1.Division of Earth and Planetary Sciences, Graduate School of Science, Kyoto University, 2.Kyoto Fission-Track Co. Ltd)

[SCG59-05] Resolving rates of landscape evolution with $^{4}He/^{3}He$ thermochronometry: examples from Grand Canyon and Yosemite Valley

★Invited Papers

*Matthew Fox[1] (1.Dept. of Earth Sciences, University College London, London UK)

[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG60] Toward Discoveries in Solid Earth Sciences by Machine Learning

convener:Takahiko Uchide(Research Institute of Earthquake and Volcano Geology, Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (AIST)), Yuki Kodera(Meteorological Research Institute, Japan Meteorological Agency), Hisahiko Kubo(National Research Institute for Earth Science and Disaster Resilience)

[SCG60-01] Automatic Digitization of Seismograms in Smoked Paper using Convolutional Neural Network

*Mitsuko Furumura[1], Yoko Ogawa[2], Kazuo Sakamoto[2], Ritsuko S. Matsu'ura[1] (1.Research Division, Earthquake Research Center, Association for the Development of Earthquake Prediction, 2.KOZO KEIKAKU ENGINEERING Inc.)

[SCG60-03] Improving the Retrieval of Offshore-Onshore Correlation Functions with Machine Learning

*Loic Viens[1], Tomotaka Iwata[1] (1.DPRI, Kyoto University)

[SCG60-04] Neural Network-Based Ground Motion Model Learning Site Property from Data

*Tomohisa Okazaki[1], Tomoharu Iwata[1,2], Asako Iwaki[3], Hiroyuki Fujiwara[3], Naonori Ueda[1] (1.Center for Advanced Intelligence Project, RIKEN, 2.NTT Communication Science Laboratories, 3.National Research Institute for Earth Science and Disaster Resilience)

[SCG60-05] Towards robust, reliable earthquake detection with deep neural networks

*Karianne J. Bergen[1] (1.School of Engineering and Applied Sciences, Harvard University)

[SCG60-06] Focal mechanism determination of inland microearthquakes in Japan based on P-wave first-motion polarities picked by neural network model

*Takahiko Uchide[1] (1.Geological Survey of Japan, AIST)

[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG61] The Japan Trench: Learning from the 2011 M=9 Tohoku-Oki earthquake, a decade later

convener:Takeshi Iinuma(National Research and Development Agency Japan Agency for Marine-Earth Science and Technology), Asuka Yamaguchi(Atomosphere and Ocean Research Institute, The University of Tokyo), Aitaro Kato(Earthquake Research Institute, the University of Tokyo), Tianhaozhe Sun(Pacific Geoscience Centre, Geological Survey of Canada)

[SCG61-01] A review of decade-long marine geophysical studies in the Japan Trench since the 2011 Tohoku-oki earthquake

*Shuichi Kodaira[1], Toshiya Fujiwara[1], Yasuyuki Nakamura[1], Gou Fujie[1], Koichiro Obana[1], Ryota Hino[2] (1.Research Institute for Marine Geodynamics, Japan Agency for Marine-Earth Science and Technology, 2.Graduate school of Science, Tohoku University)

[SCG61-02] **Geologic constraints on the geometry composition and structural evolution of the shallow subduction interface and frontal prism in the Japan Trench**

★Invited Papers

*Christine Regalla[1], Emily Schottenfels[1], Paul Bierman[2] (1.Northern Arizona University, Flagstaff Arizona, USA, 2.University of Vermont, Burlington Vermont, USA)

[SCG61-03] Frictional properties of incoming sediments and rocks at shallow conditions of the Japan Trench subduction zone

*Kyuichi Kanagawa[1], Sayumi Sagano[2], Tomoya Nakanishi[2], Junya Fujimori[2], Michiyo Sawai[1] (1.School of Science, Chiba University, 2.Graduate School of Science and Engineering, Chiba University)

[SCG61-04] Seismic imaging of the Tohoku megathrust zone using S-net and Hi-net data

*Dapeng Zhao[1], Yuanyuan Hua[1], Genti Toyokuni[1] (1.Department of Geophysics, Tohoku University)

[SCG61-05] Modeling the hydromechanical effects of seamount subduction on megathrust stress and slip in southern Japan Trench

*Tianhaozhe Sun[1], Demian M Saffer[2], Susan Ellis[3] (1.Pacific Geoscience Centre, Geological Survey of Canada, 2.Univ. of Texas Institute for Geophysics, USA, 3.GNS Science, New Zealand)

[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG61] The Japan Trench: Learning from the 2011 M=9 Tohoku-Oki earthquake, a decade later

convener:Takeshi Iinuma(National Research and Development Agency Japan Agency for Marine-Earth Science and Technology), Asuka Yamaguchi(Atomosphere and Ocean Research Institute, The University of Tokyo), Aitaro Kato(Earthquake Research Institute, the University of Tokyo), Tianhaozhe Sun(Pacific Geoscience Centre, Geological Survey of Canada)

[SCG61-06] Seismicity in the trench-outer rise region along the Japan Trench based on repeated OBS observations: Implications for large outer-rise earthquakes

*Koichiro Obana[1], Gou Fujie[1], Yasuyuki Nakamura[1], Tsutomu Takahashi[1], Yojiro Yamamoto[1], Takashi Tonegawa[1], Yuka Kaiho[1], Seiichi Miura[1], Shuichi Kodaira[1] (1.Research Institute for Marine Geodynamics, Japan Agency for Marine-Earth Science and Technology)

[SCG61-07] **Head and tail of massive earthquakes: Mechanism arresting growth of interplate earthquakes**

*Ryota Hino[1], Naoki Uchida[1], Masanao Shinohara[2], Yoshihiro Ito[3], Takeshi Iinuma[4], Yasuyuki Nakamura[4], Toshiya Kanamatsu[4], Ken Ikehara[5], Ryoko Nakata[1,4] (1.Graduate School of Science, Tohoku University, 2.Earthquake Research Institute, University of Tokyo, 3.Disaster Prevention Research Institute, Kyoto Univesity, 4.Japan Agency for Marine-Earth Science and Technology, 5.National Institute of Advanced Industrial Science and Technology)

[SCG61-08] Development of GNSS-A in this decade and observation results along the Japan Trench

★Invited Papers

*Yusuke Yokota[1], Tadashi Ishikawa[2], Shun-ichi Watanabe[2], Yuto Nakamura[2] (1.Institute of Industrial Science, The University of Tokyo, 2.Hydrographic and Oceanographic Department, Japan Coast Guard)

[SCG61-09] On the cause of enhanced landward motion of the overriding plate after the Tohoku-Oki earthquake

Mario D'Acquisto[1], Matthew Herman[1], *Rob Govers[1] (1.Utrecht University, Netherlands)

[SCG61-10] Elucidation of locking state at the shallower plate boundary after the Tohoku Earthquake based on seafloor acoustic ranging

*Ryusuke Yamamoto[1,2], Ryota Hino[1], Motoyuki Kido[3], Chie Honsho[1], Shuichi Kodaira[4], Yasuyuki Nakamura[4] (1.Graduate School of Science, Tohoku University, 2.Tokio Marine & Nichido Risk Consulting Co., Ltd., 3.International Research Institute of Disaster Science, Tohoku University, 4.Japan Agency for Marine-Earth Science and Technology)

[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG62] Investigation of inputs to subduction zones: Influence of tectonic processes on the incoming plate

convener:Makoto Yamano(Earthquake Research Institute, the University of Tokyo), Tomoaki Morishita(School of Geoscience and Civil Engineering, College of Science and Technology, Kanazawa University), Gou Fujie(Japan Agency for Marine-Earth Science and Technology)

[SCG62-01] CHIKYU IODP Full proposal for Bend-Fault Hydrology in the Old Incoming Plate (H-ODIN): Scientific objectives and drilling strategy

*Tomoaki Morishita[1,2,3], Gou Fujie[2], Shigeaki Ono[2], Makoto Yamano[4], Kohtaro Ujiie[5], Asuka Yamaguchi[4], Akira Ijiri[2], Tomohiro Toki[6], Takanori Kagoshima[4], Masahiro Ishikawa[2], Ikuo Katayama[7], Junichiro Kuroda[4], Yohey Suzuki[4] (1.Kanazawa University, 2.JAMSTEC, 3.Columbia University, 4.The University of Tokyo, 5.University of Tsukuba, 6.University of the Ryukyu, 7.Hiroshima University)

[SCG62-02] **Role of hydrated oceanic lithosphere on global water cycle in the Earth**

★Invited Papers

*Ikuo Katayama[1], Kohei Hatakeyama[1] (1.Department of Earth and Planetary Systems Science, Hiroshima University)

[SCG62-03] Heat flow observation around a young petit spot volcano on the old Pacific Plate subducting into the Japan Trench

*Yoshifumi Kawada[1], Makoto Yamano[2], Kouta Sasaki[2] (1.International Research Institute of Disaster Science, Tohoku University, 2.Earthquake Research Institute, The University of Tokyo)

[SCG62-04] $^{3}He/^{4}He$ ratios in pore fluids and bottom seawater around the Japan Trench

★Invited Papers

*Takanori Kagoshima[1], Naoto Takahata[1], Makoto Yamano[2], Asuka Yamaguchi[1], Jin-Oh Park[1], Yuji Sano[1] (1.Atmosphere and Ocean Research Institute, the University of Tokyo, 2.Earthquake Research Institute, the University of Tokyo)

[SCG62-05] **Shallow crustal structure in the outer rise of the Japan Trench by high-resolution seismic reflection survey**

*YUE SUN[1], Ehsan Jamali Hondori[1], GUO CHEN[1], Tomoko Hanyu[2], Jin-Oh Park[1] (1.Atmosphere and Ocean Research Institute, The University of Tokyo, 2.Kobe Ocean-Bottom Exploration Center, Kobe University)

[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG62] Investigation of inputs to subduction zones: Influence of tectonic processes on the incoming plate

convener:Makoto Yamano(Earthquake Research Institute, the University of Tokyo), Tomoaki Morishita(School of Geoscience and Civil Engineering, College of Science and Technology, Kanazawa University), Gou Fujie(Japan Agency for Marine-Earth Science and Technology)

[SCG62-06] Event layers within graben-fill deposits in the outer ruse of the Japan Trench

*Asuka Yamaguchi[1], Hiroaki Kurano[1], Rina Fukuchi[2], Kazuno Arai[3], Ken Ikehara[4], Toshiya Kanamatsu[5], Takanori Kagoshima[1], Tomoko Hanyu[6], Juichiro Ashi[1], Jin-Oh Park[1] (1.Atomosphere and Ocean Research Institute, The University of Tokyo, 2.DIA CONSULTANTS CO., Ltd., 3.Center for Advanced Marine Core Research, Kochi University, 4.National Institute of Advanced Industrial Science and Technology, 5.Japan Agency for Marine-Earth Science and Technology , 6.KOBEC, Kobe University)

[SCG62-07] Spatial variations in incoming oceanic plate and its implications for subduction zone processes along the Japan Trench

*Gou Fujie[1], Koichiro Obana[1], Yojiro Yamamoto[1], Tomoaki Yamada[2], Takehi Isse[2], Shuichi Kodaira[1], Seiichi Miura[1] (1.Japan Agency for Marine-Earth Science and Technology, 2.Earthquake Research Institute, Univ. of Tokyo)

[SCG62-08] Active-source seismic study with a dense linear OBS array off Nemuro, the southern Kuril subduction zone

*Ryosuke Azuma[1], Shuichi Kodaira[2], Ryota Hino[1], Gou Fujie[2], Koichiro Obana[2], Fumiaki Tomita[2], Yusaku Ohta[1] (1.Recearch Center for Prediction of Earthquake and Volcanic Eruption, Graduate School of Science, Tohoku University, 2.Japan Agency for Marine-Earth and Technology)

[SCG62-09] Fluid circulation and heat transport in fractured oceanic crust in the Japan and Kuril trench outer rise regions

*Kouta Sasaki[1], Makoto Yamano[1], Yoshifumi Kawada[2] (1.Earthquake Research Institute, the University of Tokyo, 2.International Research Institute of Disaster Science, Tohoku University)

[SCG62-11] Discussion on inputs to subduction zones

*Makoto Yamano[1] (1.Earthquake Research Institute, the University of Tokyo)

[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG63] Dynamics in mobile belts

convener:Yukitoshi Fukahata(Disaster Prevention Research Institute, Kyoto University), Ray Y Chuang(Department of Geography, National Taiwan University), Toru Takeshita(Department of Natural History Sciences, Graduate School of Science, Hokkaido University), Hikaru Iwamori(Earthquake Research Institute, The University of Tokyo)

[SCG63-01] Onshore temporal aftershock observation for the 2019 Yamagata-Oki earthquake (2)

*Tomomi Okada[1], Ayaka Tagami[1], Tatsuya Mizuta[1], Shin'ichi Sakai[2], Keisuke Yoshida[1], Naoki Uchida[1], Takashi NAKAYAMA[1], Satoshi Hirahara[1], Toru Matsuzawa[1] (1.Research Center for Prediction of Earthquakes and Volcanic Eruptions, Graduate School of Science, Tohoku University, 2.ERI, University of Tokyo)

[SCG63-02] Stationarity of aftershock activities of the 2016 Central Tottori Prefecture Earthquake revealed by dense seismic observation

*Yoshihisa Iio[1], Satoshi Matsumoto[2], Joint aftershock observation group of the Central Tottori Prefecture earthquake[1] (1.Disater Prevention Research Institute, Kyoto University, 2.Institute of Seismology and Volcanology, Faculty of Sciences, Kyushu University)

[SCG63-03] Hyperdense seismic network reveals multiscale complexity in the young fault system that hosted the 2000 Tottori earthquake, Japan

*Aitaro Kato[1], Shin'ichi Sakai[1], Satoshi Matsumoto[2], Yoshihisa Iio[3] (1.Earthquake Research Institute, the University of Tokyo, 2.Kyushu University, 3.Disaster Prevention Research Institute, Kyoto University)

[SCG63-04] Characteristic of fault geometry of the 2016 Mw7.8 Kaikoura Earthquake, New Zealand inferred from high precision aftershock distribution

*Yuta Kawamura[1], Satoshi Matsumoto[1], Tomomi Okada[2], Miu Matsuno[2], Yoshihisa Iio[3], Tadashi Sato[2], Stephen Bannister[4], John Ristau[4], Martha Savage[5], Clifford Thurber[6], Richard Sibson[7] (1.Kyushu University, 2.Tohoku University, 3.Kyoto University, 4.GNS Science, 5.Victoria University of Wellington, 6.University of Wisconsin - Madison, 7.University of Otago)

[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG63] Dynamics in mobile belts

convener:Yukitoshi Fukahata(Disaster Prevention Research Institute, Kyoto University), Ray Y Chuang(Department of Geography, National Taiwan University), Toru Takeshita(Department of Natural History Sciences, Graduate School of Science, Hokkaido University), Hikaru Iwamori(Earthquake Research Institute, The University of Tokyo)

[SCG63-07] Development of Strike-Slip Fault Related to the Mud Diapirism in SW Taiwan

★Invited Papers

*Kuo-En Ching[1], Yu-Tsung Lo[2], Song-Chuen Chen[3], Ruey-Juin Rau[1] (1.National Cheng Kung University, 2.National Central University, 3.Central Geological Survey)

[SCG63-08] **Fluid pressure gradients and permeability evolution in the crust: insights from metamorphic fluid-rock reaction zones and hydrothermal experiments**

★Invited Papers

*Masaoki Uno[1], Atsushi Okamoto[1], Diana Mindaleva[1], Hisamu Kasahara[1], Naoki Sugisawa[1], Jun Kameda[2], Noriyoshi Tsuchiya[1] (1.Graduate School of Environmental Studies, Tohoku University, 2.Department of Natural History Sciences, Graduate School of Science, Hokkaido University)

[SCG63-09] **Grain growth experiment of albitic feldspar**

*Norio Shigematsu[1], Masanori Kido[1], You Zhou[2], Hideki Hyuga[2], Yuuichi Yoshizawa[2] (1.Research Institute of Earthquake and Volcano Geology, Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology, 2.Structural Materials Research Institute, National Institute of Advanced Industrial Science and Technology)

[SCG63-10] **3D fault zone architecture across the brittle-plastic transition along the Median Tectonic Line, eastern Kii Peninsula, SW Japan**

*Takuma Katori[1,2], Norio Shigematsu[1], Jun Kameda[3], Ayumu Miyakawa[1], Tatsuya Sumita[1] (1.Geological Survey of Japan, AIST, 2.Graduate School of Science & Technology, Niigata university, 3.Department of Natural History and Sciences, Hokkaido university)

[SCG63-11] Development of the Median Tectonic Line fault zone, Mie Prefecture, southwest Japan: Processes of strain localization

*Toru Takeshita[1], Dong Van Bui[1], Jun-ichi Ando[2] (1.Department of Natural History Sciences, Graduate School of Science, Hokkaido University, 2.Department of Earth and Planetary Systems Science, Graduate School of Science, Hiroshima University)

[SCG63-12] **Fault strength of the ancient Median Tectonic Line at the brittle-ductile transitional depths**

*Ichiko Shimizu[1], Ayumi S. Okamoto, André R. Niemeijer[2], Masao Nakatani[3], Shun Arai[4], Spiers J. Christopher [2], Toru Takeshita[5], Tadamasa Ueda[1] (1.Kyoto University, 2.Utrecht University, 3.Earthquake Research Institute, the University of Tokyo, 4.Tohoku University, 5.Hokkaido University)

[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG63] Dynamics in mobile belts

convener:Yukitoshi Fukahata(Disaster Prevention Research Institute, Kyoto University), Ray Y Chuang(Department of Geography, National Taiwan University), Toru Takeshita(Department of Natural History Sciences, Graduate School of Science, Hokkaido University), Hikaru Iwamori(Earthquake Research Institute, The University of Tokyo)

[SCG63-13] Resistivity structure around the Atotsugawa fault system revealed by inversion schemes combining Wideband- and Network-MT methods

★Invited Papers

*Yoshiya Usui[1,2], Makoto Uyeshima[1], Tsutomu Ogawa[1], Ryokei Yoshimura[3], Naoto Oshiman[3], Satoru Yamaguchi[4], Hiroaki Toh[5], Hideki Murakami[6], Koki Aizawa[7], Toshiya Tanbo[8], Yasuo Ogawa[9], Tadashi Nishitani[10], Shin'ya Sakanaka[10], Masaaki Mishina[11], Hideyuki Satoh[12], Tada-nori Goto[13], Takafumi Kasaya[14], Toru Mogi[15], Yusuke Yamaya[16], Ichiro Shiozaki[17], Yoshimori Honkura[18] (1.Earthquake Research Institute, the University of Tokyo, 2.ITOCHU Techno-Solutions Corporation, 3.Disaster Prevention Research Institute, Kyoto University, 4.Graduate School of Science, Osaka City University, 5.Graduate School of Science, Kyoto University, 6.Natural Sciences Cluster-Science and Technology Unit, Research and Education Faculty, Kochi University, 7.Institute of Seismology and Volcanology, Faculty of Science, Kyushu University, 8.Tateyama Caldera Sabo Museum, 9.Volcanic Fluid Research Center, School of Science, Tokyo Institute of Technology, 10.Graduate School of International Resource Sciences, Akita University, 11.Graduate School of Science, Tohoku University, 12.Nuclear Regulation Department, Nuclear Regulation Authority, 13.Graduate School of Life Science, University of Hyogo, 14.Japan Agency for Marine–Earth Science and Technology, 15.Faculty of Science, Hokkaido university, 16.National Institute of Advanced Industrial Science and Technology, 17.Graduate School of Engineering, Tottori University, 18.Graduate School of Science and Engineering, Tokyo Institute of Technology)

[SCG63-14] High pressure electrical conductivity in a brine-saturated rock and microstructure of pores

*Tohru Watanabe[1], Kenta Yoshida[2], Katsuyoshi Michibayashi[3] (1.University of Toyama, 2.Japan Agency for Marine-Earth Science and Technology, 3.Nagoya University)

[SCG63-15] Fluid distribution beneath volcanically and seismically active island, Kyushu, based on 3-D electrical resistivity model

★Invited Papers

*Maki Hata[1] (1.Earthquake Research Institute, the University of Tokyo)

[SCG63-16] The Quaternary tectonics of central Kyushu and the 2016 Kumamoto earthquake: from a multifaceted viewpoint of geology, seismology, and geodesy

★Invited Papers

*Kiyokazu Oohashi[1], Makoto Otsubo[2], Satoshi Matsumoto[3], Kenta Kobayashi[4], Katsushi Sato[5], Takuya NISHIMURA[6] (1.Graduate School of Sciences and Technology for Innovation, Yamaguchi University, 2.Geological Survey of Japan, AIST, 3.Faculty of Science, Kyushu University, 4.Department of Geology, Faculty of Science, Niigata University, 5.Graduate School of Science, Kyoto University, 6.Disaster Prevention Research Institute, Kyoto University)

[SCG63-17] A semi-kinematic reference frame of Taiwan considering earthquake-cycle deformation at a plate boundary deformation zone

*Kwo-Hwa Chen[1], Kuo-En Ching[2], Ray Y Chuang[3], Shih-Han Hsiao[2], Ming Yang[2], He-Chin Chen[4] (1.Department of Real Estate and Built Environment, National Taipei University, New Taipei City, Taiwan, 2.Department of Geomatics, National Cheng Kung University, Tainan City, Taiwan, 3.Department of Geography, National Taiwan University, Taipei City, Taiwan, 4.Control Survey Section, National Land Surveying and Mapping Center, Taichung City, Taiwan)

[SCG63-18] Consideration of Formation factor of Trench-parallel fore-arc ridge

*Shohei Iwama[3,1], Ryoya Ikuta[2], Yuto Iwase[4] (1.Graduate school of Integrated Science and Technology, 2.Faculty of Science, Shizuoka University, 3.Kokusai Kogyo Co., Ltd., 4.Kawasaki Geological Engineering Co. Ltd.)

[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG63] Dynamics in mobile belts

convener:Yukitoshi Fukahata(Disaster Prevention Research Institute, Kyoto University), Ray Y Chuang(Department of Geography, National Taiwan University), Toru Takeshita(Department of Natural History Sciences, Graduate School of Science, Hokkaido University), Hikaru Iwamori(Earthquake Research Institute, The University of Tokyo)

[SCG63-19] Separation of Plastic, Viscous, and Elastic Strains From Observed GNSS Data in the Niigata-Kobe Tectonic Zone

*Yukitoshi Fukahata[1], Angela Meneses-Gutierrez[2,3], Takeshi Sagiya[3,4] (1.Disaster Prevention Research Institute, Kyoto University, 2.Institute for Advanced research, Nagoya University, 3.Disaster Mitigation Research Center, Nagoya University, 4.Graduate School of Environmental Studies, Nagoya University)

[SCG63-20] Elasto-plastic behavior of the concentrated deformation zone based on baseline strain rates

*Takeshi Sagiya[1], Angela Meneses-Gutierrez[1,2] (1.Disaster Mitigation Research Center, Nagoya University, 2.Institute for Advanced Research, Nagoya University)

[SCG63-21] Geodetic evidence of time-dependent viscoelastic interseismic deformation driven by megathrust locking in the southwest Japan subduction zone

*Shaoyang Li[1], Jun'ichi Fukuda[1], Onno Oncken[2] (1.The University of Tokyo, Earthquake Research Insititute, 2.German Geoscience Research Center)

[SCG63-22] Horizontal deformation in NE Japan from triangulation, trilateration, and GPS from 1890 to 2010

*Angela Meneses-Gutierrez[1,2], Paul Segall[3], Takeshi Sagiya[2,4] (1.Institute for Advanced Research, Nagoya University, 2.Disaster Mitigation Research Center, Nagoya University, 3.Stanford University, 4.Graduate School of Environmental Studies, Nagoya University)

[SCG63-23] **Interseismic slip of the Shanchiao fault in northern Taiwan from GPS and leveling measurements**

*Yining Ke[1], Wu-Lung Chang[1] (1.Department of Earth Sciences, National Central University)

[SCG63-24] Decomposition of elastic potential energy and the meaning of the energetics-based failure stress criterion

*Mitsuhiro Matsu'ura[1], Toshiko Terakawa[2] (1.Institute of Statistical Mathematics, 2.Nagoya University)

[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG64] Crust-mantle connections

convener:Yoshihiko Tamura(Research Institute for Marine Geodynamics, Japan Agency for Maine-Earth Science and Technology), Osamu Ishizuka(Geological Survey of Japan, AIST)

[SCG64-01] Synmagmatic faulting partly controls fluid-melt-peridotite reaction and lithospheric melts generation at the crust-mantle transition

*Mathieu Rospabe[1], Mathieu Benoit[2], Georges Ceuleneer[2], Mary-Alix Kaczmarek[2] (1.Research Institute for Marine Geodynamics (IMG), Japan Agency for Marine-Earth Science and Technology, 2.Géosciences Environnement Toulouse (GET), Observatoire Midi-Pyrénées, Université de Toulouse, CNRS, IRD)

[SCG64-02] Multi-stage metasomatism and metamorphism of the Mesoarchean Ulamertoq ultramafic rocks in southern West Greenland

*Ikuya Nishio[1], Tomoaki Morishita[1], Akihiro Tamura[1], Juan Miguel Ramirez Guotana[1], Kenichiro Tani[2], Yumiko Harigane[3], Kristoffer Szilas[4], D. Graham Pearson[5] (1.Kanazawa University, 2.Department of Geology and Paleontology, National Museum of Nature and Science, 3.Institute of Geology and Geoinformation Geological Survey of Japan/AIST, 4.University of Copenhagen, 5.University of Alberta)

[SCG64-03] Arc magma genesis: evidence from Kibblewhite Volcanic Complex in the Kermadec arc, New Zealand

★Invited Papers

*Yasuhiro Hirai[1,2], Yoshihiko Tamura[2], Kaj Hoernle[3], Reinhard Werner[3], Folkmar Hauff[3], Christian Timm[4], Bogdan Vaglarov[2], Qing Chang[2], Takashi Miyazaki[2], Jun-Ichi Kimura[2], Takeshi Hanyu[2] (1.Graduate School of Natural Science and Technology, Kanazawa University, Japan, 2.Research Institute for Marine Geodynamics (IMG), Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokosuka, Kanagawa, Japan, 3.GEOMAR Helmholtz Centre for Ocean Research, Kiel, Germany, 4.GNS Science, Lower Hutt, New Zealand)

[SCG64-04] The Atlantis Bank Batholith, SW Indian Ridge, the Link Between Lower Crustal Accretion at High and Low Melt Supply

*Henry J Dick[1] (1.Woods Hole Oceanographic Institution)

[SCG64-05] Oceanic lower crust and uppermost mantle of the Shikoku Basin: insights from expeditions to Mado Megamullion

*Yasuhiko Ohara[1,2,3], Kyoko Okino[4], Norikatsu Akizawa[4], Masakazu Fujii[5], Yumiko Harigane[6], Ken-ichi Hirauchi[7], Osamu Ishizuka[6], Shiki Machida[8], Katsuyoshi Michibayashi[3], Alessio Sanfilippo[9], Sani Camilla[9], Snow E. Jonathan[10], Kenichiro Tani[11], Hiroyuki Yamashita[12] (1.Hydrographic and Oceanographic Department of Japan, 2.Japan Agency for Marine-Earth Science and Technology , 3.Nagoya University, 4.Atmosphere and Ocean Research Institute, University of Tokyo, 5.National Institute of Polar Research , 6.Geological Survey of Japan, AIST, 7.Shizuoka University, 8.Chiba Institute of Technology, 9.University of Pavia, 10.Louisiana State University, 11.National Science Museum, 12.Kanagawa Prefectural Museum of Natural History)

[SCG64-06] Petrological characteristics of serpentinized peridotites dredged from oceanic core complexes in the Shikoku Basin

Izumi Segawa[1], *Ken-ichi Hirauchi[1], Yasuhiko Ohara[2,3], Yui Kouketsu[3], Katsuyoshi Michibayashi[3] (1.Department of Geosciences, Faculty of Science, Shizuoka University, 2.Hydrographic and Oceanographic Department of Japan, 3.Department of Earth & Planetary Sciences, Graduate School of Environmental Studies, Nagoya University)

[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG64] Crust-mantle connections

convener:Yoshihiko Tamura(Research Institute for Marine Geodynamics, Japan Agency for Maine-Earth Science and Technology), Osamu Ishizuka(Geological Survey of Japan, AIST)

[SCG64-07] Was the Jurassic–Cretaceous boundary a critical event for marine life in the pelagic Panthalassa?

★Invited Papers

*Atsushi Matsuoka[1] (1.Department of Geology, Faculty of Science, Niigata University)

[SCG64-08] The Renaissance of the oldest oceanic plate: Perspective of REY-rich mud as a paleoceanographic archive in a pelagic realm of the Pacific Ocean

★Invited Papers

*Erika Tanaka[1], Kazutaka Yasukawa[2,1,3], Kentaro Nakamura[1], Junichiro Ohta[2,3], Tatsuo Nozaki[4,2,5,3], Yoichi Usui[4], Koichiro Fujinaga[3,2], Koichi Iijima[4], Yasuhiro Kato[2,1,3] (1.Department of Systems Innovation, School of Engineering, The University of Tokyo, 2.Frontier Research Center for Energy and Resources, School of Engineering, The University of Tokyo, 3.Ocean Resources Research Center for Next Generation, Chiba Institute of Technology, 4.Submarine Resources Research Center, Japan Agency for Marine-Earth Science and Technology, 5.Department of Planetology, Faculty of Science, Kobe University)

[SCG64-09] REY-rich mud in the western North Pacific Ocean: An overview and implication for Earth system dynamics

★Invited Papers

*Yasuhiro Kato[1,2], Kazutaka Yasukawa[1,2], Junichiro Ohta[1,2], Erika Tanaka[1], Kazuhide Mimura[1], Koichiro Fujinaga[2,1], Kentaro Nakamura[1] (1.Graduate School of Engineering, University of Tokyo, 2.ORCeNG, Chiba Institute of Technology)

[SCG64-10] The Renaissance of the Oldest Oceanic Plate: Jurassic Oceanic Crust without Moho

*Yoshihiko Tamura[1], Mathieu Rospabe[1], Kentaro Kaneda[2], Alexander Nichols[3], Gou Fujie[1], Eiichi TAKAZAWA[4], Katsuyoshi Michibayashi[5], Shuichi Kodaira[1] (1.Research Institute for Marine Geodynamics, Japan Agency for Maine-Earth Science and Technology, 2.Japan Coast Guard, 3.University of Canterbury, New Zealand, 4.Niigata University, 5.Nagoya University)

[SCG64-11] Magma genesis model of the subduction zones based on hydrous melting experiments of a mantle peridotite

*Eiichi Takahashi[1], Jintuan Wang[1] (1.Guangzhou Institute of Geochemistry, Chinese Academy of Science)

[SCG64-12] The tectonic-magmatic characteristics in the Kamchatka: Implications for the dynamics around the northern edge of Pacific Plate

*Tatsuji Nishizawa[1], Hitomi Nakamura[2,3,4,5], Hikaru Iwamori[3,4,6] (1.Volcanic Fluid Research Center, School of Science, Tokyo Institute of Technology, 2.Institute of Earthquake and Volcano Geology, Geological Survey of Japan, AIST, 3.Department of Solid Earth Geochemistry, Japan Agency for Marine-Earth Science and Technology, 4.Depeartment of Earth and Planetary Sciences, School of Science, Tokyo Institute of Technology, 5.ORCeNG, Chiba Institute of Technology, 6.Earthquake Research Institute, The University of Tokyo)

[E] Oral | B (Biogeosciences)：B-BC Biogeochemistry

[B-BC03] Earth and Planetary Science Frontiers for Life and Global Environment

convener:Yoshinori Takano(Japan Agency for Marine-Earth Science and Technology (JAMSTEC)), Yohey Suzuki(Graduate School of Science, The University of Tokyo), Shingo Kato(RIKEN), Keisuke Fukushi(Institute of Nature & Environmental Technology, Kanazawa University)

[BBC03-01] The prebiotic chemistry of Enceladus' hydrothermal systems

*Wataru Takahagi[1,2] (1.Department of Chemistry, Graduate School of Science, The University of Tokyo, 2.Institute for Extra-cutting-edge Science and Technology Avant-garde Research (X-star), Japan Agency for Marine-Earth Science and Technology (JAMSTEC))

[BBC03-02] **Pressure-induced esterification reaction between phosphoric acid and methanol: a possibility of prebiotic formation of alkyl phosphate and phospholipid at high pressure**

*Yuchen Sun[1], Chikako Fujimoto[1], Hiroyuki Kagi[1] (1.Graduate School of Science, The University of Tokyo)

[BBC03-03] **Iron mediated synthesis of thioesters with thioacetic acid and simultaneous formation of FeS clusters in aqueous solution**

*Sebastian Adrian Sanden[1], Shawn Erin McGlynn[1], Masahiko Hara[1], Riquin Yi[1] (1.Tokyo Institute of Technology)

[BBC03-04] Japanese challenges to explore Martian biosphere

*Yohey Suzuki[1], Tomohiro Usui[2], Akihiko Yamagishi[2] (1.Graduate School of Science, The University of Tokyo, 2.Japan Aerospace Exploration Agency (JAXA))

[BBC03-05] Habitable aqueous environment on Early Mars inferred from reconstructed water chemistry at Gale

★Invited Papers

*Keisuke Fukushi[1], Yasuhito Sekine[2,1], Hiroshi Sakuma[3], Koki Morida[4], Robin Wordsworth[5] (1.Institute of Nature & Environmental Technology, Kanazawa University, 2.Earth-Life Science Institute, Tokyo Institute of Technology, 3.National Institute for Materials Science, 4.Division of Natural System, Kanazawa University, 5.Department of Earth and Planetary Sciences, Harvard University)

[BBC03-06] Toward the exploration of habitable Mars: MMX and beyond

*Tomohiro Usui[1] (1.Japan Aerospace Exploration Agency)

[E] Oral | B (Biogeosciences)：B-BC Biogeochemistry

[B-BC03] Earth and Planetary Science Frontiers for Life and Global Environment

convener:Yoshinori Takano(Japan Agency for Marine-Earth Science and Technology (JAMSTEC)), Yohey Suzuki(Graduate School of Science, The University of Tokyo), Shingo Kato(RIKEN), Keisuke Fukushi(Institute of Nature & Environmental Technology, Kanazawa University)

[BBC03-07] Isolation and physiological characterization of an archaeon at the prokaryote-eukaryote interface

★Invited Papers

*Hiroyuki Imachi[1], Masaru K Nobu[2] (1.Japan Agency for Marine-Earth Science and Technology, 2.National Institute of Advanced Industrial Science and Technology)

[BBC03-08] Genomic analyses of the closest isolated archaeal relative of eukaryotes reveals novel insights into eukaryogenesis

★Invited Papers

*Masaru Konishi Nobu[1], Hiroyuki Imachi[2], Nozomi Nakahara[2,1,3], Yuki Morono[2], Miyuki Ogawara[2], Yoshihiro Takaki[2], Katsuyuki Uematsu[4], Tetsuro Ikuta[2], Motoo Ito[2], Yohei Matsui[2], Masayuki Miyazaki[2], Kazuyoshi Murata[5], Yumi Saito[2], Sanae Sakai[2], Chihong Song[5], Eiji Tasumi[2], Yuko Yamanaka[2], Takashi Yamaguchi[3], Yoichi Kamagata[1], Hideyuki Tamaki[1], Ken Takai[2] (1.National Institute of Advanced Industrial Science and Technology, 2.Japan Agency for Marine-Earth Science and Technology, 3.Nagaoka University of Technology, Nagaoka, 4.Marine Work Japan Ltd, 5.National Institute for Physiological Sciences)

[BBC03-09] The origin of scaly-foot gastropod's scale and iron sulfide nanoparticles inside

★Invited Papers

*Okada Satoshi[1] (1.Japan Agency for Marine-Earth Science and Technology)

[BBC03-10] Interaction of organic matter and submarine hydrothermal fluids on the early Earth: its importance for origin of proto-enzyme and early microbial activities

*Takeshi Kakegawa[1] (1.Graduate School of Science, Tohoku University)

[BBC03-11] Revised kinetic parameters of the Aps reductase enzyme: effect on microbial sulfur isotope fractionation.

*Shawn E McGlynn[1], Tommy Po-Hsiang Wang[1], Mayuko Nakagawa[1], Yuichiro Ueno[1] (1.Tokyo Institute of Technology)

[BBC03-12] Climate and litter C/N ratio constrain soil organic carbon accumulation

Guoyi Zhou[1], *Shan Xu[2], Ciais Philippe [3], Manzoni Stefano [4,5] (1.Institute of Ecology, Jiangsu Key Laboratory of Agricultural Meteorology, Nanjing University of Information Science & Technology, Nanjing 210044, China, 2.Guangdong Institute of Eco-environmental and Soil Sciences, 3.Institut Pierre Simon Laplace, Laboratoire des Sciences du Climat et de l'Environnement, CEA CNRS UVSQ UPSaclay, 91191 Gif sur Yvette, France, 4.Department of Physical Geography, Stockholm University, Stockholm SE-10691, Sweden, 5.Bolin Centre for Climate Research, Stockholm SE-10691, Sweden)

[E] Oral | B (Biogeosciences)：B-PT Paleontology

[B-PT04] Biomineralization and Geochemistry of Proxies

convener:Takashi Toyofuku(Japan Agency for Marine-Earth Science and Technology (JAMSTEC)), Jelle Bijma(Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung), Hiroshi Kitazato(Tokyo University of Marine Science and Technology (TUMSAT)), Kotaro Hirose(Faculty of Science and Engineering, Waseda University)

[BPT04-01] **Shell formation of foraminifera -marine unicellular calcifiers-**

*Takashi Toyofuku[1,2], Yukiko Nagai[1,3] (1.Japan Agency for Marine-Earth Science and Technology (JAMSTEC), 2.Tokyo University of Marine Science and Technology (TUMSAT), 3.National Museum of Nature and Science,Tokyo (NMNS))

[BPT04-02] Effect of euxinic conditions on planktic foraminifers: results from laboratory culture experiments and implications for oceanic anoxic events

*Azumi Kuroyanagi[1], Takashi Toyofuku[2], Yukiko Nagai[2], Katsunori Kimoto[2], Hiroshi Nishi[1], Reishi Takashima[1], Hodaka Kawahata[3] (1.The Center for Academic Resources and Archives, Tohoku University, 2.JAMSTEC, 3.Atmosphere and Ocean Research Institute, The university of Tokyo)

[BPT04-03] Effects of larger benthic foraminifers from global warming analysed by Micro-X-ray CT

*Shunichi Kinoshita[1], Azumi Kuroyanagi[2], Hiroshi Nishi[2], Osamu Sasaki[2], Kazuhiko Fujita[3], Atsushi Suzuki[4], Hodaka Kawahata[5] (1.Tohoku University, Graduate School of Science, 2.The Tohoku University Museum, 3.University of the Ryukyus, 4.Geological Survey of Japan National Institute of Advanced Industrial Science and Technology, 5.the University of Tokyo)

[BPT04-04] Foraminiferal calcification, CO_2, precipitation rates and element incorporation

*Lennart Jan de Nooijer[1], Takashi Toyofuku[2], Esmee Geerken[1], Gert-Jan Reichart[1] (1.Netherlands Institute for Sea Research, 2.JAMSTEC)

[BPT04-05] **The coral reef-dwelling *Peneroplis pertusus* brought to light: recalcification during culture experiments**

*Laurie Charrieau[1], Takashi Toyofuku[1], Yukiko Nagai[1], Katsunori Kimoto[2], Kazuhiko Fujita[3] (1.X-STAR, JAMSTEC, 2.RIGC, JAMSTEC, 3.Department of Physics and Earth Sciences, University of the Ryukyus)

[BPT04-06] Variations in carbon and oxygen isotope composition and trace element concentrations of the modern brachiopod shells collected off Okinoshima

*Kazuma Oikawa[1], Hideko Takayanagi[1], Ryuichi Shinjo[2], Kazuyoshi Endo[3], Masa-aki Yoshida[4], Yasufumi Iryu[1] (1.Institute of Geology and Paleontology Graduate School of Science Tohoku University, 2.Department of Physics and Earth Sciences, University of the Ryukyus, 3.Department of Earth and Planetary Science, Tokyo University, 4.Shimane University Faculty of Life and Environmental Science)

[E] Oral | B (Biogeosciences)：B-PT Paleontology

[B-PT04] Biomineralization and Geochemistry of Proxies

convener:Takashi Toyofuku(Japan Agency for Marine-Earth Science and Technology (JAMSTEC)), Jelle Bijma(Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung), Hiroshi Kitazato(Tokyo University of Marine Science and Technology (TUMSAT)), Kotaro Hirose(Faculty of Science and Engineering, Waseda University)

[BPT04-07] Validation and calibration of proxies to reconstruct past oxygenation using foraminifera: Shell Mn/Ca and porosity.

*Inge van Dijk[1,2], Christine Barras[2], Aurelia Mouret[2], Grit Steinhöfel[1], Emmanuelle Geslin [2], Jelle Bijma[1] (1.Marine Biogeosciences, Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung, Bremerhaven, Germany, 2.LPG UMR CNRS 6112, University of Angers, UFR Sciences, Angers, France)

[BPT04-08] Development of new proxies using macromolecular structures of marine palynomorphs

*Takuto Ando[1], Kazumi Matsuoka[2], Karin Zonneveld[3], Gerard Versteegh[3,4] (1.Estuary Research Center, Shimane University, 2.Institute for East China Sea Research, Nagasaki University, 3.Center for Marine Environmental Sciences (marum), Bremen University, 4.Department of Earth and Environmental Science, Jacobs University Bremen)

[BPT04-09] Lipid biomarker analysis of culture samples of genus *Tetraparma* of the Parmales (Bolidophyceae)

*Ken Sawada[1], Yuki Hattori[1], Mutsuo Ichinomiya[2], Akira Kuwata[3] (1.Department of Earth and Planetary Sciences, Faculty of Science, Hokkaido University, 2.Prefectural University of Kumamoto, 3.Tohoku National Fisheries Research Institute)

[BPT04-10] Seasonal variation in assemblage of planktic foraminifera from the sediment trap samples in the Bay of Bengal

*Ayumi Maeda[1,2], Azumi Kuroyanagi[3], Hiroshi Nishi[3], Birgit Gaye[4], Hodaka Kawahata[2,1] (1.Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, 2.Atmosphere and Ocean Research Institute, The University of Tokyo, 3.The Tohoku University Museum, Tohoku University, 4.Institute of Biogeochemistry and Marine Chemistry, University of Hamburg)

[BPT04-12] Recent changes of the diatom assemblages in relation to human-induced pollution in Baltic Sea coastal inlets.

*Kotaro Hirose[1], Hanna Nilsson[3,2], Karin Rengefors[3], Olof Berglund[3], Filipsson F. Helena[2] (1.Faculty of Science & Engineering, Waseda University, 2.Dept. of Geology, Lund University, Lund, Sweden, 3.Dept. of Biology, Lund University, Lund, Sweden)

[E] Oral | B (Biogeosciences)：B-PT Paleontology

[B-PT05] Biotic History

convener:Isao Motoyama(Faculty of Science, Yamagata University), Takao Ubukata(Division of Geology & Mineralogy, Department of Earth & Planetary Sciences, Kyoto University), Kazuyoshi Moriya(Department of Earth Sciences, Faculty of Education and Integrated Arts and Sciences, Waseda University)

[BPT05-01] Adaptive evolution of marine cyanobacteria to the climate in the Neoproterozoic inferred from ancestral proteins

*Nao Masuda[1], Mariko Harada[2], Sota Yagi[3], Ryutaro Furukawa[4], Akihiko Yamagishi[5], Shin-ichi Yokobori[5] (1.Department of Biological Sciences, Graduate School of Science, The University of Tokyo, 2.Faculty of Life and Environmental Sciences, University of Tsukuba, 3.Center for Biosystems Dynamics Research, RIKEN, 4.Faculty of Human Sciences, Waseda University, 5.Department of Applied Life Sciences, Tokyo University of Pharmacy and Life Sciences)

[BPT05-02] Ontogenetic transformations and re-interpretation of Ediacaran Trilobozoa

*Maria Zakrevskaya[1], Andrey Ivantsov[1] (1.Paleontological Institute of the Russian Academy of Sciences, Moscow, Russia)

[BPT05-03] Natural assemblages of the platform-type conodont in lowermost Triassic deep-sea black claystone from northeastern Japan, with probable soft-tissue impressions

*Satoshi Takahashi[1], Satoshi Yamakita[2], Noritoshi Suzuki[3] (1.Department of Earth and Planetary Science, University of Tokyo, 2.Department of Earth Science, Faculty of Culture, Miyazaki University, 3.Institute of Geology and Paleontology, Graduate school of Tohoku University)

[BPT05-04] Tephrochronological study of the Yezo Group (uppermost Albiane-basal Campanian) in Hokkaido, Japan

*Hiroshi Nishi[1], Reishi Takashima[1], Keiichi Hayashi[2], Kuwabara Sato[2], Yuji Orihashi[3], Toshiro Yamanaka[4] (1.The Center for Academic Resources and Archives, The Tohoku Museum Tohoku University, 2.Geological Survey of Hokkaido, 3.Hirosaki University, 4.Tokyo University of Marine Science and Technology)

[BPT05-05] Molecular mechanism which controls the shell microstructure depending on environmental changes in the Japanese pearl oyster

*Kei Sato[1], Davin H.E. Setiamarga[2], Hiroshi Yonemitsu[2], Keita Higuchi[3], Yasunori Iwahashi[3], Kiyohito Nagai[3] (1.Faculty of Education and Integrated Arts and Sciences, Waseda University, 2.National Institute of Technology, Wakayama College, 3.MIKIMOTO Pearl REsearch Laboratory)

[BPT05-06] From artisanship to amateur: the challenge to identify large fossils using deep learning

*Ryuichiro Hataya[1], Kumiko Matsui[2], Tomoki Karasawa[3] (1.The University of Tokyo, 2.The Kyushu University Museum, 3.The Mikasa City Museum)

[E] Oral | B (Biogeosciences)：B-CG Complex & General

[B-CG06] Decoding the history of Earth: From Hadean to the present

convener:Tsuyoshi Komiya(Department of Earth Science & Astronomy Graduate School of Arts and Sciences The University of Tokyo), Yasuhiro Kato(Department of Systems Innovation, Graduate School of Engineering, University of Tokyo), Katsuhiko Suzuki(Submarine Resources Research Center, Japan Agency for Marine-Earth Science and Technology), Kentaro Nakamura(Department of Systems Innovation, School of Engineering, University of Tokyo)

[BCG06-01] REY-rich mud in the modern and past oceans

*Yasuhiro Kato[1,2], Kazutaka Yasukawa[1,2], Junichiro Ohta[1,2], Koichiro Fujinaga[2,1], Kentaro Nakamura[1] (1.Graduate school of Engineering, Univ. of Tokyo, 2.ORCeNG, Chiba Institute of Technology)

[BCG06-02] Fish debris and rare-earth deposition caused by topographically induced upwelling in the latest Eocene

★Invited Papers

*Junichiro Ohta[1,2,3], Kazutaka Yasukawa[1,3,2], Tatsuo Nozaki[3,1,4,2], Yutaro Takaya[5,2,3], Kazuhide Mimura[1], Koichiro Fujinaga[2,1], Kentaro Nakamura[1], Yoichi Usui[3], Jun-Ichi Kimura[3], Qing Chang[3], Yasuhiro Kato[1,2,3] (1.The University of Tokyo, 2.Chiba Institute of Technology, 3.Japan Agency for Marine-Earth Science and Technology, 4.Kobe University, 5.Waseda University)

[BCG06-03] Diversity of acritarchs from the 3.0 Ga Farrel Quartzite, Pilbara Craton, Western Australia

*Kenichirio Sugitani[1] (1.Nagoya University)

[BCG06-04] **The MIF-Sulfur record suggests the oxygenated atmosphere and sulfate-rich oceans through geologic time**

*Hiroshi Ohmoto[1] (1.The Pennsylvania State University)

[BCG06-05] Mantle data imply that secular oxidation can drive oxygenation of the atmosphere

★Invited Papers

*Shintaro Kadoya[1], David C Catling[1], Robert W Nicklas[2], Igor S Puchtel[3], Ariel D Anbar[4] (1.Department of Earth and Space Sciences / cross-campus Astrobiology Program, University of Washington, 2.Geosicence Research Division, Scripps Institution of Oceanography, 3.Department of Geology, University of Maryland, 4.School of Earth and Space Exploration and School of Molecular Sciences, Arizona State University)

[BCG06-06] Ankaramite-andesite-basalt (ANANBA) model of arc evolution

*Yoshihiko Tamura[1], Tomoki Sato[1], Osamu Ishizuka[1], Yasuhiro Hirai[1], Takashi Miyazaki[1] (1.Research Institute for Marine Geodynamics, Japan Agency for Maine-Earth Science and Technology)

[E] Oral | B (Biogeosciences)：B-CG Complex & General

[B-CG06] Decoding the history of Earth: From Hadean to the present

convener:Tsuyoshi Komiya(Department of Earth Science & Astronomy Graduate School of Arts and Sciences The University of Tokyo), Yasuhiro Kato(Department of Systems Innovation, Graduate School of Engineering, University of Tokyo), Katsuhiko Suzuki(Submarine Resources Research Center, Japan Agency for Marine-Earth Science and Technology), Kentaro Nakamura(Department of Systems Innovation, School of Engineering, University of Tokyo)

[BCG06-07] Hydrogen isotope analysis of apatite inclusions in the Hadean to early Archean zircon

Daiki Tanaka[1], *Shinji Yamamoto[1], Shoichi Itoh[2], Shuhei Sakata[3] (1.Graduate School of Environment and Information Sciences, Yokohama National University, 2.Graduate School of Faculty of Science, Kyoto Uiversity, 3.Earthquake Research Institute)

[BCG06-08] Occurrence and chemical composition of carbonate rocks in the Nuvvuagittuq supracrustal belt, Quebec, Canada: Implications for chemical composition of the Eoarchean hydrothermal fluid

★Invited Papers

*Yoshida Satoshi[1], Yusuke Sawaki[2], Tsuyoshi Komiya[2] (1.Department of Earth & Planetary Science, Graduate School of Science, The University of Tokyo, 2.Department of Earth Science & Astronomy, Graduate School of Arts and Sciences, The University of Tokyo)

[BCG06-09] Depositional setting and biological activity highlighted by Cr concentration, 3.2 Ga Moodies Group, Barberton Greenstone Belt

*Yoko Ohtomo[1], Daizo Yamauchi[1], Tsubasa Otake[1], Tsutomu Sato[1] (1.Faculty of Engineering, Hokkaido University)

[BCG06-10] Effect of Hydrocarbon Haze on Climate Stability under Mildly Oxidized Late-Archean Environment

★Invited Papers

*Yasuto Watanabe[1], Eiichi Tajika[1], Kazumi Ozaki[2], Peng Hong[3] (1.The University of Tokyo, 2.Toho University, 3.Chiba Institute of Technology)

[BCG06-11] The demise of the positive carbon isotope excursion in the Paleoproterozoic Francevillian Basins, Gabon

*Tomohiko Sato[1], Yusuke Sawaki[2], Shigenori Maruyama[1], Karen Bakakas[3], Mathieu Moussavou[3], Ambroise Edou-Minko[3] (1.Tokyo Institute of Technology, 2.The University of Tokyo, 3.University of Sciences and Technology in Masuku)

[BCG06-12] Sponge-like grains and negative excursion of carbon isotopes in late Cryogenian

*Akihiro Kano[1], Yuki Eguchi[1] (1.Graduate School of Science, The University of Tokyo)

[E] Oral | B (Biogeosciences)：B-CG Complex & General

[B-CG07] Phanerozoic biodiversity change: radiation and extinction

convener:Yukio Isozaki(Department of Earth Science and Astronomy, Multi-disciplinary Sciences - General Systems Studies, Graduate School of Arts and Sciences, The University of Tokyo), Yusuke Sawaki(The University of Tokyo)

[BCG07-01] Hierarchy in mass extinction causes: from direct kill mechanism to ultimate cause

*Yukio Isozaki[1] (1.Department of Earth Science and Astronomy, Multi-disciplinary Sciences - General Systems Studies, Graduate School of Arts and Sciences, The University of Tokyo)

[BCG07-02] A relationship between paleomagnetic data and biodiversity during the Phanerozoic

*Yasushi Harada[1], Yuto Kikuzawa[1] (1.School of Marine Science and Technology, Tokai University)

[BCG07-03] The oldest arthropod body fossils from the Cambrian Stage 1 (Fortunian) in South China

*KONO SENA[1], Yukio Isozaki[1], Tomohiko Sato[2], Xingliang Zhang[3], Wei Liu[3] (1.The University of Tokyo School of Arts &Sciences, 2.Department of Earth and Planetary Sciences, Tokyo Institute of Technology, 3.Northwest university, China)

[BCG07-04] Graptolite biostratigraphy of the Ordovician to Silurian boundary succession in the Khao Nui area, southern peninsular Thailand

*Ippei Katakura[1], Sachiko Agematsu[1], Apsorn Sardsud[2] (1.University of Tsukuba, 2.Department of Mineral Resources)

[BCG07-05] Permian Panthalassan Sr budget change

*Tomomi Kani[1], Yukio Isozaki[2], Keiji Misawa[3], Akira Ishikawa[4], Shigekazu Yoneda[5] (1.Department of Earth and Environmental Sciences, Kumamoto University, 2.The University of Tokyo, 3.National Institute of Polar Research, 4.Tokyo Institute of Technology, 5.National Museum of Nature and Science)

[BCG07-06] Marine osumium isotope records during the Carnian (Late Triassic) “pluvial episode” in the pelagic bedded cherts

*Yuki Tomimatsu[1], Tatsuo Nozaki[2,3,4,5], Honami Sato[5], Yutaro Takaya[6], Jun-Ichi Kimura[7], Chang Qing[7], Hiroshi Naraoka[8], Manuel Rigo[9], Tetsuji Onoue[8] (1.Graduate school of Science and Technology, Kumamoto University, 2.Submarine Resources Research Center, Research Institute for Marine Resources Utilization, Japan Agency for Marine-Earth Science and Technology, 3.Frontier Research Center for Energy and Resources (FRC- ER), Graduate School of Engineering, Tokyo University, 4.Department of Planetology, Graduate School of Science, Kobe University, 5.Ocean Resources Research Center for Next Generation, Chiba Institute of Technology, 6.Department of Resources and Environmental Engineering School of Creative Science and Enginerring, Waseda University, 7.Department of Solid Earth Geochemistry, Japan Agency for Marine-Earth Scienc and Technology, 8.Department of Earth and Planetary Sciences, Faculty of Sciences, Kyushu University, 9.Department of Geosciences, University of Padova)

[E] Oral | B (Biogeosciences)：B-CG Complex & General

[B-CG07] Phanerozoic biodiversity change: radiation and extinction

convener:Yukio Isozaki(Department of Earth Science and Astronomy, Multi-disciplinary Sciences - General Systems Studies, Graduate School of Arts and Sciences, The University of Tokyo), Yusuke Sawaki(The University of Tokyo)

[BCG07-07] Upper Triassic (Rhaetian) conodont biostratigraphy of the Panthalassa Ocean and the final extinction of conodonts at the end-Triassic

*Tetsuji Onoue[1], Kanna Yamasaki[2], Yuki Tomimatsu[2,1], Yixing Du[3], Daisuke Yamashita[4], Katsuhito Soda[2], Manuel Rigo[3] (1.Kyushu Univ., 2.Kumamoto Univ., 3.Univ. Padova, 4.Satsumasendai City Office)

[BCG07-08] **The Carbon-Silicon cycle coupling: insight from in situ $\delta^{30}Si$ in Mesozoic radiolarites.**

*Maximilien Bole[1], Masayuki Ikeda[1], Rie Hori, S.[2], Peter O. Baumgartner[3] (1.Department of Earth and Planetary Sciences, Tokyo University, Japan, 2.Department of Earth Science, Ehime University, Japan, 3.Institute of Earth Science (ISTE), Université de Lausanne, Switzerland)

[BCG07-09] Geology and paleontology of the Tetori Group distributed in the Shokawa area, Gifu prefecture

*WATABE SERIE[1], Sachiko Agematsu[1] (1.University of Tsukuba)

[BCG07-10] Marine Os isotopic evidence for multiple submarine volcanic activities during Aptian, mid-Cretaceous

*Hironao Matsumoto[1], Junichiro Kuroda[1], Rodolfo Coccioni[2], Fabrizio Frontalini[2] (1.Department of Earth and Planetary Science, The University of Tokyo, 2.DiSPeA, University of Urbino)

[BCG07-11] Cu- or Ag-enriched grains in the K-Pg boundary clays: New evidence for acid rain immediately after the meteorite impact

*Teruyuki Maruoka[1], Yoshiro Nishio[2], Tetsu Kogiso[3], Katsuhiko Suzuki[4] (1.University of Tsukuba, 2.Kochi University, 3.Kyoto University, 4.Japan Agency for Marine-Earth Science and Technology)

[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS01] Tsunami deposit

convener:Daisuke Ishimura(Department of Geography, Tokyo Metropolitan University), Takashi Chiba(Faculty of Bioresource Sciences, Akita Prefectural University), Masaki Yamada(Department of Geology, Faculty of Science, Shinshu University), Takashi Ishizawa(International Research Institute of Disaster Science, Tohoku University)

[MIS01-01] Evaluation for transport processes of paleo-tsunami by organic geochemical analyses of peat sediments in eastern Hokkaido, Japan

*Hiroyasu Asahi[1], Ken Sawada[2], Satoshi Furota[3] (1.Graduate School of Science, Hokkaido University, 2.Department of Earth and Planetary Science, Facility of Science, Hokkaido University, 3.National Institute of Advanced Industrial Science and Technology)

[MIS01-02] **Paleotsunami record in Hachinohe, Aomori Prefecture, northern Japan.**

*Erick Velasco R.[1], Kazuhisa Goto[2], Daisuke Sugawara[3], Yuichi Nishimura[4], Takahiro Shinohara[1], Takashi Chiba[5] (1.Earth Science Department, Graduate Faculty of Science, Tohoku University, 2.Department of Earth and Planetary Science, Graduate School of Science, the University of Tokyo, 3.Museum of Natural and Environmental History, Shizuoka, 4.Institute of Seismology and Volcanology, Graduate School of Science, Hokkaido University, 5.Faculty of Bioresource Sciences, Akita Prefecture University.)

[MIS01-03] Geological features of tsunami deposits associated with the 1983 Nihonkai-chubu earthquake in pine-based windbreak forests of Noshiro City and Happo Town in Akita Prefecture, Japan

*Takashi Chiba[1], Yuichi Nishimura[2] (1.Faculty of Bioresource Sciences, Akita Prefectural University, 2.Institute of Seismology and Volcanology, Faculty of Science, Hokkaido University)

[MIS01-04] Identification of tsunami, storm, and river flood deposits besed on the multi-proxy evidence on the coastal lowland of Odaka District, Minamisoma City, Fukushima Prefecture, Northeast Japan

*Shiori Uchiyama[1], Junichi Machida[1], Koichi Hoyanagi[1] (1.Shinshu University)

[MIS01-05] Literature review and numerical modeling for updating physical identification criteria of tsunami and storm deposit

★Invited Papers

*Masashi Watanabe[1], Kazuhisa Goto[2], Fumihiko Imamura[3] (1.Chuo University, 2.The University of Tokyo, 3.Tohoku University)

[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS01] Tsunami deposit

convener:Daisuke Ishimura(Department of Geography, Tokyo Metropolitan University), Takashi Chiba(Faculty of Bioresource Sciences, Akita Prefectural University), Masaki Yamada(Department of Geology, Faculty of Science, Shinshu University), Takashi Ishizawa(International Research Institute of Disaster Science, Tohoku University)

[MIS01-06] Relationship between the distribution of crevasse-splay deposits and the inundation distance of the October 2019 flooding of the Chikuma River, central Japan

*Masaki Yamada[1], Hajime Naruse[2], Yuhei Matsuda[1], Tetsuya Shinozaki[3], Tetsuya Tokiwa[1] (1.Faculty of Science, Shinshu University, 2.Faculty of Science, Kyoto University, 3.Center for Research in Isotopes and Environmental Dynamics, University of Tsukuba)

[MIS01-07] Numerical method for constraining maximum local size of paleotsunamis using storm boulder deposits

*Kenta Minamidate[1], Kazuhisa Goto[2], Hironobu Kan[3] (1.Department of Earth Science, Tohoku University, 2.Department of Earth and Planetary Science, The University of Tokyo, 3.Graduate School of Integrated Sciences for Global Society, Kyushu University)

[MIS01-08] Preservation and weathering of tsunami deposits formed during the eruption of Anak Krakatau volcano, Indonesia, on December 22, 2018

*Yuichi Nishimura[1], Purna Sulastya Putra[2], Septriono Hari Nugroho[2], Eko Yulianto[2], Takashi Chiba[3] (1.Graduate School of Science, Hokkaido University, 2.Research Center for Geotechnology, Indonesian Institute of Sciences (LIPI), 3.Faculty of Bioresource Sciences, Akita Prefectural University)

[MIS01-09] **Reconstruction of Hydraulic Conditions from Tsunami Deposits: Inverse Modeling using Deep-Learning Neural Network**

*Rimali Mitra[1], Hajime Naruse[1], Tomoya Abe[2] (1.Kyoto University, Graduate School of Science, 2.Research Institute of Geology and Geoinformation, Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan)

[MIS01-10] Tsunami source estimation from tsunami deposit and numerical simulation

★Invited Papers

*Kenji Satake[1], Satoshi Kusumoto[2] (1.Earthquake Research Institute, University of Tokyo, 2.JAMSTEC)

[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS02] Environmental, socio-economic and climatic changes in Northern Eurasia

convener:Pavel Groisman(NC State University Research Scholar at NOAA National Centers for Environmental Information, Asheville, North Carolina, USA), Shamil Maksyutov(National Institute for Environmental Studies), Evgeny P Gordov(Institute of Monitoring of Climatic and Ecological Systems SB RAS), Akiyo Yatagai(Hirosaki University)

[MIS02-01] Change in metals speciation in waters of Arctic lakes (1975-2018): climate, anthropogenic loads, geochemical feature

★Invited Papers

*Marina I Dinu[1] (1.Russian, Vernadsky Institute of geochemistry and analytical chemistry)

[MIS02-02] Revised methane emission estimate for West Siberia based on Landsat mapping of wetland types

*Shamil Maksyutov[1], Irina E Terentieva[2], Alexander F Sabrekov[2], Ilya Filippov[3], Mikhail V Glagolev[4,5] (1.National Institute for Environmental Studies, Tsukuba, Japan, 2.Institute of Ecology and Evolution, RAS, Moscow, Russia, 3.Yugra State University, Khanty-Mansyisk, Russia, 4.Institute of Forest Science, RAS, Uspenskoe, Russia, 5.M.V. Lomonosov Moscow State University, Moscow, Russia)

[MIS02-03] A climatological study on freezing rain, freezing drizzle, and freezing fog in northeastern China

Yang Bai[1], *Tetsuya Hiyama[2], Hatsuki Fujinami[2] (1.Graduate School of Environmental Studies, Nagoya University, 2.Institute for Space-Earth Environmental Research, Nagoya University)

[MIS02-04] Economic Assessment of Permafrost Degradation Effects on Road Infrastructure Sustainability under Climate Change in the Russian Arctic

*Dmitry Olegovich Eliseev[1], Boris Nikolaevich Porfiriev[2], Dmitry Andreevich Streletskiy[3] (1.Russian New University (RosNOU), Moscow, Russia; Sochi scientific research center, Russian Academy of Sciences, Sochi, Russia, 2.Institute of Economic Forecasting, Russian Academy of Sciences, Moscow, Russia, 3.George Washington University, Washington, United States; Earth Cryosphere Institute, Tyumen' Scientific Center, Siberian Branch, Russian Academy of Sciences, Tyumen', Russia)

[MIS02-05] Informal use of linear road infrastructure of the extraction of natural resources in Eastern Siberia.

*Viktor Bogdanov[1] (1.Institute of geography V.B. Sochava Siberian Branch of the Russian Academy of Sciences)

[MIS02-06] **Characterization of contemporary fire regimes in Russian boreal forest under impact of climate change and anthropogenic alterations: Thematic study of the Sakha Republic (Yakutia)**

*Kiunnei Kirillina[1], Wanglin Yan[1] (1.Graduate School of Media and Governance, Keio University SFC)

[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS02] Environmental, socio-economic and climatic changes in Northern Eurasia

convener:Pavel Groisman(NC State University Research Scholar at NOAA National Centers for Environmental Information, Asheville, North Carolina, USA), Shamil Maksyutov(National Institute for Environmental Studies), Evgeny P Gordov(Institute of Monitoring of Climatic and Ecological Systems SB RAS), Akiyo Yatagai(Hirosaki University)

[MIS02-07] Analysis of CMIP6 Multi-model Climate Change Smulations and Projections Over Northern Eurasia

★Invited Papers

*Qingyun Duan[1], Xuewei Fan[2], Chenwei Shen[2], Chiyuan Miao[2] (1.Hohai University, 2.Beijing Normal University)

[MIS02-08] Evaluation of a snow scheme in Integrated Land Simulator

*Tomoko Nitta[1], Kei Yoshimura[1] (1.Institute of Industrial Science, the University of Tokyo)

[MIS02-09] **Closing water budgets of the three great Siberian River Basins**

*Pavel Shabanov[1], Ambroise Dufour[1], Olga Zolina[2], Sergey Gulev[1], Martin Wegmann[3] (1.Shirshov Institute of Oceanology, Russian Academy of Sciences, 2.Institut des Géosciences de l'Environnement, Université Grenoble Alpes, 3.World Meteorological Organisation, Geneva)

[MIS02-10] Evaluation of orographical precipitation over Central Asia and its super-ensemble and downscaling simulations to evaluate precipitation change under the warming environment

*Akiyo Yatagai[1], Saki Yanagisawa[1], Kumar Vinay[2], Ayano Senda[1], Minami Masuda[1] (1.Hirosaki University, 2.Texas A&M University)

[MIS02-11] **ENVIRONMENT CHANGES IN THE EURASIAN ARCTIC**

*Pavel Groisman[1,2,3], Sergey Gulev[2], Ambroise Dufour[2], Ge Peng[1], Dmitry Streletskiy[4], Nina Speranskaya[5], Nadezhda Tchebakova[6] (1.North Carolina Institute for Climate Studies, North Carolina State University, USA, 2.Institute of Oceanology, Russian Academy of Sciences, Russia, 3.Hydrology Science and Services Corporation, USA, 4.George Washington University, USA, 5.State Hydrologic Institute, Russia, 6.Forest Institute of the Siberian Branch of the Russian Academy of Sciences, Russia)

[MIS02-12] How much variation in land surface phenology can seasonal climate oscillations explain at pasture scale in Kyrgyzstan?

*Monika Anna Tomaszewska[1], Geoffrey M. Henebry[1,2] (1.Center for Global Change and Earth Observations, Michigan State University, East Lansing, MI 48823, USA, 2.Department of Geography, Environment, and Spatial Sciences, Michigan State University, East Lansing, MI, 48824, USA)

[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS03] Structure and deformation in the overlying plate due to subduction and related feedbacks

convener:Hiroshi Sato(Earthquake Prediction Research Center, Earthquake Research Institute, The University of Tokyo), David A Okaya(University of Southern California), Eh Tan(Institute of Earth Sciences, Academia Sinica), Masahiro Ishikawa(Graduate School of Environment and Information Sciences Yokohama National University)

[MIS03-01] **Crustal structure of the Nankai subduction zone revealed by two decades of onshore-offshore and ocean-bottom seismometer data**

*Dan Bassett[1], Adrien Arnulf[2], Shuichi Kodaira[3], Ayako Nakanishi[3], Alistair Harding[4] (1.GNS Science, 2.University of Texas at Austin, 3.JAMSTEC, 4.Scripps Institution of Oceanography)

[MIS03-02] Lower lomit of seismogenic zone beneath Japan based on hyopocenter catalog determined with 3D seismic velocity structure

*Makoto MATSUBARA[1], Tomoko Elizabeth Yano[1], Hiroshi Sato[2] (1.National Research Institute for Earth Science and Disaster Resilience, 2.Earthquake Research Institute, the University of Tokyo)

[MIS03-03] Thermal structure of the Honshu arc deduced from high P-T ultrasonic experiments and seismic tomography

*Masahiro Ishikawa[1], Shigeki Sugita[1], Satoshi Fukunaga[2] (1.Graduate School of Environment and Information Sciences, Yokohama National University, 2.College of Engineering Science, Yokohama National University)

[MIS03-04] Back-arc spreading induced by weakening in the overriding plate and mantle wedge

*Eh Tan[1], Chi-Chin Lee[2] (1.Institute of Earth Sciences, Academia Sinica, 2.Department of Geosciences, National Taiwan University)

[MIS03-05] Origin of seismogenic source faults in the backarc of Honshu, Japan.

*Hiroshi Sato[1], Tatsuya Ishiyama[1], Tetsuo No[2], Makoto MATSUBARA[3], Shuichi Kodaira[2] (1.Earthquake Research Institute, The University of Tokyo, 2.Japan Agency for Marine-Earth Science and Technology, 3.National Research Institute for Earth Science and Disaster Resilience)

[MIS03-06] Stress loading on crustal source faults due to megathrust coupling: the Nankai Trough and the Kuril trench

*Akinori Hashima[1], Hiroshi Sato[1], Tatsuya Ishiyama[1], Andrew M. Freed[2], Thorsten W. Becker[3] (1.Earthquake Research Institute, University of Tokyo, 2.Purdue University, 3.The University of Texas at Austin)

[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS03] Structure and deformation in the overlying plate due to subduction and related feedbacks

convener:Hiroshi Sato(Earthquake Prediction Research Center, Earthquake Research Institute, The University of Tokyo), David A Okaya(University of Southern California), Eh Tan(Institute of Earth Sciences, Academia Sinica), Masahiro Ishikawa(Graduate School of Environment and Information Sciences Yokohama National University)

[MIS03-07] Collapse of fore-arc crust: Cretaceous Japan case

*Yukio Isozaki[1] (1.Department of Earth Science and Astronomy, Multi-disciplinary Sciences - General Systems Studies, Graduate School of Arts and Sciences, The University of Tokyo)

[MIS03-08] First stage to reveal the structure of the Fujikawa-kako Fault Zone by the integrated seismic experiments across the northwestern region of the Izu collision zone, central Japan

*Tanio Ito[1], Ken'ichi Kano[2], Toshiki Watanabe[3], Shintaro Abe[1], Hiroshi Sato[4], Takaya Iwasaki[4], Tatsuya Ishiyama[4], Makoto MATSUBARA[5], Akira Fujiwara[6], Susumu Abe[7], Motonori Higashinaka[7] (1.Association for the Development of Earthquake Prediction, 2.Shizuoka University, 3.Nagoya University, 4.University of Tokyo, 5.NIED, 6.Geosys, 7.JGI, Inc.)

[MIS03-09] The shape of Philippine sea plate and the subsurface structure near Mt. Fuji

*Yasushi Harada[1], Hinako Nomachi[1], Kenya Yamanaka[1] (1.School of Marine Science and Technology, Tokai University)

[MIS03-10] Quaternary back-arc strain localization of Northeast Japan accommodated by fault-related folding

*Tatsuya Ishiyama[1], Hiroshi Sato[1], Naoko Kato[1], Shin Koshiya[2] (1.Earthquake Research Institute, University of Tokyo, 2.Department of Civil and Environmental Engineering, Faculty of Science and Engineering, Iwate University)

[MIS03-12] Tectonostratigraphic evolution of the North Pyrenean Fold and Thrust Belt and the Aquitaine foreland basin: constraint along a SSW-NNE cross-section (West Comminges – Mirande basins).

*Larissa NGOMBI MAVOUNGOU[1], Mary FORD[2], Frédéric CHRISTOPHOUL[3] (1.Department of Earth and Planetary Systems Science, Graduate School of Science, Hiroshima University, 2.CRPG, 15 Rue Notre Dame des Pauvres, 54 501 Vandoeuvre lès Nancy, Cedex, France, 3.GET, 14 Avenue Edouard Belin, 31 400 Toulouse, France)

[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS04] An asteroid impact in SE Asia at 0.8 Ma and its effect on the environment and biota

convener:Ryuji Tada(Department of Earth and Planetary Science, Graduate School of Science, The Univeristy of Tokyo), Paul A Carling(University of Southampton), Wickanet Songtham(Nakhon Ratchasima Rajabhat University, Thailand), Kerry Sieh(Nanyang Technological University)

[MIS04-01] Converging lines of evidence for burial of the Australasian impact crater within the Bolaven volcanic field, Southern Laos

★Invited Papers

Kerry Sieh[1], *Jason S Herrin[1], Dayana Angel Schonwalder[1], Vanpheng Sihavong[2], Brian Jicha[3], Brad Singer[3], Weerachat Wewegwin[4], Paramesh Banerjee[1], Tawachai Chualaowanich[4], Punya Charusiri[5] (1.Earth Observatory of Singapore, Nanyang Technological University, Singapore, 2.Department of Geology and Mines, Ministry of Energy and Mines, Vientiane, Lao People's Democratic Republic, 3.Department of Geoscience, University of Wisconsin–Madison, Madison, Wisconsin, USA, 4.Department of Mineral Resources, Ministry of Natural Resources and Environment, Ratchatewi, Bangkok, Thailand, 5.Department of Geology, Chulalongkorn University, Khet Pathumwan, Bangkok, Thailand)

[MIS04-02] A terrestrial mafic component in Australasian tektites and associated strata; Geochemical record of the Bolaven impact.

*Jason S Herrin[1], Dayana Schonwalder[1], Kerry Sieh[1], James D. P. Moore[1], Tawatchi Chualaowanich[2], Brian Jicha[3], Brad Singer[3], Vanpheng Sihavong[4], Weerachat Wiwegwin[5], Punya Charusiri[5] (1.Earth Observatory of Singapore, Nanyang Technological University, 639798 Singapore, 2.Department of Mineral Resources, Ministry of Natural Resources and Environment, Ratchatewi, 10400 Bangkok, Thailand, 3.Department of Geoscience, University of Wisconsin–Madison, Madison, WI 53706, 4.Department of Geology and Mines, Ministry of Energy and Mines, Vientiane, Lao People's Democratic Republic, 5.Department of Geology, Chulalongkorn University, Khet Pathumwan, 10330 Bangkok, Thailand)

[MIS04-03] Identification of Ejecta Deposit formed by Australasian Tektite Event based on Discovery of Shocked Quartz and *in situ* Tektite Fragments in North Eastern Thailand

*Toshihiro Tada[1], Ryuji Tada[1,2,3], Paul Carling[4], Wickanet Songtham[5], Praphas Chansom[5], Toshihiro Kogure[1], Yu Chang[1], Eiichi Tajika[1] (1.Department of Earth and Planetary Science, The University of Tokyo , 2.Planetary Exploration Research Center, Chiba Institute of Technology, 3.Research Center for Earth System Science, Yunnan University, 4.Geography and Environmental Science, University of Southampton, 5.Northeastern Research Institute of Petrified Wood & Mineral Resources, Nakhon Ratchasima Rajabhat University)

[MIS04-04] Regionally-extensive ejecta layer of the Australian tektite strewn-field: the MIS 20 large meteorite impact in Indochina

*Paul A Carling[1,2], Toshihiro Tada[3], Ryuji Tada[3,4], Wickanet Songtham[5], Alan Cresswell[6], David Sanderson[6], Naomi Porat[7], Jaroon Duangkrayom[5], Luba Meshkova[2], Ian Croudace[2], Stephen Darby[2], Xuanmei Fan[1] (1.Chengdu University of Technology, 2.University of Southampton, 3.Chiba Institute of Technology, 4.Yunnan University, 5.Nakhon Ratchasima Rajabhat University, 6.Scottish Universities Environmental Research Centre, 7.Geological Survey of Israel)

[MIS04-05] Did Javan *Homo erectus* suffer a damage from an asteroid impact event?

★Invited Papers

*Masayuki Hyodo[1] (1.Research Center for Inland Seas, Kobe University)

[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS05] Cenozoic Evolution of the Asian Monsoon and the Indo-Pacific Paleoclimates

convener:Masanobu Yamamoto(Faculty of Environmental Earth Science, Hokkaido University), Steven C Clemens(Brown University), Hongbo Zheng(Research Center for Earth System Science, Yunnan University), Ryuji Tada(Department of Earth and Planetary Science, Graduate School of Science, The Univeristy of Tokyo)

[MIS05-01] **The Western Pacific Warm Pool hydrology during the last 1.68 million years**

*Masanobu Yamamoto[1], Sohei Kikuchi[1], Yoji Yamamoto[1], Samantha Bova[2], Yair Rosenthal[2] (1.Faculty of Environmental Earth Science, Hokkaido University, 2.Rutgers University)

[MIS05-02] **Indonesian Throughflow variability during the Mid Pleistocene Transition (IODP 363 Site U1483)**

★Invited Papers

*Kenji Matsuzaki[1], Li Gong[2], Ann Holbourn[2], Wolfgang Kuhnt[2] (1.Atmosphere and Ocean Research Institute, The university of Tokyo, 2.Institute of Geoscience, Christian Albrechts University of Kiel)

[MIS05-04] Influences of East Asian summer and winter monsoons on the millennial-scale color alternation of Japan Sea sediment

★Invited Papers

*Takuya Sagawa[1], Yusuke Narita[2], Takuya Matsuzaki[3], Masafumi MURAYAMA[4], Takashi Hasegawa[1], Akiko Goto[1], Takeshi Nakagawa[5] (1.Institute of Science and Engineering, Kanazawa University, 2.Graduate School of Natural Science and Technology, Kanazawa University, 3.Center for Advanced Marine Core Research, Kochi University, 4.Faculty of Agriculture and Marine Science, Kochi Univeristy, 5.Ritsumeikan University)

[MIS05-05] Variations in sea surface environments recorded by algal biomarkers in the Japan Sea off the western Hokkaido (IODP Site U1422) over the last 700 ky

*Asako Suzuki[1], Ken Sawada[1], Saki Yanou[1], Satoshi Furota[2], Tomohisa Irino[3] (1.Graduate School of Science, Hokkaido University, 2.National Institute of Advanced Industrial Science and Technology, 3.Graduate School of Environment, Hokkaido University)

[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS05] Cenozoic Evolution of the Asian Monsoon and the Indo-Pacific Paleoclimates

convener:Masanobu Yamamoto(Faculty of Environmental Earth Science, Hokkaido University), Steven C Clemens(Brown University), Hongbo Zheng(Research Center for Earth System Science, Yunnan University), Ryuji Tada(Department of Earth and Planetary Science, Graduate School of Science, The Univeristy of Tokyo)

[MIS05-06] Pleistocene Water Isotope Reconstructions from the Indian Monsoon Region

*Steven C Clemens[1], Masanobu Yamamoto[2], Sarah McGrath[1], Kaustubh Thirumalai[3], Yongsong Huang[1], Kerr Katrina [4], Richey Julie [5], Rosenthal Yair[6] (1.Brown University, 2.Hokkaido University, 3.University of Arizona, 4.Open University, 5.USGS, 6.Rutgers University)

[MIS05-07] Depositional environment at IODP Site U1445 in the northeastern Indian Ocean based on the litho- and isotope-stratigraphy

*Tomohisa Irino[1], Masanobu Yamamoto[1], Liviu Giosan[2], Steven Clemens[3] (1.Faculty of Environmental Earth Science, Hokkaido University, 2.Woods Hole Institution of Oceanography, 3.Brown University)

[MIS05-08] Reconstruction of asian dust flux variability since 10 Ma based on grain size specific mineral composition at IODP Site U1425 in the Japan Sea

*Mui Fa Alison Lee[1], Tomohisa Irino[1] (1.Faculty of Environmental Earth Science, Hokkaido University)

[MIS05-09] Changes in Tibetan Plateau latitude as an important factor for understanding East Asian climate since the Eocene: A modeling study

*Ran Zhang[1] (1.Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China)

[MIS05-10] From Desert to Monsoon: Irreversible Climatic Transitionat ~36 Ma in Southeastern Tibetan Plateau

*Hongbo Zheng[1], Qing Yang[1], Shuo Cao[3], Peter Dominic Clift[4], Mengying He[2], Akihiro Kano[5], Ryuji Tada[5], Fred Jourdan[6] (1.Research Center for Earth System Science, Yunnan University, 2.School of Geography Science, Nanjing Normal University, 3.School of Earth Sciences, China University of Geosciences, 4.Department of Geology and Geophysics, Louisiana State University, 5.Department of Earth and Planetary Science, University of Tokyo, 6.Western Australian Argon Isotope Facility, Department of Applied Geology and JdL Centre, Curtin University)

[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS06] Dust

convener:Ishizuka Masahide(Kagawa University), Yasunori Kurosaki(Arid Land Research Center, Tottori University), Thomas Sekiyama(Meteorological Research Institute), Kana Nagashima(Japan Agency for Marine-Earth Science and Technology, Research and Development Center for Global Change)

[MIS06-01] Assessing health risks of exposure to Asian dust among healthy individuals

★Invited Papers

*Kazunari Onishi[1], Masanori Nojima[2], Tsuyoshi Thomas Sekiyama[3], Masato Shinoda[4], Youichi Kurozawa[5], Yasunori Kurosaki[6] (1.Graduate School of Public Health, Support Unit for Conducting Clinically Essential Studies, St.Lukes International University, 2.Center for Translational Research, The Institute of Medical Science Hospital, The University of Tokyo, 3.Meteorological Research Institute, 4.Graduate School of Environmental Studies, Nagoya University, 5.Division of Health Administration and Promotion, Department of Social Medicine, Faculty of Medicine, Tottori University, 6.Arid Land Research Center, Tottori University)

[MIS06-02] Implications of overestimates in mineral dust emissions from Australia on labile iron concentrations in aerosols

*Akinori Ito[1], Morgane M. G. Perron[2], Bernadette C. Proemse[2], Michal Strzelec[2], Melanie Gault-Ringold[2], Philip W. Boyd[2], Andrew R. Bowie[2] (1.Japan Agency for Marine-Earth Science and Technology, 2.University of Tasmania)

[MIS06-03] Low dust generation from active sand dunes

*Itzhak Katra[1], Nitzan Swet[1], Jasper Kok[2], Raleigh Martin[2], Yue Huang[2], Hezi Yizhaq[1] (1.Ben-Gurion University, 2.University of California, Los Angeles)

[MIS06-04] What are the main land-surface processes affecting saltation activities in a dust hotspot of the Mongolian desert steppe?

*Kaman Kong[1], Banzragch Nandintsetseg[1,2], Masato Shinoda[1], Masahide Ishizuka[3], Yasunori Kurosaki[4] (1.Graduate School of Environmental Studies, Nagoya University, 2.School of Arts and Sciences, National University of Mongolia, 3.Faculty of Engineering and Design, Kagawa University, 4.Arid Land Research Center, Tottori University)

[MIS06-05] Effects of various vegetation factors on sand saltation from the viewpoint of roughness

*Akito Kono[1], Toshiya Okuro[1] (1.Graduate School of Agricultural and Life Sciences, The University of Tokyo)

[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS07] Aqua planetology

convener:Yasuhito Sekine(Earth-Life Science Insitute, Tokyo Institute of Technology), Hidenori Genda(Earth-Life Science Institute, Tokyo Institute of Technology), Keisuke Fukushi(Institute of Nature & Environmental Technology, Kanazawa University), Tomohiro Usui(Japan Aerospace Exploration Agency)

[MIS07-01] The Mystery of Unexpected Seasonal Rise in Oxygen on Mars

★Invited Papers

*Sushil K Atreya[1], Melissa G Trainer[2], Paul R Mahaffy[2], Michael H Wong[1] (1.University of Michigan Ann Arbor, 2.NASA-GSFC)

[MIS07-02] Water vapor vertical profiles on Mars: Results from the first full Mars Year of TGO/NOMAD science operations

*Shohei Aoki[1,2], Ann Carine Vandaele[1], Frank Daerden [1], Geronimo Luis Villanueva[3], Giuliano Liuzzi [3], Ian Thomas [1], Justin Erwin [1], Loïc Trompet [1], Lori Neary [1], Robert Todd Clancy[4], Michael Doyle Smith[3], Séverine Robert [1], Arianna Piccialli [1], Sébastien Viscardy [1], Bojan Ristic [1], Miguel Angel Lopez Valverde [5], Manish Patel [6], Giancarlo Bellucci [7], Jose Juan Lopez Moreno [5] (1.Royal Belgian Institute for Space Aeronomy, 2.Université de Liège, 3.NASA Goddard Space Flight Center, 4.Space Science Institute, 5.Instituto de Astrofísica de Andalucía, 6.Open University, 7.Istituto di Astrofisica e Planetologia)

[MIS07-03] Explanation for the increase in high altitude water on Mars observed by NOMAD during the 2018 global dust storm

*Lori Neary[1], Frank Daerden[1], Shohei Aoki[1], James Whiteway[2], Robert Todd Clancy[3], Michael Smith[4], Sébastien Viscardy[1], Justin Tyler Erwin[1], Ian Thomas[1], Geronimo Villanueva[4], Giuliano Liuzzi[4], Matteo Crismani[5], Michael Wolff[3], Stephen Lewis[6], James Holmes[6], Manish Patel[6], Marco Giuranna[7], Cedric Depiesse[1], Arianna Piccialli[1], Séverine Robert[1], Loic Trompet[1], Yannick Willame[1], Bojan Ristic[1], Ann Carine Vandaele[1] (1.Royal Belgian Institute for Space Aeronomy, Brussels, BE, 2.Centre for Research in Earth and Space Science, York University, Toronto, ON, CA, 3.Space Science Institute, Boulder, CO, USA, 4.NASA Goddard Space Flight Center, Greenbelt, MD, USA, 5.NPP/USRA, NASA Goddard Space Flight Center, Planetary Systems Laboratory, Code 693, Greenbelt, MD, USA, 6.School of Physical Sciences, The Open University, Milton Keynes, UK, 7.Instituto di Astrofisica e Planetologia Spaziali, Instituto Nazionale di Astrofisica, Rome, IT)

[MIS07-04] Stability of atmospheric redox states of early Mars inferred from time response of the regulation of H and O losses

*Shungo Koyama[1], Naoki Terada[1], Hiromu Nakagawa[1], Takeshi Kuroda[1] (1.Tohoku university)

[MIS07-05] In-situ detection of early Noachian nitrogen-bearing organics from Martian carbonates

*Mizuho Koike[1], Ryoichi Nakada[2], Kajitani Iori[1,3], Tomohiro Usui[1,4], Yusuke Tamenori[5], Haruna Sugahara[1], Atsuko Kobayashi[4,6] (1.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency , 2.Kochi Institute for Core Sample Research, Japan Agency for Marine-Earth Science and Technology, 3.Department of Earth and Planetary Science, The University of Tokyo, 4.Earth-Life Science Institute, Tokyo Institute of Technology, 5.Research and Utilization Division, Japan Synchrotron Radiation Research Institute, 6.Division of Geological and Planetary Sciences, California Institute of Technology)

[MIS07-06] Liquid Groundwater on Mars Across Time & Implications for Subsurface Habitability

★Invited Papers

*Vlada Stamenkovic[1], Ana-Catalina Plesa[2], Doris Breuer[2], Jack Mustard[3], Jesse Tarnas[3] (1.Jet Propulsion Laboratory, 2.DLR Berlin, 3.Brown University)

[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS07] Aqua planetology

convener:Yasuhito Sekine(Earth-Life Science Insitute, Tokyo Institute of Technology), Hidenori Genda(Earth-Life Science Institute, Tokyo Institute of Technology), Keisuke Fukushi(Institute of Nature & Environmental Technology, Kanazawa University), Tomohiro Usui(Japan Aerospace Exploration Agency)

[MIS07-07] Potential Positive Feedback Mechanisms in an Anoxic Environmental System of a Planet with CO_2-CH_4 Atmosphere

*Yasuto Watanabe[1], Eiichi Tajika[1], Kazumi Ozaki[2], Peng Hong[3] (1.The University of Tokyo, 2.Toho University, 3.Chiba Institute of Technology)

[MIS07-08] Sulfur species in carbonates of a 4.1-billion-year old Martian meteorite constraining conditions of water on ancient Mars

*Kajitani Iori[1,2], Ryoichi Nakada[3], Mizuho Koike[1], Gaku Tanabe[4], Tomohiro Usui[1,5], Tetsuya Yokoyama[4], Keisuke Fukushi[6] (1.Institute of Space and Astronautical Science, 2.The University of Tokyo, 3.Japan Agency for Marine-Earth Science and Technology (JAMSTEC), 4.Tokyo Institute of Technology, 5.Earth-Life Science Institute, Tokyo Institute of Technology, 6.Kanazawa University)

[MIS07-09] Experimental and thermodynamic approach on aqueous alteration of synthetic chondrite under reducing and low temperature conditions: Implication for aqueous alteration in meteorite parent bodies

*Sakiko Kikuchi[1], Takazo Shibuya[1] (1.Japan Agency for Marine-Earth Science and Technology)

[MIS07-10] Geo-electrochemical Decomposition of Amino Acids on Icy Planetesimals Reproduces Organics in Carbonaceous Meteorites

*LI Yamei[1], Norio Kitadai[1,2], ryuhei nakamura[1], Yasuhito Sekine[1] (1.Earth-Life Science Institute, Tokyo Institute of Technology, 2.Japan Agency for Marine-Earth Science and Technology)

[MIS07-11] Reduction of U(VI) to U(IV) by Fe(II)-bearing smectite

*Yoshio Takahashi[1], Jing Sun[1], Takafumi Hamamoto[2], Takayuki sasaki[3] (1.The University of Tokyo, 2.NUMO, 3.Kyoto University)

[MIS07-12] Fluorescence spectroscopy is a tool for tracing dissolved organic carbon in hot spring ecosystems

*Hilairy Ellen Hartnett[1], Joshua Nye[1] (1.Arizona State University)

[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS07] Aqua planetology

convener:Yasuhito Sekine(Earth-Life Science Insitute, Tokyo Institute of Technology), Hidenori Genda(Earth-Life Science Institute, Tokyo Institute of Technology), Keisuke Fukushi(Institute of Nature & Environmental Technology, Kanazawa University), Tomohiro Usui(Japan Aerospace Exploration Agency)

[MIS07-13] **Coupling Geochemistry to Magnetic Induction, Gravity, and Seismology in Icy Ocean Worlds**

★Invited Papers

*Steven Douglas Vance[1], Bruce G Bills[1], Mark P Panning[1], Corey Cochrane[1], Krista Soderlund[2], Tom Nordheim[1], J. Michael Brown[3], Baptiste Journaux[3], Marshall Styczinski[3], Carol Paty[4], Saikiran Tharimena[1], Mohit Melwani Daswani[1], Marc Neveu[5], Keith Chin[1] (1.NASA Jet Propulsion Laboratory, California Institute of Technology, 2.University of Texas, Austin, 3.University of Washington, Seattle, 4.University of Oregon, Eugene, 5.NASA Goddard Space Flight Center)

[MIS07-14] The Effect of Pore Structure on Water Infiltration under Different Gravity

*Yasushi Mori[1], Long Thanh Bui[1] (1.Graduate School of Environmental and Life Science, Okayama University)

[MIS07-15] Deep-seated hydrothermal circulation beneath the rdige axis: a case study of crustal diopsidite from Oman ophiolite

*Norikatsu Akizawa[1], Akira Miyake[2], Akira Tsuchiyama[3,4], Yusuke Yokoyama[1], Takahiro AZE[1], Hisashi Asanuma[5] (1.Atmosphere and Ocean Research Institute, The University of Tokyo, 2.Graduate School of Science, Kyoto University, 3.Research Organization of Science and Technology, Ritsumeikan University, 4.Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, 5.Geochemical Research Center, The University of Tokyo)

[MIS07-16] Constraint of salt compositions on Europa's surface from observations using Subaru telescope and laboratory experiments

*Shuya Tan[1,2], Yasuhito Sekine[1], Masayuki Kuzuhara[3,4], Taisei Kurosaki[5], Takashi Kikuchi[5], Hisayuki Suematsu[5], Tetsuya Hama[6], Yoshio Takahashi[2] (1.Earth-Life Science Institute (ELSI), Tokyo Institute of Technology, 2.Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, 3.Astrobiology Center, NINS, 4.National Astronomical Observatory of Japan (NAOJ), 5.Extreme Energy-Density Research Institute (EDI), Nagaoka University of Technology, 6.Komaba Institute for Science, The University of Tokyo)

[MIS07-17] Field investigation on capturing of lake water salts within surface ice on ice-covered saline lakes in Mongolia: Implications for icy shell compositions of Solar System icy bodies.

*Masahiro Yoda[1,2], Yasuhito Sekine[1,3], Keisuke Fukushi[3,4], Takuma Kitajima[4], Baasansuren Gankhurel[4], Davaadorj Davaasuren[5], Daigo Shoji[1], Yoshio Takahashi[2] (1.Earth-Life Science Institute of Tokyo Tech, 2.Department of Earth and Planetary Science, The University of Tokyo, 3.Institute of Nature and Environmental Technology, Kanazawa University, 4.Graduate School of Natural Science and Technology, Kanazawa University, 5.National University of Mongolia)

[MIS07-18] Water vapor plumes at Jupiter’s moon Europa - what we know and what we do not know

★Invited Papers

*Lorenz Roth[1] (1.KTH Royal Institute of Technology, Stockholm, Sweden)

[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS08] Paleoclimatology and paleoceanography

convener:Yusuke Okazaki(Department of Earth and Planetary Sciences, Graduate School of Science, Kyushu University), Benoit Thibodeau(University of Hong Kong), Akitomo Yamamoto(Japan Agency for Marine-Earth Science and TechnologyAtmosphere and Ocean Research Institute), Hitoshi Hasegawa(Faculty of Science and Technology, Kochi University)

[MIS08-01] **Beryllium isotopes from marine and lake sediments indicate melting of the West and East Antarctic Ice Sheet during the 4.2 Ka BP climate event**

★Invited Papers

*Adam David Sproson[1,2], Yusuke Yokoyama[1,2], Yoshinori Takano[2], Rebecca Totten Minzoni[3], Bethany Behrens[1], Yosuke Miyairi[1], Takahiro AZE[1] (1.Atmosphere and Ocean Research Institute, The University of Tokyo, 2.Department of Biogeochemistry, Japanese Agency for Marine-Earth Science and Technology, 3.Department of Geological Sciences, The University of Alabama)

[MIS08-02] **Reconstruction of the ice sheet history based on glacial geomorphology and surface exposure dating on the Soya Coast, Lützow-Holm Bay, East Antarctica**

*Moto Kawamata[1], Yusuke Suganuma[2,1], Koichiro Doi[2,1], Keiji Misawa[2,1], Motohiro Hirabayashi[2], Akihisa Hattori[1], Takanobu Sawagaki[3] (1.Department of Polar Science, School of Multidisciplinary Science, SOKENDAI (The Graduate Unversity for Advanced Studies), 2.National Institute of Polar Research, 3.Hosei University)

[MIS08-03] A portable system for acquisition of low-distortion sediment core images using computer vision and deep learning for post-processing

*Stephen Obrochta[1], Szilárd Zsolt Fazekas[2], Morén Jan[3] (1.Akita University Graduate School of International Resource Science, 2.Akita University Engineering Department, 3.Okinawa Institute of Science and Technology)

[MIS08-04] **Paleoenvironmental evolution and diagenesis of the Miocene Onnagawa Formation from mineral and elemental fluctuations**

*Jumpei Yoshioka[1], Junichiro Kuroda[2], Ryuji Tada[1,3], Kenji Matsuzaki[2] (1.Department of Earth and Planetary Science, the University of Tokyo, 2.Department of Ocean Floor Geoscience, Atmosphere and Ocean Research Institution, the University of Tokyo, 3.Yunnan University)

[MIS08-05] Reconstruction of paleoclimatic signals from groundwater in large aquifers-a case study in Leizhou peninsula, Southern China

*Shaoheng Li[1], Jianyao Chen[1], Dioni Cendon[2], Florian Freundt[3], Zongyu Chen[4], Guomin Yang[5], Shuang Xiao[2] (1.School of Geography and Planning, Sun Yat-sen University, Guangzhou, China, 2.Australian Nuclear Science and Technology Organisation, Kirrawee, Australia, 3.Institute of Environmental Physics, Heidelberg University, Im Neuenheimer Feld 229, 69120 Heidelberg, Germany, 4.Institute of Hydrogeology and Environmental Geology, Chinese Academy of Geological Sciences, Shijiazhuang, China, 5.Hefei National Laboratory for Physical Sciences at the Microscale, University of Science and Technology of China, Hefei, China)

[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS08] Paleoclimatology and paleoceanography

convener:Yusuke Okazaki(Department of Earth and Planetary Sciences, Graduate School of Science, Kyushu University), Benoit Thibodeau(University of Hong Kong), Akitomo Yamamoto(Japan Agency for Marine-Earth Science and TechnologyAtmosphere and Ocean Research Institute), Hitoshi Hasegawa(Faculty of Science and Technology, Kochi University)

[MIS08-06] **Climate conditions of the past 200 years recorded in a tufa from Tokunoshima, Kagoshima Prefecture**

*Akira Murata[1], Hirokazu Kato[1], Akihiro Kano[1] (1. Department of Earth and Planetary Science, The University of Tokyo)

[MIS08-07] **Preliminary results of 10.5 m core record from lake Olgoy, Valley of the Lake in Mongolia**

*Uyangaa Udaanjargal[1], Noriko Hasebe[1], Davaadorj Davaasuren, Yudai Igarashi[1], Keisuke Fukushi[1], Hitoshi Hasegawa[2], Baasansuren Gankhurel[1], Nagayoshi Katsuta, Shuuhaaz Ganbat, Ichinnorov Niiden (1.Kanazawa University, 2.Kochi University)

[MIS08-08] Sea Levels and coastal evolutions during the Medieval Climate Anomaly related to the construction and the abandonment of the ancient harbor “Tangseong”, western coast of Korea Peninsula, presumed by diatom analysis

*Kaoru Kashima[1], Dong-Yoon Yang[2], MIn Han[2] (1.Department of Earth and Planetary Sciences, Kyushu University, 2.Korea Institute of Geoscience & Mineral Resources (KIGAM))

[MIS08-09] **Diatom composition and distribution in surface sediments of the Laptev and East-Siberian seas and their changes during last decades**

*Mariia Sergeevna Obrezkova[1], Ira Borisovna Tsoy[1], Anastasiya Evgenievna Kolyada[1,2], Aleksandr Nikolaevich Kolesnik[1], Aleksandr Nikolaevich Charkin[1] (1.Pacific Oceanological Institute, Far Eastern Branch, Russian Academy of Sciences, 2.Far Eastern Federal University)

[MIS08-10] **Impact of catastrophic natural events on accumulation of diatoms in sediments of Amur Bay, Sea of Japan**

*Irina Aleksandrovna Prushkovskaya[1], Ira Borisovna Tsoy[1] (1.Pacific Oceanological Institute, Far Eastern Branch, Russian Academy of Sciences)

[MIS08-11] Carbon, oxygen and neodymium isotope characterization of recent benthic foraminifers around Okinawa-jima, southwestern Japan.

*Andros Daniel Cruz Salmeron[1], Hideko Takayanagi[1], Shigeyuki Wakaki[2], Hitomi Uchimura Wakaki[3], Takuya Itaki[4], Tsuyoshi Ishikawa[2], Yasufumi Iryu[1] (1.Tohoku University, 2.JAMSTEC, 3.Kochi University, 4.AIST)

[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS08] Paleoclimatology and paleoceanography

convener:Yusuke Okazaki(Department of Earth and Planetary Sciences, Graduate School of Science, Kyushu University), Benoit Thibodeau(University of Hong Kong), Akitomo Yamamoto(Japan Agency for Marine-Earth Science and TechnologyAtmosphere and Ocean Research Institute), Hitoshi Hasegawa(Faculty of Science and Technology, Kochi University)

[MIS08-12] Ecosystem response to Cretaceous OAEs - the continental perspective

★Invited Papers

*Ulrich Heimhofer[1] (1.Leibniz University Hannover, Germany)

[MIS08-13] Carbon and hydrogen isotopes of C_{40} alkenones and C_{41} *n*-alkane from OAE2 interval of IODP Site U1516 in southern high latitude

*Takashi Hasegawa[1], Akiko S. Goto[1] (1.Faculty of Geoscience and Civil Engineering, Institute of Science and Engineering, Kanazawa University)

[MIS08-14] Millennial-scale climate instability in 'hothouse' state: implication from mid-Cretaceous and Quaternary lacustrine records in Mongolia

*Hitoshi Hasegawa[1] (1.Faculty of Science and Technology, Kochi University)

[MIS08-15] The history of Earth's biospheric productivity: a biogeochemical modeling perspective

★Invited Papers

*Kazumi Ozaki[1] (1.Toho University)

[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS08] Paleoclimatology and paleoceanography

convener:Yusuke Okazaki(Department of Earth and Planetary Sciences, Graduate School of Science, Kyushu University), Benoit Thibodeau(University of Hong Kong), Akitomo Yamamoto(Japan Agency for Marine-Earth Science and TechnologyAtmosphere and Ocean Research Institute), Hitoshi Hasegawa(Faculty of Science and Technology, Kochi University)

[MIS08-16] Change in the Atlantic Meridional Overturning Circulation over the last 1,500 years

★Invited Papers

*Benoit Thibodeau[1] (1.The University of Hong Kong, Division of Earth and Planetary Sciences & SWIRE Institute of Marine Science)

[MIS08-17] Simulating the Atlantic Meridional Overturning Circulation of the glacial period with comprehensive climate models

★Invited Papers

*Sam Sherriff-Tadano[1] (1.Atmosphere and Ocean Research Institute, the University of Tokyo)

[MIS08-18] **Deglacial productivity changes reflect XRF Br fueled by Cordilleran Ice Sheet dynamics**

*Md Nurunnabi Mondal[1], Keiji Horikawa[2], Katsuya Nejigaki[3], Hideki Minami[4], Masafumi MURAYAMA[5], Osamu Seki[6], Yusuke Okazaki[7] (1.a. Graduate School of Science and Engineering for Education, University of Toyama, Japan, b. Department of Fisheries Management, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Bangladesh, 2.Graduate School of Science and Engineering for Research, University of Toyama, Japan, 3.Graduate School of Integrated Arts and Sciences, Kochi University, Japan, 4.School of Biological Science and Engineering, Tokai University, Japan, 5.Faculty of Agriculture and Marine Science, Kochi University, Japan, 6.Institute of Low Temperature Science, Hokkaido University, Japan, 7.Graduate School of Science, Kyushu University, Japan)

[MIS08-19] Ventilation change in the southern Bering Sea since the last glacial maximum

*Yusuke Okazaki[1], Hirofumi Asahi[2] (1.Department of Earth and Planetary Sciences, Graduate School of Science, Kyushu University, 2.Center for Advance Marine Core Research, Kochi University)

[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS08] Paleoclimatology and paleoceanography

convener:Yusuke Okazaki(Department of Earth and Planetary Sciences, Graduate School of Science, Kyushu University), Benoit Thibodeau(University of Hong Kong), Akitomo Yamamoto(Japan Agency for Marine-Earth Science and TechnologyAtmosphere and Ocean Research Institute), Hitoshi Hasegawa(Faculty of Science and Technology, Kochi University)

[MIS08-21] Planktonic foraminiferal analysis of the Plio-Pleistocene sequence at IODP Site U1499: Response of the northern South China Sea environment to the intensity of the East Asian monsoon after Pliocene

*Mizuki Kitamura[1], Akira Furusawa[1], Hiroki Hayashi[1] (1.SHIMANE University)

[MIS08-22] Rapid and precise carbon dioxide clumped isotope composition analysis by tunable infrared laser differential absorption spectroscopy

*David L Dettman[1], Zhennan Wang[1], Jay Quade[1], David D Nelson[2], J Barry McManus[2], Katharine W Huntington[3], Andrew J Schauer[3], Saburo Sakai[4] (1.Univ. of Arizona, Dept. of Geosciences, 2.Aerodyne Research Inc., Boston, Massachusetts, 3.Univ. of Washington, Dept. of Earth and Space Sciences, 4.Japan Agency for Marine-Earth Science and Technology, Inst. of Biogeochemistry)

[MIS08-23] Holocene biomass burning history reconstructed from the Lake Suigetsu sediments

*Song Lu[1], Yoshie Nakai[1], Youhei Yamashita[2], Tomohisa Irino[2], Yuzo Miyazaki[3], Ryuji Tada[4], Takeshi Nakagawa[5] (1.Graduate School of Environmental Science, Hokkaido University , 2.Faculty of Environmental Earth Science, Hokkaido University, 3.Institute of Low Temperature Science, Hokkaido University , 4.Department of Earth and Planetary Science , Graduate School of Science, The University, of Tokyo , 5.Research Center for Palaeoclimatology, Ritsumeikan University)

[MIS08-24] Pollen isotope records from Lake Suigetsu, Japan

★Invited Papers

*Keitaro Yamada[1], Takayuki Omori[2], Ikuko Kitaba[3], Yamasaki Akiteru[4], Takeshi Nakagawa[3] (1.Research Organization of Science and Technology, Ritsumeikan University, 2.The University Museum, The University of Tokyo, 3.Research Centre for Palaeoclimatology, Ritsumeikan University, 4.Fukui Prefectural Satoyama-Satoumi Reserch Institute)

[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS09] Interdisciplinary studies on pre-earthquake processes

convener:Katsumi Hattori(Department of Earth Sciences, Graduate School of Science, Chiba University), Dimitar Ouzounov(Center of Excellence in Earth Systems Modeling & Observations (CEESMO) , Schmid College of Science & Technology Chapman University, Orange, California, USA), Jann-Yenq LIU(Department of Space Science and Engineering, National Central University, Taiwan), Qinghua Huang(Peking University)

[MIS09-01] Prediction of Geomagnetic Daily Variations

*Suqin Zhang[1] (1.Institute of Geophysics, China Earthquake Administration)

[MIS09-02] **Evaluation of the 2017 *M* 6.6 Jinghe earthquake epicenter based on the Parkinson vector**

*aisa yisimayili[1,2], Chieh-Hung Chen[1], Zhiqiang Mao[1] (1.China University of Geosciences, 2.Earthquake Agency of Xinjiang Uygur Autonomous Region)

[MIS09-03] Seismogenic structures in western Yunnan revealed by three-dimensional magnetotelluric imaging

Tao Ye[1,2], Xiaobin Chen[2], *Qinghua Huang[1] (1.Peking University, 2.Institute of Crustal Dynamics, China Earthquake Administration)

[MIS09-04] **Seismo-conductivity anomaly associated with the 2017 M_S 7.0 Jiuzhaigou earthquake**

*Zhiqiang Mao[1], Chieh-Hung Chen[1], Suqin Zhang[2], Aisa Yisimayili[3] (1.China University of Geosciences, 2.Institute of Geophysics, China Earthquake Administration, 3.Earthquake Agency of Xinjiang Uygur Autonomous Region)

[MIS09-05] The ULF waves possibly related to earthquakes in geomagnetic field from CSES and SWARM satellites

★Invited Papers

*Xuemin Zhang[1], Yulin Zhou[1] (1.Institute of Earthquake Forecasting, China Earthquake Administration)

[MIS09-06] Statistical analysis of pre-earthquake electromagnetic anomalies in the Ultra Low Frequency (ULF) range

★Invited Papers

*Sheldon Dwight Warden[1,2], Laura MacLean[1], Jim Lemon[1], Dan Schneider[1] (1.QuakeFinder, 250 Cambridge Avenue (Suite 204), Palo Alto, CA 94306-1555, United States, 2.Hyperion Geophysical Services, 7 rue de Châtenois, 67100, Strasbourg, France.)

[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS09] Interdisciplinary studies on pre-earthquake processes

convener:Katsumi Hattori(Department of Earth Sciences, Graduate School of Science, Chiba University), Dimitar Ouzounov(Center of Excellence in Earth Systems Modeling & Observations (CEESMO) , Schmid College of Science & Technology Chapman University, Orange, California, USA), Jann-Yenq LIU(Department of Space Science and Engineering, National Central University, Taiwan), Qinghua Huang(Peking University)

[MIS09-07] Statistical analysis of AETA geo-acoustic signal based on Fractal Theory

*Jing Wang[1,2], Shanshan Yong[1,2], Xin'an Wang[1,2], Binyan Ma[1,2], Qinmeng Guo[1,2], Binghui Jiang[1,2], Chao Yang[1,2] (1.Earthquake Monitoring and Prediction Technology Research Center, Peking University Shenzhen Graduate School, Shenzhen, China, 2.The Key Laboratory of Integrated Micro-Systems Science and Engineering Applications, Peking University Shenzhen Graduate School, Shenzhen, China)

[MIS09-08] Statistical study on correlation between AETA electromagnetic signals and earthquakes

*Qinmeng Guo[1,2], Shanshan Yong[1,2], Xin'an Wang[1,2], Binghui Jiang[1,2], Jing Wang[1,2], Chao Yang[1,2] (1.Earthquake Monitoring and Prediction Technology Research Center, Peking University Shenzhen Graduate School, Shenzhen, China, 2.The Key Laboratory of Integrated Micro-Systems Science and Engineering Applications,Peking University Shenzhen Graduate School, Shenzhen, China)

[MIS09-09] Negentropy anomaly analysis of the borehole strain data associated with the *M*s 7.0 Lushan earthquake

*Zining Yu[1,2], Hattori Katsumi[2], Kaiguang Zhu[1], Chengquan Chi[1], Xiaodan He[1] (1.Key Laboratory of Geo-Exploration Instrumentation, Ministry of Education, Jilin University, Changchun, China, 2.Graduate School of Science, Chiba University, Chiba, Japan)

[MIS09-10] Observations of Backstops in the Overriding Plate During the Megathrust Earthquake Cycle

*Rob Govers[1], Taco Broerse[1], Matthew Herman[1] (1.Utrecht University, Netherlands)

[MIS09-11] **Relationships between seismogenic areas and crustal vibration before earthquakes**

★Invited Papers

*Chieh-Hung Chen[1], Yang-Yi Sun[1], Strong Wen[2], Peng Han[3], Li-Ching Lin[4] (1.Institute of Geophysics and Geomatics, China University of Geosciences, Wuhan, Hubei, China, 2.Department of Earth and Environmental Sciences, National Chung Cheng University,Chia-Yi, Taiwan, 3.Department of Earth and Space Sciences, Southern University of Science and Technology, Shenzhen, China, 4.Science and Technology Policy Research and Information Center Taiwan, Taipei, Taiwan)

[MIS09-12] **Statistical Test of Spatio-Temporal Variation of b Value in Japan**

*weiyun xie[1], Peng Han[2], Katsumi Hattori[1] (1.chiba university, 2.Southern University of Science and Technology)

[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS09] Interdisciplinary studies on pre-earthquake processes

convener:Katsumi Hattori(Department of Earth Sciences, Graduate School of Science, Chiba University), Dimitar Ouzounov(Center of Excellence in Earth Systems Modeling & Observations (CEESMO) , Schmid College of Science & Technology Chapman University, Orange, California, USA), Jann-Yenq LIU(Department of Space Science and Engineering, National Central University, Taiwan), Qinghua Huang(Peking University)

[MIS09-13] The latest results of CSES mission

★Invited Papers

*Zeren Zhima[1], Xuhui Shen[1], Jianping Huang[1] (1.Institute of Crustal Dynamics, China Earthquake Administration)

[MIS09-14] Seismo-ionospheric precursors (SIPs) of the TEC associated with the 21 September 1999 M7.3 Chi-Chi earthquake and the statistical analyses on SIPs in Taiwan

*YUN-CHENG WEN[1], JANN-YENQ Liu[1] (1.Institute of Space Science, National Central University, Taiwan)

[MIS09-15] **The three-dimensional ionospheric tomography in Japan using the adaptive Kalman Filter algorithm**

*Rui Song[1], Katsumi Hattori[2], Xuemin Zhang[3], Chie Yoshino[2] (1.Graduate School of Science and Engeering, Chiba University, 2.Graduate School of Science, Chiba University, 3.Institute of Earthquake Forecasting, China Earthquake Administration)

[MIS09-16] **FORMOSAT-5/AIP observe seismo-ionospheric precursors and ionospheric storms**

*JANN-YENQ Liu[1,2,3], FU-YUAN CHANG[1,2], YUN-CHENG WEN[2], Yuh-ING Chen[4], Chi-Kuang Chao[1,2], Loren Chang[1,2] (1.Center for Astronautical Physics and Engineering, National Central University, TAIWAN, 2.Graduate Institute of Space Science and Engineering, National Central University, TAIWAN, 3.Center for Space and Remote Sensing Research, National Central University, TAIWAN, 4.Graduate Institute of Statistics, National Central University, TAIWAN)

[MIS09-17] Transient Effects in Atmosphere and Ionosphere Associated with January 2020 Caribbean Earthquakes

*Dimitar Ouzounov[1], Sergey Pulinets[2], Alexander Rozhnoi[3], Maria Solovieva[3], Katsumi Hattori[4], Menas Kafatos[1], Patrick Taylor[5] (1.Center of Excellence in Earth Systems Modeling & Observations (CEESMO) , Schmid College of Science & Technology Chapman University, Orange, California, USA, 2.Space Research Institute, Russian Academy of Sciences, Moscow, Russia, 3.The Schmidt Institute of Physics of the Earth, Russian Academy of Sciences, Moscow, Russia, 4.Department of Earth Sciences, Graduate School of Science, Chiba University, Chiba, Japan, 5.NASA Goddard Space Flight Center, Greenbelt, MD, USA)

[MIS09-18] Earth’s outgoing longwave radiation variability prior to M ≧ 6.0 earthquakes in the Taiwan area during 2009-2016

★Invited Papers

*Ching-Chou FU[1], Lou-Chuang Lee[1], Dimitar Ouzounov[2] (1.Institute of Earth Sciences, Academia Sinica, 2.Chapman University, One University Drive, Orange, CA, USA)

[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS10] Coupling between the atmosphere, ionosphere and magnetosphere above thunderstorms

convener:Pasko Victor P(Pennsylvania State University Main Campus), Yukihiro Takahashi(Department of Cosmosciences, Graduate School of Science, Hokkaido University), Mitsuteru Sato(Department of Cosmoscience, Hokkaido University), Teruaki Enoto(RIKEN)

[MIS10-01] One TGF and two elves produced by the same thunderstorm system

★Invited Papers

*Nikolai Ostgaard[1], Steve Cummer[4], Andrey Mezentsev[1], Torsten Neubert[2], Victor Reglero[3], Olivier Chanrion[2], Martino Marisaldi[1], Pavlo Kochkin[1], Nikolai Lehtinen[1], David Sarria[1], Carolina Maiorana[1], Chris Skeie[1], Anders Lindanger[1], Yunjiao Pu[4], Chris Eyles[3], Freddy Christiansen[2], Kjetil Ullaland[1], Georgi Genov[1] (1.Birkeland Centre for Space Science, University of Bergen, Norway, 2.National Space Institute, Technical University of Denmark, Denmark, 3.University of Valencia, Spain, 4. Duke University, North Carolina, US)

[MIS10-02] The Global Distribution and Photometric Characteristics of the Intense Lightning and Their Association With Transient Luminous Events

★Invited Papers

*Alfred Bing-Chih Chen[1], Chiawen Chuang[1], Han-Tzong Su[1], Rue-Ron Hsu[1] (1.National Cheng Kung University)

[MIS10-03] Detailed temporal structure of multiple ELVES recorded at the Pierre Auger Observatory

*Roberto Mussa[1,2], Kevin-Druis Merenda[3,2], Lawrence Wiencke[2,3], Collaboration Pierre Auger[2] (1.Istituto Nazionale Fisica Nucleare - Sezione di Torino, Italy, 2.Observatorio Pierre Auger, Malargue, Mendoza , Argentina, 3.Colorado School of Mines, Golden, Colorado , USA)

[MIS10-04] Upward TGF observations with TARANIS XGRE

*Kazuhiro Nakazawa[1], Yuuki Wada[2], Philippe Laurent[3,4], Pierre-Louis Blelly[5], Sébastien Célestin[6], Jean-Louis Pinçon[6] (1.Nagoya University, 2.RIKEN, 3.CEA Saclay, 4.APC, 5.IRAP, Toulouse, 6.LPCEE, Orléans)

[MIS10-05] Downward Terrestrial Gamma-ray Flashes Coincident with Enegetic In-cloud Pulses

*Yuuki Wada[1], Teruaki Enoto[1], Takeshi Morimoto[2], Yoshitaka Nakamura[3], Mitsuteru Sato[4], Tomoo Ushio[5], Kazuhiro Nakazawa[6], Takayuki Yuasa[7], Daisuke Yonetoku[8], Tatsuya Sawano[8], Masashi Kamogawa[9], Hideo Sakai[10], Yoshihiro Furuta[11], Kazuo Makishima[1,12], Harufumi Tsuchiya[11] (1.RIKEN, 2.Kindai University, 3.KCCT, 4.Hokkaido University, 5.Osaka University, 6.Nagoya University, 7.Private Company, 8.Kanazawa University, 9.University of Shizuoka, 10.University of Toyama, 11.Japan Atomic Energy Agency, 12.University of Tokyo)

[MIS10-06] Photodetachment of electrons at sprite altitudes by visible radiation of tropospheric lightning discharges as a mechanism of initiation of sprite streamers

*Victor P Pasko[1], Reza Janalizadeh[1] (1.Pennsylvania State University Main Campus)

[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS11] Expedition Earth: discovering our planet's past and future through scientific drilling

convener:Junichiro Kuroda(Department of Ocean Floor Geoscience, Atmosphere and Ocean Research Institute, the University of Tokyo), Katsuyoshi Michibayashi(Department of Earth and Planetary Sciences, Nagoya University), Kohtaro Ujiie(Graduate School of Life and Environmental Sciences, University of Tsukuba), Clive Robert Neal(University of Notre Dame)

[MIS11-01] Exploring the Arctic deep biosphere and its linkage to carbon cycling and climate variation with Chikyu

*Fumio Inagaki[1], Steffen L. Jørgensen[2], Yasuhiro Yamada[1], Rolf Birger Pedersen[2], ArcDB Project Team (1.Japan Agency for Marine-Earth Science and Technology (JAMSTEC), 2.University of Bergen, Norway)

[MIS11-02] Exploring the World's Largest LIP: Testing the Ontong Java Nui hypothesis

*Takashi Sano[1], Maria Luisa Tejada[2], Clive R. Neal[3], Millard Coffin[4], Masao Nakanishi[5], Peter J. Michael[6], Jörg Geldmacher[7], Takeshi Hanyu[2], Seiichi Miura[2], Christian Timm[8], Anthony A. P. Koppers[9], Daisuke Suetsugu[2], Takashi Tonegawa[2], Akira Ishikawa[10], Kenji Shimizu[2], Paterno Castillo[11] (1.National Museum of Nature and Science, 2.Japan Agency for Marine-Earth Science and Technology, 3.University of Notre Dame, USA, 4.University of Tasmania, Australia, 5.Chiba University, 6.The University of Tulsa, USA, 7.GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany, 8.GNS Science, New Zealand, 9.Oregon State University, USA, 10.Tokyo Institute of Technology, 11.Scripps Institution of Oceanography, UCSD, USA)

[MIS11-03] Pre-prososal 951: The middle aged upper crust penetration on the North Arch off-Hawaii MoHole candidate site

*Susumu Umino[1,2], Tomoaki Morishita[1,2], Jun-Ichi Kimura[2], Mikiya Yamashita[3,2], Nobukazu Seama[4], Shigeaki Ono[2], Natsue Abe[2,1], Katsuyoshi Michibayashi[5,2] (1.Kanazawa University, 2.JAMSTEC, 3.Geological Survey of Japan, 4.Kobe University, 5.Nagoya University)

[MIS11-04] The crustal and upper mantle structure of the Hawaiian-Emperor Seamount Chain from marine seismic data

★Invited Papers

*Brian Boston[1], Philip Cilli[2], Robert Dunn[3], Donna J. Shillington[4], Anthony B. Watts[2], Ingo Grevemeyer[5], Laura Gómez de la Peña[5], Garrett Ito[3], Paul Wessel[3], Uri ten Brink[6], Nathan Miller[6] (1.Lamont-Doherty Earth Observatory, 2.University of Oxford, 3.University of Hawaii at Manoa, 4.Northern Arizona University, 5.GEOMAR, 6.USGS)

[MIS11-05] Drilling a Heterogeneous Lower Ocean Crust and Mantle

★Invited Papers

*Henry J Dick[1] (1.Woods Hole Oceanographic Institution)

[MIS11-06] Overview of IODP Exp. 376: hydrothermal systems and submarine eruption processes of Brothers volcano, Kermadec Arc

*Iona McIntosh[1], Cornel de Ronde[2], Susan Humphris[3], Tobias Höfig[4], Agnes Reyes[2], the IODP Expedition 376 Scientists (1.Japan Agency for Marine-Earth Science and Technology, 2.GNS Science, New Zealand, 3.Woods Hole Oceanographic Institution, USA, 4.International Ocean Discovery Program, Texas A&M University, USA)

[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS11] Expedition Earth: discovering our planet's past and future through scientific drilling

convener:Junichiro Kuroda(Department of Ocean Floor Geoscience, Atmosphere and Ocean Research Institute, the University of Tokyo), Katsuyoshi Michibayashi(Department of Earth and Planetary Sciences, Nagoya University), Kohtaro Ujiie(Graduate School of Life and Environmental Sciences, University of Tsukuba), Clive Robert Neal(University of Notre Dame)

[MIS11-07] IODP/ICDP Expedition 364: Using Geophysical Data to Map Suevite and Impact Melt in the Chicxulub Impact Crater

★Invited Papers

*Gail Lynn Christeson[1], Joanna Morgan[2], Sean Gulick[1] (1.University of Texas at Austin, 2.Imperial College London)

[MIS11-08] Cretaceous paleoceanographic events recorded in sedimentary sequences from IODP Exp. 369 at southern high latitude: Oxygen and carbon isotope stratigraphy and implications from biomarkers

*Takashi Hasegawa[1], Akiko S. Goto[1], Scientists of IODP Exp. 369 (1.Faculty of Geoscience and Civil Engineering, Institute of Science and Engineering, Kanazawa University)

[MIS11-09] **Preliminary results of IODP Expedition 379 (Amundsen Sea West Antarctic Ice Sheet History)**

*Keiji Horikawa[1], Masahiro Noda[2], Masao Iwai[3], Masako Yamane[4], Karsten Gohl[6], Julia S Wellner[7], Scientists IODP Expedition 379[5] (1.Graduate School of Engineer and Science for Research, University of Toyama, 2.Graduate School of Engineer and Science for Education, University of Toyama, 3.Center for Advanced Marine Core Research, Kochi University, 4.Institute for Space-Earth Environmental Research, Nagoya University, 5.IODP Expedition 379 Scientists, 6.Alfred Wegener Institute Helmholtz—Center for Polar and Marine Research, Germany, 7.Earth & Atmospheric Sciences, University of Houston)

[MIS11-10] **Foraminiferal Na/Ca suggests decreased seawater Ca concentration over the past 40 Myr.**

★Invited Papers

*Yair Rosenthal[1], Xiaoli Zhou[1], Weimin Si[2] (1.Rutgers University, 2.Brown University)

[MIS11-11] **Deep microbial proliferation at the basalt interface in aged oceanic crust**

*Yohey Suzuki[1] (1.Graduate School of Science, The University of Tokyo)

[MIS11-12] IODP Expedition 385: Guaymas Basin Tectonics and Biosphere

*Yuki Morono[1], Andreas Teske[2], Daniel Lizarralde[3], Tobias W Höfig[4], IODP EXPEDITION 385 SCIENTISTS[5] (1.Kochi Institute for Core Sample Research, Japan Agency for Marine-Earth Science and Technology, 2.Department of Marine Sciences, University of North Carolina at Chapel Hill, 3.Department of Geology and Geophysics, Woods Hole Oceanographic Institution, 4.International Ocean Discovery Program, Texas A&M University, 5.Full list of Exp. 385 Scientific Participants: http://iodp.tamu.edu/scienceops/precruise/guaymas/participants.html)

[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS11] Expedition Earth: discovering our planet's past and future through scientific drilling

convener:Junichiro Kuroda(Department of Ocean Floor Geoscience, Atmosphere and Ocean Research Institute, the University of Tokyo), Katsuyoshi Michibayashi(Department of Earth and Planetary Sciences, Nagoya University), Kohtaro Ujiie(Graduate School of Life and Environmental Sciences, University of Tsukuba), Clive Robert Neal(University of Notre Dame)

[MIS11-13] The next step following the accomplished drilling into seismogenic zones of M2.0-5.5 earthquakes in South African gold mines (ICDP DSeis)

★Invited Papers

*Hiroshi Ogasawara[1], Bennie Liebenberg[2], Yasuo Yabe[3], Takatoshi Ito[3], Jim Mori[4], Tetsuro Hirono[5], Yuhji Yamamoto[6], Tullis C Onstott[7], Tom L. Kieft[8], Ray J. Durrheim[9], Musa S.D. Manzi[9], Martin Ziegler[10], Thomas Wieresberg[11], Serge Shapiro[12], Surendra N. Samala[13], Esta van Heerden[14], Julio Castillo[15], Phil Dight[16] (1.Faculty of Science and Engineering, Ritsumeikan University, 2.Moab Khotsong mine, 3.Tohoku Univ., 4.Kyoto Univ., 5.Osaka Univ., 6.Kochi Core Center, Kochi Univ., 7.Princeton Univ., 8.New Mexico Inst., 9.Univ. Witwatersrand, 10.ETH, Zurich, 11.GFZ, Potsdam, 12.Berlin Free Univ., 13.Indian Inst. Tech., Hyderabad, 14.iWater, 15.Free State Univ., 16.W. Australia Univ.)

[MIS11-15] **Constraints on paleo-stress magnitude in Hikurangi Margin, New Zealand, at Site U1518, Expedition 375**

*Yoshitaka Hashimoto[1], Ryo Nishimori[1], Annika Greve[2], Julia Morgan[3] (1.Kochi University, 2.Utrecht University,, 3.Rice University)

[MIS11-16] Can subducting Kyushu-Palau Ridge weaken Hyuga-nada subduction interface, western Nankai Trough: A Proposal to IODP

*Rie Nakata[1], Masataka Kinoshita[1], Yoshitaka Hashimoto[2], Yusuke Yamashita[3] (1.University of Tokyo, 2.Kochi University, 3.Kyoto University)

[MIS11-17] Overview of drilling active backarc basin, Okinawa Trough: ongoing rifting of Eurasian continental margin

*Makoto Otsubo[1] (1.Geological Survey of Japan, Research Institute of Earthquake and Volcano Geology)

[MIS11-18] Outline of JBBP (Japan Beyond-Brittle Project) to drill into supercritical geothermal systems

★Invited Papers

*Hiroshi Asanuma[1] (1.AIST)

[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS12] Developments and applications of XRF-core scanning techniques in natural archives

convener:Huang Jyh-Jaan Steven(Institute of Geology, University of Innsbruck), Atsuko Amano(National institute of Advanced Industrial Science and Technology), Masafumi MURAYAMA(Faculty of Agriculture and Marine Science, Kochi University), Liang-Chi Wang(National Chung Cheng University)

[MIS12-01] Bromine (Br) counts measured by XRF core scanner (ITRAX) as a proxy of marine organic carbon content in the hemiperagic sediments of the Japan Sea

★Invited Papers

*Arisa Seki[1], Ryuji Tada[2,3,4], Shunsuke Kurokawa[4], Masafumi Murayama[5] (1.Faculty of Science, Shinshu University, 2.Chiba Institute of Technology, 3.Yunnan University, 4.Graduate School of Science, The University of Tokyo, 5.Faculty of Agriculture and Marine Science, Kochi University)

[MIS12-02] The advantages and limits of ITRAX core scanner: Learning by comparison with destructive element and isotope data from the Gulf of Alaska sediment core

★Invited Papers

*Keiji Horikawa[1], Nurunnabi MD Mondal[2], Masafumi MURAYAMA[3], Katsuya Nejigaki[4], Osamu Seki[5], Yusuke Okazaki[6] (1.Graduate School of Engineer and Science for Research, University of Toyama, 2.Graduate School of Engineer and Science for Education, University of Toyama, 3.Faculty of Agriculture and Marine Science, Kochi University, 4.Graduate School of Integrated Arts and Sciences, Kochi University , 5.Institute of Low Temperature Science, Hokkaido University, 6.Graduate School of Science, Kyushu University)

[MIS12-03] Quantitative micro-XRF scanning spectroscopy of freshwater lake sedimentary sequences based on the X-ray absorption and emission theories

★Invited Papers

*Nagayoshi Katsuta[1] (1.Faculty of Education, Gifu University)

[MIS12-04] The characteristics of turbidites beds of southwestern Ryukyu Trench floor: A new approach from the X-ray fluorescence core scanning analysis

*KanHsi Hsiung[1], Kiichiro Kawamura[2], Toshiya Kanamatsu[1], Ken Ikehara[3], Kazuko Usami[4], Chorng-Shern Horng[5], Naohiko Ohkouchi[1], Nanako O. Ogawa[1], Saneatsu Saito[1], Masafumi MURAYAMA[6] (1.Japan Agency for Marine-Earth Science and Technology, 2.Yamaguchi University, 3.Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology, 4.Japan NUS Co., Ltd., 5.Institute of Earth Sciences, Academia Sinica, 6.Faculty of Agriculture and Marine Science, Kochi University)

[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS13] Integrated Analysis of Geoscience Observations from the Floor to Surface of the Ocean

convener:Keisuke Ariyoshi(Japan Agency for Marine-Earth Science and Technology), Joan S Gomberg(USGS Earthquake Science Center), Narumi Takahashi(National Research Institute for Earth Science and Disaster Resilience), Motoyuki Kido(International Research Institute for Disaster Science, Tohoku University)

[MIS13-01] **Relationship between Kuroshio's meander and crustal deformation around Nankai Trough**

*Keisuke Ariyoshi[1], Akira Nagano[1], Takuya Hasegawa[1,2], Hiroyuki Matsumoto[1] (1.Japan Agency for Marine-Earth Science and Technology, 2.Graduate School of Science and Faculty of Science, Tohoku University)

[MIS13-02] **An integrated observation system from the ocean bottom to the atmosphere to study air-sea interaction in the Kuroshio region south of Shionomisaki**

★Invited Papers

*Kosei Komatsu[1,2], Akira Kuwano-Yoshida[3], Keisuke Ariyoshi[4] (1.GSFS, Univ. Tokyo, 2.AORI, Univ. Tokyo, 3.DPRI, Kyoto Univ., 4.Japan Agency for Marine-Earth Science and Technology)

[MIS13-03] Isolating oceanic contributions to ocean bottom pressure observations by using numerical ocean models to detect transient seafloor displacements

★Invited Papers

*Yoichiro Dobashi[1], Daisuke Inazu[1] (1.Tokyo University of Marine Science and Technology)

[MIS13-04] Continuous buoy observation of ocean bottom pressure and sea surface height and the system revision

*Narumi Takahashi[1,2], Kentaro Imai[2], Motoyuki Kido[3], Yusaku Ohta[3], Tatsuya Fukuda[2], Yasuhisa Ishihara[2], Hiroshi OCHI[2], Ryota Hino[3] (1.National Research Institute for Earth Science and Disaster Resilience, 2.Japan Agency for Marine Earth Science and Technology, 3.Tohoku University)

[MIS13-05] Improvement in estimation of seafloor crustal deformation from ocean bottom pressure observations at the Hikurangi subduction zone offshore New Zealand

*Tomohiro Inoue[1], Tomoya Muramoto[2], Daisuke Inazu[3], Yoshihiro Ito[4], Ryota Hino[5], Kazuaki Ohta[6], Syuichi Suzuki[5] (1.Kyoto University, 2.National Institute of Advanced Industrial Science and Technology, 3.Tokyo University of Marine Science and Technology, 4.Disaster Prevention Research Institute, 5.Tohoku University, 6.National Research Institute for Earth Science and Disaster Resilience)

[MIS13-06] Earthquake-triggered Submarine Sediment Gravity Flows in Action

★Invited Papers

*Joan S Gomberg[1], Keisuke Ariyoshi[2], Paul Johnson[3], Susan Hautala[3] (1.USGS Earthquake Science Center, USA, 2.JAMSTEC, Japan, 3.University of Washington, USA)

[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS14] Evolution of Pelagic Realm

convener:Atsushi Matsuoka(Department of Geology, Faculty of Science, Niigata University), Toshiyuki Kurihara(Graduate School of Science and Technology, Niigata University), Tetsuji Onoue(Department of Earth and Planetary Sciences, Faculty of Science, Kyushu University), XIN LI(State Key Laboratory of Palaeobiology and Stratigraphy, Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences)

[MIS14-01] Permian radiolarians from chert distributed in the Hashidate area, Itoigawa City, Niigata Prefecture, central Japan

*Toshiyuki Kurihara[1], Urara Murakami[2], Atsushi Matsuoka[2] (1.Graduate School of Science and Technology, Niigata University, 2.Faculty of Science, Niigata University)

[MIS14-02] Myr-scale monsoon records paced with Milankovitch cycles during Triassic-Jurassic

*Masayuki Ikeda[1], Kazumi Ozaki[2], Shintaro Kadoya[3] (1.Shizuoka University, 2.Toho University, 3.Washington University)

[MIS14-03] The oldest oceanic plate and Minami Tori Shima: Minato Project

★Invited Papers

*Yoshihiko Tamura[1], Tomoki Sato[1], Yasuhiro Hirai[1], Kenta Yoshida[1], Mathieu Rospabé[1], Osamu Ishizuka[1], Takashi Miyazaki[1], Qing Chang[1] (1.Research Institute for Marine Geodynamics, Japan Agency for Maine-Earth Science and Technology)

[MIS14-04] Detailed stratigraphy around the Jurassic–Cretaceous boundary in the Bosso Valley section, central Italy and international correlation based on radiolarian biostratigraphy

*Atsushi Matsuoka[1], Xin Li[2], Marco Chiari[3], Angela Beritinelli[4] (1.Department of Geology, Faculty of Science, Niigata University, 2.Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, 3.Institute of Earth Sciences and Georisources, Florence, Italy, 4.University of Perugia, Italy)

[MIS14-05] **Ocean Plate Stratigraphy and accretionary process of the Yarlung-Tsangpo suture zone based on radiolarian biostratigraphy of mélanges near Najiu, southern Tibet**

*XIN LI[1], Matsuoka Atsushi[2], Yalin Li[3] (1.State Key Laboratory of Palaeobiology and Stratigraphy, Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, 2.Department of Geology, Faculty of Science, Niigata University, 3.China University of Geosciences, Beijing)

[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS15] Global climate change driven by the Southern Ocean and the Antarctic Ice Sheet

convener:Osamu Seki(Institute of Low Temperature Science, Hokkaido University), Akira Oka(Atmosphere and Ocean Research Institute, The University of Tokyo), Yoshifumi Nogi(National Institute of Polar Research), Robin Elizabeth Bell(Lamont Doherty Earth Observatory)

[MIS15-01] **Shallow Sea Trial of the Under Ice AUV “MONACA”**

*Hirokazu Yamagata[1], Toshihiro Maki[1], Hiroshi Yoshida[2], Yoshifumi Nogi[3] (1.Institute of Industrial Science, The University of Tokyo, 2.Japan Marine Science and Technology Cente, 3.National Institute of Polar Research)

[MIS15-02] **Modeling warm water intrusion into Lützow-Holm Bay, East Antarctica**

*Kazuya Kusahara[1], Daisuke Hirano[2], Masakazu Fujii[3], Alexander D. Fraser[4], Takeshi Tamura[3] (1.Japan Agency for Marine-Earth Science and Technology, 2.Hokkaido University, 3.National Institute of Polar Research, 4.University of Tasmania)

[MIS15-03] Estimation of the Antarctic ice sheet surface mass balance using the polar regional climate model NHM-SMAP

*Masashi Niwano[1], Akihiro Hashimoto[1], Shun Tsutaki[2], Hideaki Motoyama[2], Naohiko Hirasawa[2], Ayako Abe-Ouchi[3] (1.Meteorological Research Institute, 2.National Institute of Polar Research, 3.Atmosphere Ocean Research Institute, University of Tokyo)

[MIS15-04] Accurate chronology and climatic reconstruction around MIS 11 from the Dome Fuji ice core

*Kenji Kawamura[1,2,3], Ikumi Oyabu[1], Shuji Aoki[4], Takakiyo Nakazawa[4], Ayako Abe-Ouchi[5], Fuyuki SAITO[3] (1.National Institute of Polar Research, Research Organization of Information and Systems, 2.Graduate School for Advanced Studies, SOKENDAI, 3.Japan Agency for Marine-Earth Science and Technology (JAMSTEC), 4.Tohoku University, 5.University of Tokyo)

[MIS15-05] **Deglaciation history of the East Antarctic Ice sheet revealed by exposure ages and marine-lake sedimentary records in Lutzow-Holm Bay**

*Yusuke Suganuma[1,2], Moto Kawamata[2], Yuki Haneda[1], Takeshige Ishiwa[1], Kota Katsuki[5], Takuya Itaki[3], Osamu Seki[4], Jun'ichi Okuno[1,2] (1.National institute of Polar Research, 2.The Graduate University for Advanced Studies (SOKENDAI), 3.Geological Survey of Japan, AIST, 4.Hokkaido University, 5.Shimane University)

[MIS15-06] Cross-check of dust-magnetic correlation and oxygen isotope stratigraphy in the Southern Ocean

*Hiroki Matsui[1], Minoru Ikehara[1], Yusuke Suganuma[2,3], Osamu Seki[4], Jun'ichi Okuno[2,3], Ikumi Oyabu[2], Kenji Kawamura[2,3] (1.Center for Advanced Marine Core Research, Kochi University, 2.National Institute of Polar Research, 3.Department of Polar Science, School of Multidisciplinary Sciences, The Graduate University for Advanced Studies (SOKENDAI), 4.Institute of Low Temperature Science, Hokkaido University)

[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS15] Global climate change driven by the Southern Ocean and the Antarctic Ice Sheet

convener:Osamu Seki(Institute of Low Temperature Science, Hokkaido University), Akira Oka(Atmosphere and Ocean Research Institute, The University of Tokyo), Yoshifumi Nogi(National Institute of Polar Research), Robin Elizabeth Bell(Lamont Doherty Earth Observatory)

[MIS15-07] **IODP Expedition 382 (Iceberg Alley) – Preliminary results on dust-climate couplings**

★Invited Papers

*Michael E Weber[1], Maureen E Raymo[2], Victoria L Peck[3], Trevor Williams[4], Osamu Seki[5], Yuji Kato[6], Mutsumi Iizuka[5], and IODP 382 Scientists (1.Steinmann Institute, University of Bonn, Bonn, Germany, 2.Lamont-Doherty Earth Observatory of Columbia University, Palisades, New York, USA, 3.British Antarctic Survey, Cambridge, UK, 4.International Ocean Discovery Program, Texas A&M University, College Station, USA, 5.Institute of Low Temperature Science, Hokkaido University, Japan, 6.Center for Advanced Marine Core Research, Kochi University, Japan)

[MIS15-08] Property of eddy and AABW observed off Cape Pointset

*Kitade Yujiro[1], Kohei Mizobata[1], Daisuke Hirano[2], Keishi Shimada[1], Shigeru Aoki[2], Takeshi Tamura[3] (1.Tokyo University of Marine Science and Technology, 2.Hokkaido University, 3.National Institute of Polar Research)

[MIS15-09] Antarctic Bottom Water and global ocean meridional overturning circulation

★Invited Papers

*Katsuro Katsumata[1] (1.JAMSTEC)

[MIS15-10] Temporal variation of the Antarctic Bottom Water revealed by the mooring measurements off the Vincennes Bay

*Kohei Mizobata[1], Yujiro Kitade[1], Keishi Shimada[1], Daisuke Hirano[2], Yoshimasa Matsumura[3], Cheng Lingqiao[4], Shigeru Aoki[2], Takeshi Tamura[5] (1.Tokyo University of Marine Science and Technology, 2.Institute of Low Temperature Science, Hokkaido University, 3.Atmosphere and Ocean Research Institute, The University of Tokyo, 4.Shanghai Ocean University, 5.National Institute of Polar Researc)

[MIS15-11] Foraging movements and prey of short-tailed shearwaters in the Southern Ocean

★Invited Papers

*Yutaka Watanuki[1], Sarara Azumi[1], Akinori Takahashi[2], Nobuo Kokubun[2], Yasuhiro Ando[1], Masato Moteki[3], Fernando Arce, Mary-Anne Lea, Mark Hindell (1.Faculty of Fisheries Science, Hokkaido University, 2.National Institute of Polar Research, 3.Tokyo University of Marine Science and Technology)

[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS17] Astrobiology

convener:Hikaru Yabuta(Hiroshima University, Department of Earth and Planetary Systems Science), Seiji Sugita(Department of Earth and Planetary Science, Graduate School of Science Sciece, The University of Tokyo), Misato Fukagawa(National Astronomical Observatory of Japan), Fujishima Kosuke(Tokyo Institute of Technology, Earth-Life Science Institute)

[MIS17-01] Observations and modelling of exoplanetary atmospheres

★Invited Papers

*Giovanna Tinetti[1] (1.UCL)

[MIS17-02] Astrochemistry in planetary system formation: from molecular clouds to protoplanetary disks and planetary system material

★Invited Papers

*Yuri Aikawa[1] (1.Department of Astronomy, Graduate School of Science, University of Tokyo)

[MIS17-03] Formation of Complex Amino Acid Precursors by Cosmic Rays in Interstellar Environments

★Invited Papers

*Kensei Kobayashi[1], Soushi Kuramoto[1], Tomohito Sato[1], Miki Nakayama[2], MITA Hajime[2], Satoshi Yoshida[3], Hitoshi Fukuda[4], Yoshiyuki Oguri[4], Hiromi Shibata[5], Yoko Kebukawa[1] (1.Department of Chemistry, Yokohama National University, 2.Fukuoka Institute of Technology, 3.National Institutes for Quantum and Radiological Science and Technology, 4.Tokyo Institute of Technology, 5.Osaka University)

[MIS17-04] Ground-based transmission spectroscopy of TRAPPIST-1g

*Mayuko Mori[1], Akihiko Fukui[1], Norio Narita[2], Hannu Parviainen[4], Yui Kawashima[3], John H. Livingston[1], Kiyoe Kawauchi[1], Motohide Tamura[1,2,5] (1.The University of Tokyo, 2.Astrobiology Center, NINS, 3.Netherlands Institute for Space Research, 4.Instituto de Astrofisica de Canarias, 5.National Astronomical Observatory of Japan)

[MIS17-05] UV irradiation and organic synthesis on growing dust particles in protoplanetary disks

*Kazuaki Homma[1], Satoshi Okuzumi[1] (1.Tokyo Institute of Technology)

[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS17] Astrobiology

convener:Hikaru Yabuta(Hiroshima University, Department of Earth and Planetary Systems Science), Seiji Sugita(Department of Earth and Planetary Science, Graduate School of Science Sciece, The University of Tokyo), Misato Fukagawa(National Astronomical Observatory of Japan), Fujishima Kosuke(Tokyo Institute of Technology, Earth-Life Science Institute)

[MIS17-06] Everyone's an Astrobiologist

★Invited Papers

*Mary A Voytek[1,2] (1.NASA Headquarters, 2.Earth-Life Science Institute, Tokyo Institute of Technology)

[MIS17-07] New strategies for extraterrestrial life exploration compatible to planetary protection

★Invited Papers

*Yohey Suzuki[1] (1.Graduate School of Science, The University of Tokyo)

[MIS17-08] Polyester microdroplets, coacervates, and other membraneless non-biological assemblies as primordial compartments

★Invited Papers

*Tony Z Jia[1], Kuhan Chandru, Yayoi Hongo, Rehana Afrin, Tomohiro Usui, Kunihiro Myojo, H. James Cleaves (1.Earth-Life Science Institute, Tokyo Institute of Technology)

[MIS17-09] Reconstruction of the original core of RNA polymerase from short peptide

*Sota Yagi[1], Aditya K. Padhi[2], Kam Y. J. Zhang[2], Shunsuke Tagami[1] (1.Laboratory for Advanced Biomolecular Engineering, RIKEN Center for Biosystems Dynamics Research, 2.Laboratory for Structural Bioinformatics, RIKEN Center for Biosystems Dynamics Research)

[MIS17-10] Screening RNA-binding peptides using restricted set of amino acids

*Shota Nishikawa[1], Hidenori Watanabe[2], Naohiro Terasaka[3], Takayuki Katoh[3], Kosuke Fujishima[2] (1.School of Life Science and Technology, Tokyo Institute of Technology, 2.Earth Life Science Institute, Tokyo Institute of Technology, 3.Department of Chemistry, Graduate school of Science, The University of Tokyo)

[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS17] Astrobiology

convener:Hikaru Yabuta(Hiroshima University, Department of Earth and Planetary Systems Science), Seiji Sugita(Department of Earth and Planetary Science, Graduate School of Science Sciece, The University of Tokyo), Misato Fukagawa(National Astronomical Observatory of Japan), Fujishima Kosuke(Tokyo Institute of Technology, Earth-Life Science Institute)

[MIS17-11] Formation of organic compounds by hypervelocity impacts on terrestrial planets

*Yoshihiro Furukawa[1], Yuto Takeuchi[1], Takamichi Kobayashi[2], Toshimori Sekine[3], Naoki Terada[1], Takeshi Kakegawa[1] (1.Tohoku University, 2.NIMS, 3.Center for High Pressure Science & Technology Advanced Research)

[MIS17-12] Following the fundamentals of serpentinization: an experimental approach to mineral and organic reaction pathways at serpentinizing conditions

*Kristin N Johnson-Finn[1,2], Akira Yamaguchi[2], Ryuhei Nakamura[1,3] (1.Earth-Life Science Institute, 2.Tokyo Institute of Technology, 3.RIKEN Center for Sustainable Resource Science)

[MIS17-13] Third year results and current status of Tanpopo: Capture and exposure experiment of micrometeoroids and microbes on Exposure Facility of International Space Station

*Akihiko Yamagishi[1,2], Hirofumi Hashimoto[2], Hajime Yano[2], Yuko Kawaguchi[9], Shin-ichi Yokobori[1], Kensei Kobayashi[3], Mita Hajime[4], Hikaru Yabuta[5], Masumi Higashide[6], Makoto Tabata[7], Eiichi Imai[8] (1.Tokyo University of Pharmacy and Life Science, Department of Molecular Biology, 2.ISAS/JAXA, , 3.Yokohama National University, , 4.Fukuoka Institute of Technology, , 5.Hiroshima University, 6.Japan Aerospace Exploration Agency, 7.Chiba University, 8.Nagaoka University of Technology, 9.Chiba Institute of Technology)

[MIS17-14] THE BIOPAUSE PROJECT: SCIENTIFIC BALLOON EXPERIMENTS FOR SAMPLING STRATOSPHERIC BIOAEROSOL

*Sohsuke Ohno[1], Norimune Miyake[1], Ko Ishibashi[1], Yuko Kawaguchi[1], Osamu Okudaira[1], Keisuke Maeda[1], Issei Iijima[2], Yuya Kakehashi[2], Manabu Yamada[1], Akihiko Yamagishi[3], Kazuhiko Yamada[2], Yusuke Takahashi[4], Satoshi Nonaka[2], Segawa Takahiro[5], Hideyuki Fuke[2], Tetsuya Yoshida[2], Takafumi Matsui[1] (1.Chiba Institute of Technology, 2.Japan Aerospace Exploration Agency, 3.Tokyo University of Pharmacy and Life Sciences, 4.Hokkaido University, 5.University of Yamanashi)

[MIS17-15] Microscope for Life-signature Detection in Venus Cloud

*Satoshi Sasaki[1], Akihiko Yamagishi[2,5], Yoshitaka Yoshimura[3], Keigo Enya[5], Sosuke Ohno[4], Atsuo Miyakawa[2], Tomohiro Usui[5], Kazuhisa Fujita[5], Sanjay Limaye[6] (1.Tokyo University of Technology, 2.Tokyo University of Pharmacy and Life Sciences, 3.Tamagawa University, 4.Chiba Institute of Technology, 5.JAXA, 6.University of Wisconsin)

[MIS17-16] Discussion

*Hikaru Yabuta[1] (1.Hiroshima University, Department of Earth and Planetary Systems Science)

[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS19] Conservation of geoparks, natural geosites, and cultural heritage: weathering and damage assessment

convener:Luigi Germinario(Saitama University), Celine Schneider(University of Reims-Champagne-Ardenne), Chiaki T. Oguchi(Institute for Environmental Science and Technology, Graduate School of Science and Engineering, Saitama University), Tetsuya Waragai(Graduate School of Science and Engineering, Nihon University), Miguel Gomez-Heras(Universidad Autonoma de Madrid), Patricia Vazquez(GEGENAA EA 3795 University of Reims Champagne-Ardenne), Magdalini Theodoridou(Cardiff University), Wonsuh Song(Waseda University)

[MIS19-01] **Representation of three-dimensional cave structure using point cloud data by terrestrial and airborne laser scanning**

★Invited Papers

*Yuichi S. Hayakawa[1,3], Takuro Ogura[2], Yasuhiko TAMURA[3], Chiaki T. Oguchi[4] (1.Faculty of Environmental Earth Science, Hokkaido University, 2.Graduate School of Frontier Sciences, The University of Tokyo, 3.Center for Spatial Information Science, The University of Tokyo, 4.Graduate School of Science and Engineering, Saitama University)

[MIS19-02] Detection of microcracks in rock specimens due to thermal changes using the acoustic emission method

*Tetsuya Waragai[1] (1.Graduate School of Science and Engineering, Nihon University)

[MIS19-03] **Coupled capillary water uptake and Infrared Thermography to assess crack evolution**

★Invited Papers

Thomas Junique[1], *Patricia Vazquez[1], Céline Thomachot-Schneider[1], Myrlène Jean Baptiste[1], Issra Hassoun[1] (1.GEGENAA EA 3795, University of Reims Champagne-Ardenne, France)

[MIS19-04] Study on groundwater quality inside of the Taya cavern

*Chiaki T. Oguchi[1], Sohyun Ahn[1], Yasuhiko TAMURA[2] (1.Institute for Environmental Science and Technology, Graduate School of Science and Engineering, Saitama University, 2.Exective Committee for the prevention of Taya Cavern)

[MIS19-05] Unveiling the underground cultural heritage of Yokohama, Japan – the contribution of geosciences

*Luigi Germinario[1], Chiaki T. Oguchi[1] (1.Saitama University)

[MIS19-06] Reproducing typical strains of a monument through aging tests to anticipate stone weathering.

*Emilie Huby[1], Céline Thomachot-Schneider[1], Patricia Vázquez[1], Gilles Fronteau[1] (1.Université de Reims Champagne-Ardenne, GEGENAA EA 3795, 51097 Reims, France)

[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-GI General Geosciences, Information Geosciences & Simulations

[M-GI33] Data assimilation: A fundamental approach in geosciences

convener:Shin ya Nakano(The Institute of Statistical Mathematics), Yosuke Fujii(Meteorological Research Institute, Japan Meteorological Agency), Takemasa Miyoshi(RIKEN), SHINICHI MIYAZAKI(Graduate School of Science, Kyoto University)

[MGI33-01] Inference of Hidden States by Coupled Thermosphere-Ionosphere Data Assimilation: Applications to Observability and Predictability of Neutral Mass Density

★Invited Papers

*Tomoko Matsuo[1], Chih-Ting Hsu[2] (1.University of Colorado Boulder, 2.National Center for Atmospheric Research)

[MGI33-02] Weight Structure of the Local Ensemble Transform Kalman Filter: A Case with an Intermediate AGCM

★Invited Papers

*Shunji Kotsuki[1], Pensoneault Andrew[3], Okazaki Atsushi[4], Takemasa Miyoshi[2] (1.Center for Environmental Remote Sensing, Chiba University, 2.RIKEN Center for Computational Science, 3.University of Iowa, 4.The Pennsylvania State University)

[MGI33-03] Local Particle Filter Implemented with Minor Modifications to the LETKF Code

*Takemasa Miyoshi[1], Shunji Kotsuki[1,2], Keiichi Kondo[1,3], Roland Potthast[4] (1.RIKEN, 2.Chiba University, 3.Meteorological Research Institute, 4.German Weather Service (DWD))

[MGI33-04] Combining data assimilation and machine learning to predict chaotic dynamics with imperfect observations and models

*Futo Tomizawa[1], Yohei Sawada[1] (1.The University of Tokyo)

[MGI33-05] Socio-hydrologic data assimilation: Analyzing human-flood interactions by model-data integration

*Yohei Sawada[1], Risa Hanazaki[1] (1.University of Tokyo)

[MGI33-06] Observing System Simulation Experiments for Tidal Motion from Wide-Swath Ocean Satellite Altimeter Data

*CAO Jiangwei[1], Naoki HIROSE[2], Osamu ISOGUCHI[3] (1.Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, 2.Research Institute for Applied Mechanics, Kyushu University, 3.Remote Sensing Technology Center of Japan)

[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-GI General Geosciences, Information Geosciences & Simulations

[M-GI33] Data assimilation: A fundamental approach in geosciences

convener:Shin ya Nakano(The Institute of Statistical Mathematics), Yosuke Fujii(Meteorological Research Institute, Japan Meteorological Agency), Takemasa Miyoshi(RIKEN), SHINICHI MIYAZAKI(Graduate School of Science, Kyoto University)

[MGI33-07] Development of an ensemble Kalman filter-based regional ocean data assimilation system

*Shun Ohishi[1,2], Tsutomu Hihara[3], Hidenori AIKI[2], Joji Ishizaka[2], Yasumasa Miyazawa[3], Misako Kachi[4], Takemasa Miyoshi[1] (1.RIKEN, 2.Nagoya Univ., 3.JAMSTEC, 4.JAXA)

[MGI33-08] Dealing with Model Uncertainty and Deficiencies when Assimilating Thermal Breakthrough Observations

★Invited Papers

*Elvar Karl Bjarkason[1], Anna Suzuki[1] (1.Tohoku University)

[MGI33-10] EnKF estimation of the viscoelastic deformation and the viscosity

*Makiko Ohtani[1] (1.Earthquake Research Institute, the University of Tokyo)

[MGI33-11] Ensemble Kalman Filter estimation of frictional parameters and slip evolution on L-SSE faults : application to the Bungo Channel L-SSE fault

★Invited Papers

Megumi Fujita[1], Takuya NISHIMURA[2], *Kazuro Hirahara[3,4], Mamoru Hyodo[5], SHINICHI MIYAZAKI[1] (1.Graduate School of Science, Kyoto University , 2.Disaster Prevention Research Institute, Kyoto University , 3.Institute of Education, Research and Regional Cooperation for crisis Management Shikoku, Kagawa University , 4.Riken AIP center, 5.JAMSTEC)

[MGI33-12] Iterative ensemble variational methods and its application for the prediction of geomagnetic secular variation

*Shin ya Nakano[1], Takuto Minami[2], Futoshi Takahashi[3], Masaki Matsushima[4], Hisayoshi Shimizu[5], Hiroaki TOH[6] (1.The Institute of Statistical Mathematics, 2.Graduate School of Science, Kobe University, 3.Faculty of Science, Kyushu University, 4.Department of Earth and Planetary Sciences, School of Science, Tokyo Institute of Technology, 5.Earthquake Research Institute, the University of Tokyo, 6.Data Analysis Center for Geomagnetism and Space Magnetism, Graduate School of Science, Kyoto University)

[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-GI General Geosciences, Information Geosciences & Simulations

[M-GI34] Near Surface Investigation and Modeling for Groundwater Resources Assessment and Conservation

convener:Jui-Pin Tsai(National Taiwan University, Taiwan), Hwa-Lung Yu(National Taiwan University), Makoto Taniguchi(Research Institute for Humanity and Nature), Ping-Yu Chang(National Central University)

[MGI34-01] Conjunctive Use Simulation and Applications with MODFLOW-OWHM

*Scott E Boyce[1], Claudia C Faunt[1], Wesley Henson[1], Marisa M Earll[1], Randall T Hanson[1] (1.U.S. Geological Survey, California Water Science Center)

[MGI34-02] Estimating the specific yields and groundwater variations with the resistivity method in the northern Pingtung Plain

*Ping-Yu Chang[1,2] (1.National Central University, 2.Earthquake Disaster Evaluation and Management Center, National Central University)

[MGI34-03] Development of a multi-level groundwater monitoring system using fiber Brag grating approach

*Jui-Pin Tsai[1], Yen-To Ho[2], Liang-Cheng Chang[3] (1.National Taiwan University, Taiwan , 2.Citpo technology, Taiwan, 3.National ChiaoTung University, Taiwan)

[MGI34-04] **Objective Modeling Method of Hydrogeological Structure Applied in MODFLOW Modeling – A Case Study of Taipei Basin**

*Ting Hua Tseng[1], Hwa-Lung Yu[1] (1. National Taiwan University)

[MGI34-05] Master Plan of Water Resources Management for Central Taiwan

*Chih Chao Ho[1], TA-WEI CHIEN[2] (1.Feng Chia University, 2.Taiwan Hsin-Chu Irrigation Association)

[MGI34-06] **Geotemperature distributions due to surface temperature variations and groundwater flow in a stratum with a convection boundary**

*Chia-Hao Chang[1], Jui-Pin Tsai[1] (1.National Taiwan University, Taiwan)

[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-GI General Geosciences, Information Geosciences & Simulations

[M-GI36] Open Science in Progress: Data Sharing, e-Infrastructure, and Transparency in International Contexts

convener:Yasuhisa Kondo(Research Institute for Humanity and Nature), Baptiste Cecconi(LESIA, Observatoire de Paris, CNRS, PSL Research University), Yasuhiro Murayama(Strategic Program Produce Office, National Institute of Information and Communications Technology), Shelley Stall(American Geophysical Union)

[MGI36-01] Metadata from findable to searchable at PADC

★Invited Papers

*Pierre Le Sidaner[1], Stephane Erard[1,2,3], Baptiste Cecconi[1,2,3] (1.Observatoire de Paris, 2.PSL, 3.CNRS)

[MGI36-02] FAIR and Open Data: Current progress within the Earth, Space, and Environmental Sciences to Share Our Data (and Software)

*Shelley Stall[1] (1.American Geophysical Union)

[MGI36-03] Multi-source, Multi-wavelength FAIR Data and Science-driven E-infrastructure challenges toward OpenScience in Earth, Planetary and Astronomy Sciences: an overview of the CNRS-INSU ongoing initiatives

★Invited Papers

*Jean-Pierre Vilotte[1] (1.Institut de Physique du Globe de Paris)

[MGI36-04] The Path Toward Open Collections and Samples

★Invited Papers

*Kerstin Lehnert[1], Jens F Klump[2], Lesley Wyborn[3], Sarah Ramdeen (1.Columbia University, 2.CSIRO, Perth, Australia, 3.Australian National University, Canberra, Australia)

[MGI36-05] Open Science Policy and its Implementation in Japan: Trials of Monitoring and Developing an Advanced Data Management

★Invited Papers

*Kazuhiro Hayashi[1] (1.National Institute of Science and Technology Policy)

[MGI36-06] Five key elements to enable open science for society

*Yasuhisa Kondo[1,2], Kei Kano[3,2,1], Terukazu Kumazawa[1], Satoe Nakahara[1], Ken'ichiro Nakashima[4,1], Noboru Okuda[1], Hideyuki Onishi[5,1], Takeshi Osawa[6,1], KAZUHIKO OTA[1] (1.Research Institute for Humanity and Nature, 2.National Institute of Science and Technology Policy, 3.Shiga University, 4.Hiroshima University, 5.Doshisha Women's College of Liberal Arts, 6.Tokyo Metropolitan University)

[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-GI General Geosciences, Information Geosciences & Simulations

[M-GI36] Open Science in Progress: Data Sharing, e-Infrastructure, and Transparency in International Contexts

convener:Yasuhisa Kondo(Research Institute for Humanity and Nature), Baptiste Cecconi(LESIA, Observatoire de Paris, CNRS, PSL Research University), Yasuhiro Murayama(Strategic Program Produce Office, National Institute of Information and Communications Technology), Shelley Stall(American Geophysical Union)

[MGI36-07] Looking back on World Data System and WDS International Programme Office in the last decade from Japan

*Yasuhiro Murayama[1], Takashi Watanabe[2] (1.Strategic Program Produce Office, National Institute of Information and Communications Technology, 2.World Data System International Programme Office)

[MGI36-08] The World Data System – Building Trust in Scientific Data

*Rorie Edmunds[1] (1.World Data System of the International Science Council)

[MGI36-09] Active Data Product Archive Tracking (ADAPT) and the Future of Heliophysics Data Access

*Lee Frost Bargatze[1] (1.Earth, Planetary, and Space Sciences, Institute of Geophysics and Planetary Physics, University of California Los Angeles)

[MGI36-10] Introduction of TG-Data: IPCC Task Group on Data Support for Climate Change Assessments

*Michio Kawamiya[1] (1.Japan Agency for Marine-Earth Science and Technology)

[MGI36-11] Issues and progress of Open Science in geodesy

*Yusuke Yokota[1], Tadashi Ishikawa[2], Basara Miyahara[3], Toshimichi Otsubo[4] (1.Institute of Industrial Science, The University of Tokyo, 2.Hydrographic and Oceanographic Department, Japan Coast Guard, 3.Geospatial Information Authority of Japan, 4.Hitotsubashi University)

[MGI36-12] Open Data for Seismology

*Yasuyuki Kano[1] (1.Earthquake Research Institute, The University of Tokyo)

[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-GI General Geosciences, Information Geosciences & Simulations

[M-GI37] Integration of Earth Observations and Multiple Use for Earth Science and Benefits to Societies - GEO

convener:Hiroyuki Muraoka(River Basin Research Center), Kentaro Ando(Japan Agency for Marine and Earth Science and Technology), Osamu Ochiai(Japan Aerospace Exploration Agency), Shinichi Sobue(Japan Aerospace Exploration Agency)

[MGI37-01] Development and current status of Group on Earth Observation (GEO) and Asia-Oceania GEO (AOGEO)

*Kentaro Ando[1], Hiroyuki Muraoka[2] (1.Japan Agency for Marine and Earth Science and Technology, 2.Gifu University)

[MGI37-02] Strengthening governance and investment for water-related disaster resilience under climate change in Asia

★Invited Papers

*Toshio Koike[1] (1.International Centre for Water Hazard and Risk Management)

[MGI37-03] GEOGLAM Asia Rice Crop Monitoring Activity

*Shinichi Sobue[1], Kei Oyoshi[1], Youichiro Kato[2] (1.Japan Aerospace Exploration Agency, 2.Unversity of Tokyo)

[MGI37-04] Preliminary Study of Water Quality Determination using Spectro-polarimetric Bidirectional Reflectance Factor

*Ahmad Shaqeer Mohamed Thaheer[1], Yukihiro Takahashi[1] (1.Department of Cosmosciences, Graduate School of Science, Hokkaido University)

[MGI37-05] Earth observation data utilization for Global Forest Observation Initiative (GFOI)

*Osamu Ochiai[1] (1.Japan Aerospace Exploration Agency)

[MGI37-06] **Climate and land use changes will degrade the distribution of Rhododendrons in China**

*Fangyuan Yu[1], Tiejun Wang[2], Thomas A Groen[2], Andrew K Skidmore[2], Xuefei Yang[3], Keping Ma[4], Zhifeng Wu[1] (1.Guangzhou University, 2.University of Twente, 3.Laboratory of Biogeography and Biodiversity, Kunming Institute of Botany, Chinese Academy of Sciences, Kunming , 4.State Key Laboratory of Vegetation and Environmental Change, Institute of Botany, Chinese Academy of Sciences)

[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-AG Applied Geosciences

[M-AG42] CTBT IMS Technologies for Detecting Nuclear Explosion and Their Applications to Earth Science

convener:Ozel Nurcan Meral(Comprehensive Nuclear-Test-Ban Treaty Organization), Hiroyuki Matsumoto(Japan Agency for Marine-Earth Science and Technology), Noriko Kamaya(Earthquake Research Institute, The University of Tokyo), Yosuke Naoi(Japan Atomic Energy Agency)

[MAG42-01] **CTBT International Monitoring System (IMS) Reaches the Milestone of 300 Certified Facilities**

*Nurcan Meral Ozel[1], Georgios Haralabus[1], Hideaki Komiyama[1] (1.Comprehensive Nuclear-Test-Ban Treaty Organization)

[MAG42-02] **Offshore real-time monitoring system and its application to disaster resilience**

★Invited Papers

*Yoshiyuki Kaneda[1,2,3], Narumi Takahashi[3,2], Hiroyuki Matsumoto[2] (1.Kagawa University, 2.Japan Agency for Marine-Earth Science and Technology (JAMSTEC), 3.National Research Institute for Earth Science and Disaster Resilience (NIED))

[MAG42-03] Beyond the antipode: Hydroacoustic detection of earthquake activity along the Middle America Trench

*Dirk Metz[1], Julien Vergoz[2] (1.Japan Agency for Marine-Earth Science and Technology, 2.French Alternative Energies and Atomic Energy Commission)

[MAG42-04] Tremendous damage of I30JP by typhoon “FAXAI”

Takanari Fujii[1], Takayuki Otsu[1], Toyomi Sakamoto[1], Soshi Iwata[1], RYOHEI EMURA[1], Mami Nogami[1], Makiko Iwakuni[1], *Masashi Motohashi[1] (1.Japan Weather Association)

[MAG42-05] Observation results of the Fukushima Daiichi accident at CTBT radionuclide monitoring stations

*Yoichi Yamamoto[1], Yuichi Kijima[1], Yutaka Tomita[1] (1.Japan Atomic Energy Agency)

[MAG42-06] **A synthesis of worldwide sediment source tracing research including fallout radiocesium (^{137}Cs)**

*Olivier Evrard[1], Pierre-Alexis Chaboche[1], Rafael Ramon[1,2], Anthony Foucher[1], J. Patrick Laceby[3] (1.Laboratoire des Sciences du Climat et de l'Environnement (LSCE, joint laboratory CEA-CNRS-UVSQ), University Paris-Saclay, France, 2.Graduate Program in Soil Science, Federal University of Rio Grande do Sul, Porto Alegre, Rio Grande do Sul, Brazil, 3.Environmental Monitoring and Science Division (EMSD), Alberta Environment and Parks (AEP), Calgary, Alberta, Canada)

[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-SD Space Development & Earth Observation from Space

[M-SD46] Effects of lightning, severe weather and tropical storms

convener:Mitsuteru Sato(Department of Cosmoscience, Hokkaido University), Yoav Yair(Interdisciplinary Center Herzliya), Xiushu Qie(Institute of Atmospheric Physics, Chinese Academy of Sciences), Yukihiro Takahashi(Department of Cosmosciences, Graduate School of Science, Hokkaido University)

[MSD46-01] Is there a "weekend effect" in precipitation and lightning activity during winter thunderstorms over the Tel-Aviv, Israel metropolitan area?

*Yoav Yair[1], Mordecai Yaffe[1] (1.Interdisciplinary Center (IDC) Herzliya, Israel)

[MSD46-02] An unusual multiple-stroke positive cloud-to-ground lightning flash with different terminations

*Xiushu Qie[1], Shanfeng Yuan[1], Rubin Jiang[1] (1.Institute of Atmospheric Physics, Chinese Academy of Sciences)

[MSD46-03] **Cell-Scale Analysis of Convective Cloud Merging in a Squall Line and the Associated Lightning Behaviour**

★Invited Papers

*Jingyu Lu[1,2], Xiushu Qie[1,2], Rubin Jiang[1], Dongxia Liu[1], Dongfang Wang[1], Shanfeng Yuan[1], Zhixiong Chen[1,2], Jinliang Li[3], Xian Xiao[4,5], Xiaoyuan Yi[6] (1.Key Laboratory of Middle Atmosphere and Global Environment Observation (LAGEO), Institute of Atmospheric Physics, Chinese Academy of Science, Beijing, China., 2.College of Earth and Planetary Science, University of Chinese Academy of Science, Beijing, China., 3.Key Laboratory of Semi-Arid Climate Change, Ministry of Education, College of Atmospheric Sciences, Lanzhou University, Lanzhou, China., 4.Institute of Urban Meteorology, China Meteorological Administration, Beijing, China., 5.Beijing Urban Meteorological Engineering Research Center, Beijing, China., 6.Tianjin Meteorological Observatory, Tianjin, China.)

[MSD46-04] On-going development of ground observation system for typhoon and thunderstorm activities connected to real-time micro-satellite operation

*Yukihiro Takahashi[1,2], Mitsuteru Sato[1,2], Hisayuki Kubota[1,2], Tetsuro Ishida[1,2], Kozo Yamashita[4], Ellison Caparas Castro[3], Loren Jay Estrebillo[1], Purwadi Purwadi[1], Gay Perez[3], Joel Marciano[3], Jun Matsumoto[5], Jun-Ichi Hamada[5] (1.Department of Cosmosciences, Graduate School of Science, Hokkaido University, 2.Faculty of Science, Hokkaido University, 3.University of the Philippines, Diliman, 4.Ashikaga University, 5.Tokyo Metropolitan UNniversity)

[MSD46-05] **Summer monsoon experiment in Metro Manila of Philippines in 2019**

*Hisayuki Kubota[1], Yukihiro Takahashi[1], Mitsuteru Sato[1], Glenn Vincent Lopez[2], Joel Marciano[2] (1.Hokkaido University, 2.Advanced Science and Technology Institute)

[MSD46-06] Implementation of the ULAT Project : Quasi-Real Time Monitoring of Lightning and Weather in the Philippines

*Mitsuteru Sato[1], Glenn Vincent C. Lopez[2], Yukihiro Takahashi[1], Hisayuki Kubota[1] (1.Department of Cosmoscience, Hokkaido University, 2.Advanced Science and Technology Institute, DOST)

[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-SD Space Development & Earth Observation from Space

[M-SD46] Effects of lightning, severe weather and tropical storms

convener:Mitsuteru Sato(Department of Cosmoscience, Hokkaido University), Yoav Yair(Interdisciplinary Center Herzliya), Xiushu Qie(Institute of Atmospheric Physics, Chinese Academy of Sciences), Yukihiro Takahashi(Department of Cosmosciences, Graduate School of Science, Hokkaido University)

[MSD46-07] Lightning Geolocation using a Ground-based Lightning Observation Network in the Western North Pacific

*Loren Joy De Vera Estrebillo[1], Mitsuteru Sato[1], Yukihiro Takahashi[1], Hisayuki Kubota[1] (1.Hokkaido University)

[MSD46-08] **Typhoon energy input estimation using lightning data and backtracing technique**

★Invited Papers

*Purwadi Purwadi[1,2], Yukihiro Takahashi[1], Mitsuteru Sato[1], Hisayuki Kubota[1], Kozo Yamashita[3] (1.Department of Cosmosciences, Hokkaido University, Sapporo 0600810, Japan, 2.National Laboratory for Weather Modification Technology, Agency for Assessment and Application of Technology, Jakarta 10340, Indonesia, 3.Division of Electrical and Electronic Engineering, Dept. of Innovative engineering, Ashikaga University, Tochigi 3268558, Japan)

[MSD46-09] Estimation of relationship between tropical cyclone intensity and electrical properties of lightning

*Shunsuke Niwa[1], Mitsuteru Sato[1], Yukihiro Takahashi[1], Hisayuki Kubota[1] (1.Department of Cosmoscience, Hokkaido University)

[MSD46-10] Infrasound multi-site observation of thunders 4: regional testing process for SATREPS

*Masa-yuki Yamamoto[1], Taisei Yamamoto[1] (1.Department of systems engineering, Kochi University of Technology)

[MSD46-12] **3D Reconstruction of Typhoon and Thunderstorm Cloud Top Using Airborne and Satellite-borne Camera**

★Invited Papers

*Meryl Regine Llenaresas Algodon[1], Yukihiro Takahashi[1], Hisayuki Kubota[1], Joel Joseph Marciano[2] (1.Hokkaido University, 2.DOST - Advanced Science and Technology Institute)

[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-TT Technology & Techniques

[M-TT48] Cryoseismology - A new proxy for detecting surface environmental variations of the Earth -

convener:Masaki Kanao(National Institute of Polar Research), Seiji Tsuboi(JAMSTEC, Center for Earth Information Science and Technology), Genti Toyokuni(Research Center for Prediction of Earthquakes and Volcanic Eruptions, Graduate School of Science, Tohoku University), Yoshihiro Hiramatsu(School of Geosciences and Civil Engineering, College of Science and Engineering, Kanazawa University)

[MTT48-01] **Seismic tremors and their candidate origins in relation to cryosphere dynamics in Lützow-Holm Bay, Antarctica**

*Masaki Kanao[1], Yoshihiro Hiramatsu[2] (1.National Institute of Polar Research, 2.Kanazawa University)

[MTT48-02] An effort to utilize the infrasound monitoring network data for understanding surface environment of Antarctica

*Takahiko Murayama[1], Masaki Kanao[2], Masa-yuki Yamamoto[3], Yoshiaki Ishihara[4], Takeshi Matsushima[5], Yoshihiro Kakinami[6] (1.Japan Weather Association, 2.National Institute of Polar Research, 3.Kochi University of Technology, 4.National Institute for Environmental Studies, 5.Kyushu University, 6.Hokkaido Information University)

[MTT48-03] Locating earthquakes around Antarctica by using neural networks based on deep learning

*Seiji Tsuboi[1], Daisuke Sugiyama[1], Masaki Kanao[2], Yoshiaki Ishihara[3], Takahiko Murayama[4] (1.JAMSTEC, Center for Earth Information Science and Technology, 2.National Institute of Polar Research, 3.National Institute of Environmental Studies, 4.Japan Weather Service)

[MTT48-04] Ice dynamics inferred from the detection of icequake seismicity near the Princess Elisabeth base, eastern Dronning Maud Land, East-Antarctica

★Invited Papers

*Denis Lombardi, Guilhem Barruol[1], Lionel Benoit[2], Thierry Camelbeeck[3], Irina Gorodetskaya[4], Olivier Martin[5], Christophe Meynard[5], Christian Thom[5] (1.Institut de Physique du Globe, Paris, France, 2.Université de Lausanne, Lausanne, Switzerland, 3.Royal Observatory of Belgium, Brussels, Belgium, 4.Centre for Environmental and Marine Studies,University of Aveiro, Portugal, 5.Institut National de l'Information Géographique et Forestière, St-Mandé, France)

[MTT48-05] P-wave tomography beneath Greenland and surrounding regions

*Genti Toyokuni[1], Takaya Matsuno[1], Dapeng Zhao[1] (1.Research Center for Prediction of Earthquakes and Volcanic Eruptions, Graduate School of Science, Tohoku University)

[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-TT Technology & Techniques

[M-TT49] GEOSCIENTIFIC APPLICATIONS OF HIGH-DEFINITION TOPOGRAPHY AND GEOPHYSICAL DATA IN THE ANTHROPOCENE

convener:Yuichi S. Hayakawa(Faculty of Environmental Earth Science, Hokkaido University), Shigekazu Kusumoto(Graduate School of Science and Engineering for Research, University of Toyama), Christopher A Gomez(Kobe University Faculty of Maritime Sciences Volcanic Risk at Sea Research Group)

[MTT49-01] Assessing topographical change of peatland using drones

*Kotaro Iizuka[1], Tsuyoshi Kato[2], Asep Andi Yusup[2], Sisva Silsigia[2], Alifia Yuni Soufiningrum[2] (1.Center for Spatial Information Science, University of Tokyo, 2.PT Mayangkara Tanaman Industri / PT Wana Subur Lestari)

[MTT49-02] Monitoring of topographic changes using RTK-UAV in landslide area caused by 2018 Hokkaido Eastern Iburi Earthquake

★Invited Papers

*Yasutaka Nakata[1], Masato Hayamizu[1], Satoshi Hasui[1], Hajime Sato[1] (1.Hokkaido Research Organization, Forest Research Institute, Forest Environment Division)

[MTT49-03] Comparison of LiDAR data using three platforms (Aerial-LiDAR, UAV-LiDAR, Terrestrial-LiDAR) in evergreen coniferous forest

*Ebina Masuto[1], Akira Kato[2], Fumio Takeuchi[1], Shouichi Kondou[3] (1.Forestry Research Institute, Hokkaido Research Organization, 2.Graduate School of Horticulture, Chiba University, 3.Industrial Research Institute, Hokkaido Research Organization)

[MTT49-04] Ground Penetrating Radar Imaging of Pro-glacial Landforms in the upper Waimakariri River (New Zealand)

*Christopher A Gomez[1], Heather Purdie, Justin Harrison, Paul Bealing, Nicholas Key (1.Kobe University Faculty of Maritime Sediment Hazards and Disaster Risk Laboratory)

[MTT49-05] A New Method for Gully Detection on High-Resolution Digital Elevation Models

*Jun-Ping Zhao[1], Shen Yu Hsiao[1] (1.National Chung Hsing University)

[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-TT Technology & Techniques

[M-TT50] Distributed Fiber Optic Sensing for Geophysical Applications

convener:Matthew Becker(California State University Long Beach), Xiangfang Zeng(Institute of Geodesy and Geophysics, Chinese Academy of Sciences), Ziqiu Xue(Research Institute of Innovative Tech for the Earth), Herbert F Wang(University of Wisconsin Madison)

[MTT50-01] On the broadband instrument response of fiber-optic DAS arrays

★Invited Papers

*Nate Lindsey[1,2], Horst Rademacher[3], Jonathan Ajo-Franklin[4,2] (1.Stanford University, 2.Lawrence Berkeley National Laboratory, 3.University of California, Berkeley, 4.Rice University)

[MTT50-02] Importance of using optimum gauge length for DAS measurement to observe geophysical events

*Tsunehisa KIMURA[1] (1.Schlumberger)

[MTT50-03] Surface-wave dispersion spectrum inversion method applied to Love and Rayleigh waves recorded by DAS

*Zhenghong Song[1,2], Xiangfang Zeng[1], Clifford Thurber[3] (1.State Key Laboratory of Geodesy and Earth's Dynamics, Innovation Academy for Precision Measurement Science and Technology, Chinese Academy of Science, 2.School of Earth and Space Sciences, University of Science and Technology of China, 3.Department of Geoscience, University of Wisconsin-Madison)

[MTT50-04] Recent Advances in Fiber-optic Distributed Acoustic Sensor (DAS) Based on Time-gated Digital Optical Frequency Domain Reflectometry

★Invited Papers

*Qingwen Liu[1], Zuyuan He[1], Dian Chen[1] (1.Shanghai Jiao Tong University)

[MTT50-05] A Field Test in Preparation for Long-Range Distributed Acoustic Sensing in Subsea Applications

*Martin Horst Karrenbach[1], Carson Laing[1] (1.OptaSense Inc.)

[MTT50-06] **Hydroacoustic Field Lake Trial Using High Performance Fiber Distributed Acoustic Sensing System**

*Hao Li[1], Cunzheng Fan[1], Tao Liu[1], Zhijun Yan[1], Deming Liu[1], Qizhen Sun[1] (1.Huazhong University of Science and Technology, Wuhan, Hubei, China)

[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-ZZ Others

[M-ZZ53] Availability of earth science data in renewable energy field

convener:Hideaki Ohtake(National Institute of Advanced Industrial Science and Technology), Fumichika Uno(Nihon University, College of Humanities and Sciences), Teruhisa Shimada(Graduate School of Science and Technology, Hirosaki University), Daisuke Nohara(Central Research Institute of Electric Power Industry)

[MZZ53-01] Study on effective use of incidental gas from hot spring waters: a case study in Toyotomi town, Hokkaido

Takumi Takahashi[2], *Masahiko Fujii[1,2], Maki Ikegami[3] (1.Faculty of Environmental Earth Science, Hokkaido University, 2.Graduate School of Environmental Science, Hokkaido University, 3.Hokkaido University Sustainable Campus Management Office)

[MZZ53-02] **Investigation of Offshore Wind Climate in the Southeast Asia**

*Inovasita Alifdini[1], Teruhisa Shimada [1], Anindya Wirasatriya [2] (1.Graduate School of Science and Technology, Hirosaki University, Japan, 2.Department of Oceanography, Faculty of Fisheries and Marine Sciences, Diponegoro University, Indonesia)

[MZZ53-03] A webGIS-based application of solar radiation data and related information

*Ken T. Murata[1], Atsushi Higuchi[2], Hideaki Takenaka[3], Yohei Yamaguchi[4], Shinya Yoshizawa[5], Takashi Nakajima[6] (1.National Institute of Information and Communications Technology, 2.Center for Environmental Remote Sensing (CEReS), Chiba University, 3.JAXA/EORC, 4.Osaka University, 5.Waseda University, 6.Research and Information Center, Tokai University)

[MZZ53-04] Harmonised global datasets of wind and solar farm locations and power

*Sebastian Lionel Dunnett[1], Alessandro Sorichetta[2,1], Gail Taylor[3], Felix Eigenbrod[1] (1.University of Southampton, 2.WorldPop, 3.University of California)

[MZZ53-05] **General issues of Photovoltaic power forecasts for energy management in Japan**

*Hideaki Ohtake[1], Takashi Oozeki[1] (1.National Institute of Advanced Industrial Science and Technology)

[MZZ53-06] Predictability Assessment of Photovoltaic Solar Energy Production with Analog Ensemble

*Weiming Hu[1], Guido Cervone[1], Matteo Turilli[2], Andre Merzky[2], Shantenu Jha[2] (1.Pennsylvania State University Main Campus, 2.Rutgers, The State University of New Jersey)

[E] Oral | U (Union)：Union

Sun. Jul 12, 2020 9:00 AM - 10:30 AM JST | Sun. Jul 12, 2020 12:00 AM - 1:30 AM UTC | Ch.1

[U-11] Planetary Metabolism: The Science of Living Worlds

convener:Anbar Ariel D(Arizona State University), John W Hernlund(Earth-Life Science Institute), Hilairy Ellen Hartnett(Arizona State University), ryuhei nakamura(Tokyo Institute of Technology, Earth-Life Science Institute), Chairperson:Ariel D Anbar(Arizona State University), Hilairy Ellen Hartnett(Arizona State University), John W Hernlund(Earth-Life Science Institute), ryuhei nakamura(Tokyo Institute of Technology, Earth-Life Science Institute)

The geosciences are poised for transformation because of the convergence of two rapidly emerging revolutions: The advent of the Anthropocene, and the radical realization that Earth is one of countless planets in the Universe. These twin revolutions expose major gaps in our understanding of the integrated Earth-life system. The gaps are apparent when we realize that we cannot answer fundamental questions now confronting us: What are Earth's most likely future trajectories? What are the prospects for life on even the most Earth-like extrasolar worlds? The solution is to develop a truly integrated science of living worlds. Building on - 250 years of investigation across an ever-increasing range of subdisciplines, we now know the evolution of life and of Earth's biogeochemical cycles are inextricably linked to the evolution of the solid Earth. The emergence of life, the rise of an aerobic biosphere, biological radiations, mass extinctions, and even human evolution-these events and their placement in time are shaped by the trajectory of Earth's internal differentiation and dynamics, and their expression in surface tectonics and volcanism. From this vantage point, life emerged as an epiphenomenon of geophysics, and will remain coupled to the solid Earth far into the Anthropocene. Hence our greatest questions can only be answered through integration of our subdisciplines, considering the entire planet as a system. We must develop a quantitative, predictive "theory" of the Earth system that describes the mechanistic links between the interior and the surface, and how they have changed with time. Without such a theory, we cannot readily generalize from our understanding of the modern Earth system to forecast its future state, nor can we reliably model the likely states of Earth-like worlds beyond our own.

9:00 AM - 9:15 AM JST | 12:00 AM - 12:15 AM UTC

[U11-01] Syngeosis: Application of the Principles of Symbiosis to Geological Processes

*John W Hernlund[1] (1.Earth-Life Science Institute)

9:15 AM - 9:30 AM JST | 12:15 AM - 12:30 AM UTC

[U11-02] Redox Revolutions on Earth and Beyond

*Ariel D Anbar[1] (1.Arizona State University)

9:30 AM - 9:45 AM JST | 12:30 AM - 12:45 AM UTC

[U11-03] The future life span of Earth's oxygenated biosphere and its controlling factors

★Invited Papers

*Kazumi Ozaki[1], Christopher Reinhard[2] (1.Toho University, 2.Georgia Institute of Technology)

9:45 AM - 10:00 AM JST | 12:45 AM - 1:00 AM UTC

[U11-04] Water worlds may be habitable, but not detectable

*Hilairy Ellen Hartnett[1], ASU NExSS Team (1.Arizona State University)

10:00 AM - 10:15 AM JST | 1:00 AM - 1:15 AM UTC

[U11-05] CHALLENGES TO PREDICTING PLANETARY DIVERSITY

★Invited Papers

*Steven J Desch[1], Hilairy Ellen Hartnett[1], Cayman T Unterborn[1] (1.Arizona State University/CSPO)

10:15 AM - 10:30 AM JST | 1:15 AM - 1:30 AM UTC

[U11-06] Planetary Dyspepsia: Finding Planets that work by understanding the planets that don’t

★Invited Papers

*Cayman T Unterborn[1], Steven J Desch[1] (1.Arizona State University/CSPO)

Syngeosis: Application of the Principles of Symbiosis to Geological Processes

*John W Hernlund[1]

1. Earth-Life Science Institute

The ultimate aim of geology is to understand the role of natural processes in shaping a terrestrial planet. A process is that which animates and transforms matter, driven by available energy. Rock deformation, tectonics, mantle convection, partial melting, differentiation, orogeny, weathering, erosion, geodynamo, and even life are all processes that operate on a living planet, which involve many of the same materials and energy sources. Symbiosis, the intricate interplay of the collective processes carried out by a community of organisms, is widely established in ecological science. Less well-understood, however, is the extension of these emergent communal behaviors to include non-biological processes operating across the planet scale through deep time, something I term "syngeosis." In this presentation I will examine the interplay of abiotic processes from the viewpoint of ecological dynamics, and attempt to establish the difference between "life on a planet" and a "living planet."

Keywords: Ecology, Symbiosis, Habitability, Evolution, Dynamics

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Redox Revolutions on Earth and Beyond

*Ariel D Anbar[1]

1. Arizona State University

The molecule O_2 looms large in the search for life on extrasolar planets, because Earth's O_2-rich atmosphere is a consequence of biology. Commonly, it is assumed that an Earth-like planet on which oxygenic photosynthesis evolves will inevitably accumulate O_2 in its atmosphere and pervasively alter the surface environment –that biological redox innovations inexorably lead to environmental redox revolutions. However, close examination of Earth's environmental redox history challenges this assumption.

Increasingly, it appears that evolution of the solid Earth played a key role in modulating the oxygenation of Earth's surface environment. Multiple lines of evidence now suggest that O_2 was being produced biologically hundreds of millions of years before its accumulation in the atmosphere during the Great Oxidation Event (GOE), ca. 2.4 Ga, and hence that Earth's surface redox revolution was substantially delayed. This delay can be accounted for by interactions between the atmosphere and the solid planet, because the biological production of O_2 is ultimately balanced by consumption through reaction with reductants derived from Earth's interior. In particular, recent examinations of oxygen fugacity during the formation of Precambrian basalts and komatiites suggest that large volumes of the mantle underwent a secular increase of oxygen fugacity through the Archean and early Proterozoic. The cause(s) of this secular shift remain unclear, but when translated into a secular evolution of the redox state of volcanic gases, the observed mantle trend can account for a shift from net O_2 consumption to net O_2 production at about 2.4 Ga.

This emerging understanding of Earth's redox revolution raises important questions about the likelihood of similar revolutions on other worlds even in the presence of large biospheres powered by oxygenic photosynthesis. Even modest differences in mantle compositions or tectonics might substantially alter the timing of surface oxygenation. On some worlds, atmospheric O_2 accumulation might be impossible. This realization highlights the need for far better understanding of solid Earth processes - and how these processes might operate on other nominally "Earth-like" worlds - as a key part of a new science of living worlds.

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The future life span of Earth's oxygenated biosphere and its controlling factors

*Kazumi Ozaki[1], Christopher Reinhard[2]

1. Toho University, 2. Georgia Institute of Technology

Detecting atmospheric biosignatures on Earth-like exoplanets is one of the primary objectives of ongoing and future exoplanetary observational surveys. Significant gaps, however, remain in our understanding of the atmospheric evolution of exoplanets, and in particular the cause-and-effect relationships with an evolving biosphere. Many of these gaps arise from a lack of quantitative frameworks for interpreting atmospheric biosignatures. Construction of such a framework is a subject of broad inter-disciplinary interest. Numerous potential atmospheric biosignatures have been proposed, but molecular oxygen (O_2) (and commensurately abundant ozone, O_3) is still on top of the list of remotely detectable exoplanet biosignatures. However, a fundamental question of how much longer the remotely observable O_2/O_3 in Earth's atmosphere would be sustained on Earth remains uncertain. Solving this question has great ramifications not only for the future of our planet but also for the search for life beyond our planet. Here, we examine this problem using an Earth system model of biogeochemistry and climate that tracks the coupled carbon, oxygen, phosphorus, and sulfur cycles, and captures the global redox (O_2) budget between the exogenic system (atmosphere, ocean, and crust) and the mantle. Our model, which builds upon previous similar Earth system models, incorporates a variety of biogeochemical processes, such as biological productivity in the surface oceans and on land, a series of respiration pathways under oxic and anoxic conditions, an explicit calculation of carbonate system in the seawater, and terrestrial weathering processes, allowing an examination of biogeochemical response to changes in the O_2 levels over geologic timescales. We also include a global biogeochemical CH_4 cycle (methanogenesis, methanotrophy, a parameterized O_2-O_3-CH_4 photochemistry, and the radiative impact of CH_4 on global energy balance) in this study. The model is designed to capture the major components of the biogeochemistry and climate of Earth (and Earth-like planets more broadly) with oxic/anoxic biosphere, but is abstracted enough to allow for a stochastic approach involving large model ensembles that are run for billions of years. Implementation of a stochastic approach reveals that the mean lifespan of Earth's oxygenated biosphere (atmospheric pO_2 >1% of the present atmospheric level, PAL) is $0.81^{+0.08}_{-0.10}$ Gyr (1*sigma*), with a most probable value of 0.78 Gyr. The model predicts that a 'great deoxygenation' of atmosphere, with atmospheric pO_2 dropping sharply to levels reminiscent of the Archaean Earth (<<0.01% PAL), could conceivably be triggered within the next 1 Gyr. We also find that the future lifespan of oxygenated atmosphere depends mainly on an exchange flux of reducing power between the mantle and the exogenic (i.e., ocean-atmosphere-crust) system. We estimate that total duration of Earth's oxygenated biosphere would be ~1.5 Gyr, or roughly 25% of Earth's whole history as an inhabited planet, emphasizing the need for robust atmospheric biosignatures for anoxic exoplanet atmospheres.

Keywords: Atmosphere, Oxygen, Biogeochemical cycle

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Water worlds may be habitable, but not detectable

*Hilairy Ellen Hartnett[1], Group ASU NExSS Team

1. Arizona State University

Water worlds and pelagic planets with extensive surface liquid water, are intriguing types of planet to consider in the search for life beyond Earth. They fall squarely within the traditional definition of habitable because they have surface oceans. However they may have many times more water than the Earth, which has implications for their biogeochemical cycles. We define a Detectability Index to quantify the likelihood that oxygen (O_2) could be assigned a biological vs. non-biological origin and apply it to the case of O_2 on Earth-like planets with varying amounts of water. On Earth-like exoplanets with just 0.2wt% water, i.e., no exposed continents, a reduced flux of bioessential phosphorus limits O_2 production by photosynthesis to levels indistinguishable from abiotic O_2 production due to photolysis of water vapor plus hydrogen escape. Higher water contents, > 1wt%, lead to high-pressure ice mantles and even lower rates of oxygen production. The counter-intuitive conclusion that planets with more water may be more difficult targets for life detection, highlights the importance of a biogeochemical framework for assessing biological process rates in context with geochemical and geophysical process rates.

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CHALLENGES TO PREDICTING PLANETARY DIVERSITY

*Steven J Desch[1], Hilairy Ellen Hartnett[1], Cayman T Unterborn[1]

1. Arizona State University/CSPO

Current strategies for detecting life on exoplanets rely on finding (e.g., by transmission spectroscopy) atmospheric oxygen and/or CH_4 in abundances that demand production rates that cannot be explained by purely abiotic processes. To predict their abundances on a lifeless planet requires several inputs from many fields. Host star elemental abundances constrain the starting composition of the protoplanetary disk, especially H (H_2O), C, and S. Subsequent disk processes like snow lines can fractionate these, leading to planetary materials with different H:C:S ratios. Disk processes also are important for setting the redox state of planetary materials; e.g., by modifying the FeO/Fe^0 ratio by reaction of Fe metal with H_2O vapor in the disk. Within a planet, elements are further fractionated by sequestration in the core. Although H, C, and S do not dominate the density deficit of Earth's core, most of the H, C, and S on Earth nonetheless may reside in the core. This process depends on the mantle redox during core formation. Core formation in turn can affect the mantle redox state, e.g., through reactions like 3 Fe + SiO_2 àFeSi + 2 FeO, which can oxidize the mantle. Oxygen is produced abiotically by photolysis of H_2O vapor, but consumed by reduced gases (H_2S, CO) and minerals (Fe_2S) brought up from the planet interior. Translating O_2 abundance into a production rate requires fixing the speciation of S (H_2S vs. SO_2), and C (CH_4 vs. CO vs. CO_2), i.e., constraining the redox state of the near-surface interior. Likewise, CH_4 is destroyed by photolysis, but its production rate depends on the speciation of C. Predicting production rates of O_2 and CH_4, or just identifying the most important determinants, means combining results from stellar astronomy, astrophysical modeling of planet formation, geophysical modeling of core formation, and mineral and aqueous geochemistry.

We consider C; extension to S and N would be similar. Stellar abundances suggest a factor-of-2 variations in C/Mg and thus C/rock ratios in disks [1]. Earth's mantle has up to 120 ppm C, yielding 8×10^{-5} M_E or $40{,}000 \times 10^{18}$ moles of C in the mantle, plus 7000×10^{18} moles of C is in the crust and surface [3]. This represents a decrease by a factor of 40,000 below the solar C/rock ratio [3.5], due to a combination of disk processes and sequestration of C in the core. The plausible range of C contents of Earth's core, ~0.1 - 1wt% C [4,5], suggests a mass 3×10^{-4} –3×10^{-3} M_E, so C in the Earth's mantle was reduced by a factor of 4-40 during core formation. Solubility of C in metal is sensitive to the pressure of core formation, varying by a factor of 3 for pressures between 0 and 44 GPa [6]. Variations in mantle oxygen fugacity during core formation likely lead to significant differences in the C partitioning [5]. The partitioning of N into the core decreases by two orders of magnitude across the plausible range of mantle oxygen fugacities, ΔIW=-5 to 0 [7]. Mantle redox must play a role in setting the CH_4/CO_2 ratio of outgassed C. We conclude that the largest determinants of C content and CH_4 outgassing are snow line-like disk processes, followed by a planet's mantle redox. Stellar abundances, circumstances of core formation, near-surface mineralogies, and mode of volatile exchange (stagnant lid vs. plate tectonics) also play important roles.

Understanding the geochemical cycles of a nominally Earth-like exoplanet requires constraining its formation history and its redox state. This demands an interdisciplinary approach to solve.

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References: [1] Hinkel, NR et al. (2016) *ApJS* 226, 4. [2] McDonough, WF and Sun, SS (1995) *Chem. Geol.* 120, 223. [3] Sleep, NH and Zahnle, KJ (2001) *JGR* 106, 1373. [3.5] Lodders, K (2003) *ApJ* 591, 1220. [4] Hirose, K et al. (2013) *AREPS* 41, 657. [5] Dasgupta, R and Walker, D (2008) *GCA* 72, 4627. [6] Lord, O et al. (2009) *EPSL* 284, 157. [7] Kadik, AA et al. (2008) LPSC 39, 1037.

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Planetary Dyspepsia: Finding Planets that work by understanding the planets that don’t

*Cayman T Unterborn[1], Steven J Desch[1]

1. Arizona State University/CSPO

In our search for life outside of our solar system, the all-important question is “Where to look?” With more than 4000 exoplanets discovered, nature has revealed a diversity of rocky worlds. From exo-Mercuries to super-Earths, the vast majority of rocky planet discovered to date are unlike anything found in our Solar System. Our current data set reveals planets with masses smaller than Mercury to ten times that of Earth. For these rocky planets, the diversity increases even more so with the relative abundances of rock-building elements in stars showing factors of two difference relative to the Sun and Earth. In the building a predictive model of the trajectory a planet can take, the Earth offers our best data set to benchmark these models. The Earth, however, is unique, even in our Solar System as it undergoes plate tectonics, underwent remelting to produce continental crust and, of course, is abundant with life. We are presented with a problem: how to reconcile the need to know where to best point our telescopes to find life, the large and decidedly non-Earth parameter space of rocky exoplanet and our best source of benchmark data for any predictive models of exoplanet evolution being exceedingly complex and unique in the Earth. Given the problem’s scale coupled with the inherent need for a cross disciplinary approach to solve it, where do we start? Underlying each of these questions is a want to search for “Earth-like,” habitable planets with temperate climates over geologic timescales. As such, knowing which planets based on their observable properties are less likely to produce these conditions tell us where not to look for life. Here I present a series of examples of rocky planet compositions, ages and formation environments that outline the parameter space of planetary conditions over which emergence should be explored. By taking an “outside-in” approach to mapping the parameters for which planets stop behaving in an Earth-like manner, many of the complexities present in our models for the Earth evolution are much less relevant. By concentrating on only the most basic aspects of a planet’s evolution, we can quickly trace the planets with trajectories that are not fruitful for expensive observational follow up time in our search for life. Indeed, by mapping those planets which are more likely to be non-Earth-like can provide us with a much more robust data set to understand the population of planets to which Earths and non-Earths belong.

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[E] Oral | U (Union) : Union

Mon. Jul 13, 2020 2:15 PM - 3:45 PM JST | Mon. Jul 13, 2020 5:15 AM - 6:45 AM UTC | Ch.2

[U-13] Open Colloquium-NASA/JAXA: Our advance and future load in Heliophysics

convener:Yusuke Iida(Niigata University), Mariko Teramoto(Kyushu Institute of Technology), Chun Ming Mark Cheung(Lockheed Martin Advanced Technology Center), Chairperson:Yusuke Iida(Niigata University), Mariko Teramoto(Kyushu Institute of Technology), Chun Ming Mark Cheung(Lockheed Martin Advanced Technology Center)

The connection between the Sun and the earth is becoming a more critical issue in the modern era of space use. Recent advances in the satellite observation have brought breakthroughs in our understanding of the solar-terrestrial system and also the solar activity itself. In this session, the researchers who played a central role in the NASA and JAXA heliophysics missions introduce their achievements to the Geoscience community members and discuss the future payload of the heliophysics missions. We have discussion time not only in each talk but also at the end of the session. Open discussions are very welcomed from both space science and other fields.

2:15 PM - 2:40 PM JST | 5:15 AM - 5:40 AM UTC

[U13-01] Geospace Explorations: Toward cycle 25

★Invited Papers

*Yoshizumi Miyoshi[1] (1.Institute for Space-Earth Environmental Research, Nagoya University)

2:40 PM - 3:05 PM JST | 5:40 AM - 6:05 AM UTC

[U13-02] **The State and Vision for the Future of Heliophysics at NASA**

★Invited Papers

*James F Spann[1] (1.NASA Headquarters)

3:05 PM - 3:30 PM JST | 6:05 AM - 6:30 AM UTC

[U13-03] The Solar-C_EUVST Mission and Solar Observations in 2020s

★Invited Papers

*Toshifumi Shimizu[1] (1.Institute of Space and Astronautical Science, JAXA)

3:30 PM - 3:35 PM JST | 6:30 AM - 6:35 AM UTC

Discussion

3:35 PM - 3:40 PM JST | 6:35 AM - 6:40 AM UTC

Discussion

3:40 PM - 3:45 PM JST | 6:40 AM - 6:45 AM UTC

Discussion

Geospace Explorations: Toward cycle 25

*Yoshizumi Miyoshi[1]

1. Institute for Space-Earth Environmental Research, Nagoya University

In this presentation, we will show current research activities and future perspectives of geospace, mainly focusing on magnetosphere and ionosphere. During solar cycle 24, new satellites NASA/THEMIS, Van Allen Probes, MMS and JAXA/Arase are operated and provide many new findings about geospace. Besides these in-situ observations, ground-based observations such as SuperDARN, EISCAT, global magnetometer etc provide global view of geospace phenomena, convection, global current, plasma wave distributions. Coordinated observations between in-situ satellite measurements and ground-observations are very useful to understand cause and consequence occurred in different regions. For solar cycle 25, new missions for geospace imaing are planned, which provides new view of geospace.

Keywords: Geospace, Cycle 24 and 25

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The State and Vision for the Future of Heliophysics at NASA

*James F Spann[1]

1. NASA Headquarters

NASA is a mission driven agency whose science mission is focused on discovering the secrets of the universe, looking for life elsewhere, and safeguarding and improving life on Earth. Heliophysics plays a key role in every aspect of the NASA science mission and focuses on increasing our knowledge of the dynamic nature of our star, and its impact on Earth, and throughout the Solar System to the boundary of interstellar space. This includes advancing our understanding of drivers of and enabling the prediction of space weather. Heliophysics has an established research program that motivates and funds solar and space physics, which is the essence and foundation of space weather research. This talk will provide an overview of the Heliophysics Program and how the science investigations through missions, technology, and R&A address all aspects of solar and space physics, and its relation to space weather.

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The Solar-C_EUVST Mission and Solar Observations in 2020s

*Toshifumi Shimizu[1]

1. Institute of Space and Astronautical Science, JAXA

High resolution observations with advanced techniques of the Sun have been improving our knowledge on fundamental physics working in solar dynamical atmosphere, which is full of MHD processes including waves, magnetic reconnection, magneto-convection, and instability. The Solar-C_EUVST mission is a JAXA competitive M-class mission to be developed with participations from NASA and European space agencies. The mission will carry EUV High-Throughput Spectroscopic Telescope, which is an EUV imaging spectrometer with slit-jaw imaging system that will simultaneously observe the solar atmosphere from the photosphere/chromosphere up to the corona with seamless temperature coverage, high spatial resolution, and high throughput for the first time. The mission is designed to comprehensively understand how mass and energy are transferred throughout the solar atmosphere, which would provide an answer to the most fundamental questions in solar physics: how fundamental processes lead to the formation of the solar atmosphere and the solar wind, and how the solar atmosphere becomes unstable, releasing the energy that drives solar flares and eruptions. This is a fundamental step towards answering how the plasma universe is created and evolves, and how the Sun influences the Earth and other planets in the heliosphere. In 2020s, we will acquire new observations from a large variety of new instruments, such as DKIST for high-spatial solar surface observations, Indian and Chinese satellites, Parker Solar Probe to reach less than 10 solar radius, Solar Orbiter in an inclined orbit, PUNCH for polarimetric observations of the outer corona. The Solar-C_EUVST will provide spectroscopic measurements to fill a gap from the solar surface to the outer corona and the heliosphere.

Keywords: The Sun, New space mission

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[E] Oral | U (Union)：Union

Mon. Jul 13, 2020 2:15 PM - 3:45 PM JST | Mon. Jul 13, 2020 5:15 AM - 6:45 AM UTC | Ch.3

[U-21] Frontiers of Antarctic Environmental Research

convener:Kenji Kawamura(National Institute of Polar Research, Research Organization of Information and Systems), Carol Finn(USGS), Osamu Seki(Institute of Low Temperature Science, Hokkaido University), Yusuke Suganuma(National institute of Polar Research), Chairperson:Kenji Kawamura(National Institute of Polar Research, Research Organization of Information and Systems), Carol Finn(USGS), Osamu Seki(Institute of Low Temperature Science, Hokkaido University), Yusuke Suganuma(National institute of Polar Research)

Antarctica and the Southern Ocean play important roles in the global climate system, with their crucial influences on, e.g., sea level, ocean circulation and heat/carbon storage. They are also the least known components because the precise understanding of the processes requires observations of various interactions, such as those between ocean, ice shelf and ice sheet, in the harshest conditions on the Earth's surface. Recent advancements in direct and satellite observations and data analyses have suggested significant changes in the Antarctic. However, as the spatial and temporal scales of the changes are diverse (from sub-annual to over millennial), significant challenges remain in their understanding and modeling.

This session will invite several presentations that address the Antarctic environmental changes in the past, present and potential future, and the importance of interdisciplinary and international observations and modeling for better understanding and projection of the Antarctic and their influences on the global environments.

2:15 PM - 2:17 PM JST | 5:15 AM - 5:17 AM UTC

Introduction

2:17 PM - 2:39 PM JST | 5:17 AM - 5:39 AM UTC

[U21-01] Oceanographic and geophysical observation campaign off Sabrina Coast, East Antarctica, in 2019/2020

★Invited Papers

*Shigeru Aoki[1], Takeshi Tamura[2], Yoshihiro Nakayama[1], Kazuya Ono[1], Pat Wongpan[1], Kaihe Yamazaki[1], Takuya Itaki[3], Yuki Tokuda[4], Satoshi Sasaki[5], Daisuke Hirano[1], Yuichi Aoyama[2] (1.Hokkaido University, 2.NIPR, 3.AIST, 4.Tottori University of Environmental Studies, 5.Shimane University)

2:39 PM - 3:01 PM JST | 5:39 AM - 6:01 AM UTC

[U21-02] Hot-water drilling for exploring subglacial environment of the Antarctic ice sheet

★Invited Papers

*Shin Sugiyama[1], Masahiro Minowa[2] (1.Institute of Low Temperature Science, Hokkaido University, 2.Instituto de Ciencias Físicas y Matemáticas, Universidad Austral de Chile)

3:01 PM - 3:23 PM JST | 6:01 AM - 6:23 AM UTC

[U21-03] **Modelling the Stability of Antarctic ice sheet in the past interglacials and its implication on future projection.**

★Invited Papers

*Ayako Abe-Ouchi[1], Takashi Obase[1], Ralf Greve[4], Sam Sheriff-Tadano[1], Fuyuki SAITO[2], Kenji Kawamura[3] (1.Atmosphere and Ocean Research Institute, The University of Tokyo, 2.JAMSTEC, 3.NIPR, 4.Hokkaido University)

3:23 PM - 3:45 PM JST | 6:23 AM - 6:45 AM UTC

[U21-04] **Looking to the Future Collaborative Antarctic Science with Global Impacts**

★Invited Papers

*Robin Elizabeth Bell[1], Terry Wilson[2] (1.Lamont Doherty Earth Observatory, 2.Ohio State University, Columbus ,OH, USA)

Oceanographic and geophysical observation campaign off Sabrina Coast, East Antarctica, in 2019/2020

*Shigeru Aoki[1], Takeshi Tamura[2], Yoshihiro Nakayama[1], Kazuya Ono[1], Pat Wongpan[1], Kaihe Yamazaki[1], Takuya Itaki[3], Yuki Tokuda[4], Satoshi Sasaki[5], Daisuke Hirano[1], Yuichi Aoyama[2]

1. Hokkaido University, 2. NIPR, 3. AIST, 4. Tottori University of Environmental Studies, 5. Shimane University

Totten Glacier is one of the fastest-flowing glaciers in East Antarctica. The glacier's drainage system as a whole has a potential of 3.5m rise of global sea level. Recent various researches have revealed Totten Glacier and nearby glaciers are changing, which has some similarity with the situation in West Antarctica. Totten Glacier is now losing its ice mass and has a potential of contributing to a significant sea level rise in the future. Warm water of the ocean off Sabrina Coast, flowing through a deep channel under the glacier, is considered as the major driver of the rapid ice melting, but yet little is known about the oceanic role in melting the ice. Although this region has been attracting growing attention, in-situ observational understandings are still inadequate because of its heavy sea ice cover.

Based on Icebreaker Shirase, we conducted oceanographic and geophysical observations off Sabrina Coast, East Antarctica, during Dec. 2019 and Feb.-Mar. 2020 as a program of 61st Japanese Antarctic Research Expedition (JARE61). Hydrographic measurements, including CTD (Conductivity-Temperature Depth profiler)/MS (Multi-water Sampler) and XCTD (eXpendable CTD), revealed the ubiquitous presence of deep warm water in this region, which is the source of the large thermal forcing. Air-borne XCTD and XBT(eXpendable BathyThermograph) helped enhance the spatial sampling in difficult access area, and largely expand the distribution of water mass property. At the same time, sediments and their cores were taken for the first time in this region. Bathymetric survey with multi-narrow beam was effective and describes new and detailed topographic features in the least explored area. Sea ice research including wave motion measurements were conducted at the marginal ice zone off Dolton Polynya. International cooperation was effective in filling gaps of our observational systems. Further analysis of these data enables us to decipher a detailed pathway of warm water and meltwater discharge to and from the Totten Glacier Ice Shelf and its historical evolution.

Keywords: Totten Glacier, Japanese Antarctic Research Expedition, Modified Circumpolar Deep Water, Sealevel rise

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Hot-water drilling for exploring subglacial environment of the Antarctic ice sheet

*Shin Sugiyama[1], Masahiro Minowa[2]

1. Institute of Low Temperature Science, Hokkaido University, 2. Instituto de Ciencias Físicas y Matemáticas, Universidad Austral de Chile

Subglacial environment of the Antarctic ice sheet is one of the least investigated areas on the Earth. Base of the ice sheet forms an important boundary, which controls ice dynamics and thermal conditions. Existence of subglacial channels and lakes poses important questions about basal hydrology and microbial ecosystem under several-kilometer-thick ice. Recent mass loss of the ice sheet is driven by the melting of ice shelves, which occurs at the basal boundary of floating ice. Sensing physical properties beneath the ice is possible by using seismic and electromagnetic waves, but in-situ measurements and sampling are required to answer many of the questions. Hot-water drilling is a powerful tool to provide an access to the bed of glaciers and ice sheets. In this contribution, I introduce recent progress in our understanding of subglacial environment of the Antarctic ice sheet based on direct observations through boreholes, including our project in Langhovde Glacier in East Antarctica.

Langhovde Glacier is a 3-km wide outlet glacier located 20 km south of the Japanese Syowa Station in East Antarctica. Lower 2–3 km of the glacier forms a floating tongue, which feeds into the Lützow-holm bay. To study basal melting and subshelf ocean environment, we drilled four boreholes in January 2018 using a hot-water drilling system. The boreholes were utilized to measure spatial variations of temperature, salinity and current under the ice. Two of the boreholes were equipped with a temperature and CTD/current sensors for year-round observations. Potential temperature of the seawater underneath the ice was between −1.4 and −1.1˚C, approximately 1˚C warmer than the freezing temperature. Water temperature within several hundred meters from the grounding line was −1.2˚C in January 2018. Temperature dropped to −1.6˚C from January to May, which was followed by gradual warming to −1.55˚C in December. The temperature in January 2018 (−1.2˚C) was significantly warmer than that in the summer 2019 (−1.55˚C), as well as temperature measured at the same location in 2012 and 2013 (−1.55˚C). A possible interpretation of the unusually warm water in 2018 was break-up of land-fast sea ice in the Lü tzow-holm bay in 2016. Presumably, open water near the glacier front facilitated transport of heat to the grounding line. Our subshelf observations implied significant amount of basal melting occurs under the entire ice shelf of Langhove Glacier, and thermal conditions near the grounding line is susceptible to changes in the ocean.

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Modelling the Stability of Antarctic ice sheet in the past interglacials and its implication on future projection.

*Ayako Abe-Ouchi[1], Takashi Obase[1], Ralf Greve[4], Sam Sheriff-Tadano[1], Fuyuki SAITO[2], Kenji Kawamura[3]

1. Atmosphere and Ocean Research Institute, The University of Tokyo, 2. JAMSTEC, 3. NIPR, 4. Hokkaido University

Ice sheet volume changes are the largest potential source of sea level change in the past and future. Projection of the ice sheet in future has been challenging and requires different approach from other components of climate system for model validation because of two main reasons. One is its millennial-scale long response time to external forcing which leads to its long commitment. The other is the existence of threshold or tipping point in the system which characterizes the irreversible behavior under climate changes. It can make a large difference in Antarctica ice sheet volume even under a small change in forcing. Here we show the case studies of the last interglacial climate and Antarctic ice sheet compared to the present interglacial. Multiple lines of evidence show that the sea level was higher at the last interglacial than today and the Antarctica ice sheet mass loss may have contributed substantially to it. One study using NCAR CCSM3 climate model and another one using MIROC 4m both simulate the climate change from the penultimate glacial maximum to the last interglacial and are compared with ice core studies and paleoceanography studies. Several ice sheet modelling studies show a mass loss of Antarctica ice sheet at the last interglacials under a few degree warmer conditions than our current interglacial. It is shown in many models that subsurface ocean warming and the marine ice sheet instability are the key processes. There are still many steps needed to link the lessons from modelling the interglacials to the model validation for future projection through both domestic and international collaboration.

Keywords: Climate model, ice sheet, Antarctica ice sheet, deglaciation

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Looking to the Future Collaborative Antarctic Science with Global Impacts

*Robin Elizabeth Bell[1], Terry Wilson[2]

1. Lamont Doherty Earth Observatory, 2. Ohio State University, Columbus ,OH, USA

Antarctica is stunning in its vast whiteness. It remains a continent encased in ice and long just an empty space on maps. Filling in this blank space has been a collaborative international effort. Over sixty years ago in 1958 nations came together as international collaboration blossomed in the International Geophysical Year (IGY). Two lasting impacts of the IGY are the discovery that the Antarctic ice sheet was over two miles thick and the concept that Antarctica should be a continent dedicated to science. The Scientific Committee for Antarctic Research became the hub for fostering collaboration in the challenging Antarctic environment where collaboration is essential.

In 2002, just as Larsen B ice shelf broke up catastrophically, the international community recognized the essential need to address the emerging evidence for change in the polar regions using the framework of collaboration fostered by the IGY. A small group of scientists launched the concept of the International Polar Year 2007-9 (IPY). Over 65,000 scientists collaborated and succeeded in reaching places that had not been visited for over 50 years. Using new technologies and leveraging shared logistical assets, scientists discovered everything from subglacial water networks that run uphill to glacial isostatic uplift at rates over 40 mm/year. These discoveries were only possible due to the collaborative framework of the IPY.
The Antarctic Ice Sheet is changing at rates greater than IGY scientists could have imagined. The rapidly changing ice has pushed the driving motivation for Antarctic science beyond simple awe and discovery to science that is critical for coastal residents around the globe. Suddenly change in Antarctica matters. The challenge for SCAR and the global science community will be to build truly inclusive teams to improve our understanding of how fast the ice sheet will change and how much sea level will rise. Antarctic science has an opportunity to move beyond the image of the frosty bearded explorer to embracing international teams where data is openly shared and leaders reflect the diverse population of the cities that will be impacted by the future Antarctic change.

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[E] Oral | U (Union)：Union

Mon. Jul 13, 2020 9:00 AM - 10:30 AM JST | Mon. Jul 13, 2020 12:00 AM - 1:30 AM UTC | Ch.1

[U-22] Environmental drivers and impacts of the evolving COVID-19 pandemic

convener:Benjamin F Zaitchik(Johns Hopkins University), Teppei J Yasunari(Arctic Research Center, Hokkaido University), Chairperson:Teppei J Yasunari(Arctic Research Center, Hokkaido University), Chairperson:Benjamin F Zaitchik(Johns Hopkins University)

9:00 AM - 9:20 AM JST | 12:00 AM - 12:20 AM UTC

[U22-01] Lessons learned from emission fluctuation of greenhouse gases and air pollutants due to restrictions associated with the COVID-19 pandemic

★Invited Papers

*Toshihiko Takemura[1] (1.Research Institute for Applied Mechanics, Kyushu University)

9:20 AM - 9:40 AM JST | 12:20 AM - 12:40 AM UTC

[U22-02] **Satellite Observations of Aerosols during COVID-19 Pandemic**

★Invited Papers

*Pawan Gupta[1,2], Robert C. Levy[3] (1.Universities Space Research Association Greenbelt, 2.MSFC, 3.GSFC)

9:40 AM - 10:00 AM JST | 12:40 AM - 1:00 AM UTC

[U22-03] Seasonal sensitivity of COVID-19: perspectives from viral-host interactions

★Invited Papers

*Miyu Moriyama[1], Akiko Iwasaki[1] (1.Yale University)

10:00 AM - 10:20 AM JST | 1:00 AM - 1:20 AM UTC

[U22-04] Air pollution, COVID-19, and public health: What we know and don’t know

★Invited Papers

*Susan Anenberg[1] (1.George Washington University)

10:20 AM - 10:30 AM JST | 1:20 AM - 1:30 AM UTC

Discussion

Lessons learned from emission fluctuation of greenhouse gases and air pollutants due to restrictions associated with the COVID-19 pandemic

*Toshihiko Takemura[1]

1. Research Institute for Applied Mechanics, Kyushu University

The decrease in the concentration of air pollutants due to the limitation of socio-economic activities associated with the COVID-19 pandemic has been detected by ground-based and satellite observations. Since most of the air pollutants originate from fossil fuels, it is thought that the emission of carbon dioxide, which is a greenhouse gas, has also been reduced. However, as behavior restrictions have been lifted, air pollutant concentrations have returned to their original levels. Although it was a very short period of time, it is a fact that there was a rapid global reduction in their emissions that could not have been normal situations. What should we learn from this experience toward mitigating future climate change and air pollution? I will provide a few perspectives based on my public articles posted to Yahoo Japan News (sorry, but only in Japanese) (https://news.yahoo.co.jp/byline/takemuratoshihiko/) for discussion.

<Mitigating global warming by reducing carbon dioxide vs. Accelerating global warming by reducing air pollutants>
Both carbon dioxide and air pollutant emissions were reduced globally in the first few months of this year. Carbon dioxide reduction works to mitigate global warming, of course. On the other hand, climate change caused by aerosols is quantitatively large among the air pollutants, and its reduction brings about positive radiative forcing, and therefore accelerates global warming. Most of the air pollutants have short lifetimes in the atmosphere, then as soon as the amount of emission changes, the concentration also changes significantly. In the case of carbon dioxide, even if the amount of emission changes temporarily, the concentration in the atmosphere does not immediately change. Therefore, temporary reductions in fossil fuel consumption may have resulted in temperature increases of the order of months in some regions. An international project with climate models is underway to analyze how the climate change caused by the COVID-19 pandemic was. Regarding the long-term relationship between air pollution and climate change, developed countries that have continued to increase greenhouse gas emissions by only reducing particulate matter that cools the
atmosphere to mitigate air pollution have accelerated global warming. Air pollution control and global warming mitigation had to proceed simultaneously.

<Sustainable behavior change is effective in mitigating global warming>
Improving the atmospheric environment and reducing carbon dioxide emissions associated with the COVID-19 pandemic is only temporary. Although it was only temporary, we were able to experience that if the consumption of fossil fuels is reduced, the carbon dioxide emissions will decrease and the atmospheric environment will improve. It was analyzed that the largest reduction in carbon dioxide emissions due to this behavior change was in the transportation sector. It was proved that individual commuting by foot or bicycle, and reduction of going to office and business trips by remote work were effective. We tend to have the impression that we have to put up with something to mitigating global

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warming (especially Japanese people). “Patience” of behavior restriction does not become an essential solution to global warming and air pollution, but we have experienced that sustainable behavioral change by each person is effective in achieving a decarbonized society. I think that what we have done is of great significance.

Keywords: COVID-19 pandemic, Climate change, Air pollution, Carbon dioxide, Aerosols, Behavior change

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Satellite Observations of Aerosols during COVID-19 Pandemic

*Pawan Gupta[1,2], Robert C. Levy[3]

1. Universities Space Research Association Greenbelt, 2. MSFC, 3. GSFC

As a result of an ongoing COVID-19 pandemic, global human activities have been limited or completely halted in many parts of the world. As a result of reduced anthropogenic emissions, this has created a natural experiment to observe the changes in atmospheric composition at different temporal and spatial scales. Some of these changes will be short-term, and some will last over a more prolonged period. Aerosols, however, are produced by not only human activities, but also natural sources such as dust, sea salt and biomass burning. As we now have a good-quality, stable, satellite-derived, global aerosol dataset from the past two decades, we can evaluate the recent COVID-19 impacts on aerosols. In this study, we will present results of satellite data analysis from around the world, focusing on urban centers as well as regions where significant changes were observed.

Keywords: Aerosols, Satellites, Lockdown, Emissions, Impacts

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Seasonal sensitivity of COVID-19: perspectives from viral-host interactions

*Miyu Moriyama[1], Akiko Iwasaki[1]

1. Yale University

Coronavirus disease 2019 (COVID-19) has emerged in December 2019 and continues to spread throughout over 200 countries and territories. To flatten the epidemic curve of COVID-19 cases, prolonged strict restriction of movement has been applied which has unfortunately led to severe economic crises in many countries. COVID-19 is caused by respiratory tract infection with a newly emerging coronavirus, severe acute respiratory syndrome-related coronavirus 2 (SARS-CoV2). Other members of the coronaviruses are well known to cause the common cold, which has seasonality in winter. Therefore, whether the seasonal changes impact on COVID-19 outbreak is of great importance. In this presentation, we will discuss the seasonal sensitivity of COVID-19 by focusing on the key determinants of the seasonality of other respiratory viral infections. In particular, we will highlight the effects of seasonal changes in the environmental factors on the host antiviral immune responses. Further, we will discuss the latest studies on seasonal effects on the COVID-19 pandemics.

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Air pollution, COVID-19, and public health: What we know and don’t know

*Susan Anenberg[1]

1. George Washington University

Air pollution, COVID-19, and public health intersect in several ways. Air pollution may contribute to both spread of SARS-CoV-2 and severity of COVID-19 infection. Rapid declines in personal vehicle activity during stay-at-home orders and physical distancing have also affected ambient air pollution levels. This talk will address what we know and don’t know about how air pollution, COVID-19, and public health interact, drawing from the rapidly evolving body of research on these topics. Understanding these interactions can inform the public health response to COVID-19, as well as longer-term environmental policies.

Keywords: Environmental health, Air pollution, COVID-19

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[E] Oral | U (Union)：Union

Mon. Jul 13, 2020 10:45 AM - 12:15 PM JST | Mon. Jul 13, 2020 1:45 AM - 3:15 AM UTC | Ch.1

[U-23] New challenges to diversity, equality and inclusion under COVID-19

convener:Chiaki T. Oguchi(Institute for Environmental Science and Technology, Graduate School of Science and Engineering, Saitama University), Rie Hori, S.(Department of Earth Science, Faculty of Science, Ehime University), Claudia Jesus-Rydin(European Research Council), Hodaka Kawahata(Atmosphere Ocean Research Institute, the University of Tokyo), Chairperson:Chiaki T. Oguchi(Institute for Environmental Science and Technology, Graduate School of Science and Engineering, Saitama University)

10:45 AM - 11:00 AM JST | 1:45 AM - 2:00 AM UTC

[U23-01] Large-scale survey of work and life in scientific and technological profession in Japan under Emergency Declaration caused due to COVID-19 and requests to Japanese government

★Invited Papers

*Noriko Hirata-Kohno[1], Misa Shimuta[2,3] (1.Nihon University, 2.EPMEWSE, 3.The Jikei University School of Medicine)

11:00 AM - 11:15 AM JST | 2:00 AM - 2:15 AM UTC

[U23-02] The impacts of COVID-19 and how racism is hindering our diversity and inclusion efforts

★Invited Papers

*Robin E Bell[1,2] (1.American Geophysical Union, 2.Lamont-Doherty Earth Observatory)

11:15 AM - 11:30 AM JST | 2:15 AM - 2:30 AM UTC

[U23-03] New challenges and opportunities for equality, diversity and inclusivity under COVID-19 and beyond

★Invited Papers

*Alberto Montanari[1] (1.University of Bologna)

11:30 AM - 12:15 PM JST | 2:30 AM - 3:15 AM UTC

Discussion

Large-scale survey of work and life in scientific and technological profession in Japan under Emergency Declaration caused due to COVID-19 and requests to Japanese government

*Noriko Hirata-Kohno[1], Misa Shimuta[2,3]

1. Nihon University, 2. EPMEWSE, 3. The Jikei University School of Medicine

In Japan , since the ratio of female professionals in science, technology, engineering and mathematics (STEM) field is far behind other developed countries, "The Japan Inter-Society Liaison Association Committee for Promoting Equal Participation of Men and Women in Science and Engineering (EPMEWSE in short)" was established in 2002. Around 100 academic societies belong to the association and do working for gender equality.

As some JpGU member may already know, the major roll of EPMEWSE could be summarized as: 1) large Scale Survey for every five years to know the actual conditions of gender equality in STEM field in Japan, 2) proposals and requests to Japanese Government based on the survey results, 3) light survey the activities and female ratio of each member societies associated with EPMEWSE and 4) support STEM Programs for high school girls.
In this talk, we discuss our actual situation under Emergency Declaration caused due to COVID-19 based on our recent "Large-scale survey of work and life in scientific and technological profession" in Japan as well as related requests to Japanese government.

Keywords: EPMEWSE, STEM, Large scale survey, COVID-19, Requests to Japanese government

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The impacts of COVID-19 and how racism is hindering our diversity and inclusion efforts

*Robin E Bell[1,2]

1. American Geophysical Union, 2. Lamont-Doherty Earth Observatory

AGU has recently established an updated Strategic Plan which outlines three primary strategic goals to: (1) catalyze discovery and solutions to scientific and societal challenges; (2) promote and exemplify an inclusive scientific culture; and (3) partner broadly with other organizations and sectors to effectively address scientific and societal challenges. AGU has also adopted a diversity and inclusion strategic plan in 2018 and put in place a Diversity and Inclusion Advisory Committee to help assure progress towards our diversity equity and inclusion goals. Many new initiatives are underway across AGU programs and metrics are in development to help publicly track progress. The recent COVID-19 impacts and simultaneous major social protest in response to long-standing U.S. racial issues are now creating additional challenges for scientific societies' awareness and resolve to assure accomplishing our objectives across all programming, including for diversity and inclusion. This talk will highlight several of the impacts, challenges and opportunities, and will discuss strategies and action to help AGU and others move forward with intention and purpose towards achieving our diversity, equity and inclusion goals.

Keywords: COVID, Diversity, Inclusion, Pandemic, equity, society

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New challenges and opportunities for equality, diversity and inclusivity under COVID-19 and beyond

*Alberto Montanari[1]

1. University of Bologna

Diversity, equality and inclusivity are topical issues in science at large. While diversity is unanimously recognised to be an essential ingredient of science, it is still difficult to find a successful strategy to ensure diversity in the widest sense. Meanwhile, the tragedy of coronavirus, with more than 400, 000 deaths to date, is going to broadly change our lifestyle, including research targets and avenues. While COVID-19 has been initially seen as an additional obstacle to diversity, it has been later observed that virtual networking may actually offer unexpected opportunities.
In particular, I believe that virtual connections may allow us to remove barriers to inclusivity therefore moving forward to an improved diversity. Furthermore, strategies and actions to support economic recovery of countries during COVID-19 and beyond may also contribute to improve equality in science. In fact, the current crisis has created a window of opportunity to change the way we organise scientific activities. In this talk we will discuss the conditions, strategies and attitude that may help geoscientists to improve equality, diversity and inclusivity under the current health emergency

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[E] Oral | U (Union)：Union

Mon. Jul 13, 2020 4:00 PM - 5:30 PM JST | Mon. Jul 13, 2020 7:00 AM - 8:30 AM UTC | Ch.1

[U-25] Special session for a Borderless World of Geoscience after COVID-19 (Challenges for the future)

convener:Hodaka Kawahata(Atmosphere Ocean Research Institute, the University of Tokyo), Robin Elizabeth Bell(Lamont Doherty Earth Observatory), Alberto Montanari(University of Bologna), David Laurence Higgitt(Lancaster University College at Beijing Jiaotong University, Weihai, China), Chairperson:Hodaka Kawahata(Atmosphere Ocean Research Institute, the University of Tokyo)

4:00 PM - 4:03 PM JST | 7:00 AM - 7:03 AM UTC

Introduction

4:03 PM - 4:20 PM JST | 7:03 AM - 7:20 AM UTC

[U25-01] Collaborative, Inclusive, Connected Earth and Space Science for our Future

★Invited Papers

*Robin E Bell[1] (1.American Geophysical Union)

4:20 PM - 4:37 PM JST | 7:20 AM - 7:37 AM UTC

[U25-02] A new mission for the geosciences in an age of pandemics and beyond

★Invited Papers

*Alberto Montanari[1], Helen Glaves[2] (1.University of Bologna, 2.British Geological Survey, Environmental Science Centre)

4:37 PM - 4:54 PM JST | 7:37 AM - 7:54 AM UTC

[U25-03] A Borderless World of Geoscience in Asia after COVID-19… for Asia and the World

★Invited Papers

*David Laurence Higgitt[1] (1.Lancaster University College at Beijing Jiaotong University, Weihai, China)

4:54 PM - 5:09 PM JST | 7:54 AM - 8:09 AM UTC

[U25-04] Borderless World of Geoscience after COVID-19 (Challenges for the future)

★Invited Papers

*Yue-Gau Chen[1] (1.Research Center for Environmental Changes, Academia Sinica)

5:09 PM - 5:24 PM JST | 8:09 AM - 8:24 AM UTC

[U25-05] Contribution by JpGU to the future global development of Earth and Planetary Science – by overcoming COVID-19 -

*Hodaka Kawahata[1] (1.Atmosphere Ocean Research Institute, the University of Tokyo)

5:24 PM - 5:30 PM JST | 8:24 AM - 8:30 AM UTC

Discussion

Collaborative, Inclusive, Connected Earth and Space Science for our Future

*Robin E Bell[1]

1. American Geophysical Union

The COVID-19 pandemic has impacted lives and communities around the world, including upending much scientific research. But it has also served to reveal the underlying inequities and institutionalized racism inherent in our health care, economic and other systems.

Unfortunately, the global crisis of human-induced climate change continues unabated and will also have outsized effects on our most vulnerable populations.

In the face of these twin challenges, scientific societies must act, but how? We can foster both discovery-based and solutions-focused science to address massive societal problems. We can build meetings accessible on all seven continents so that we work truly globally to address these planet-wide issues.

We can support programs for STEM students and early career scientists and be more deliberate in fostering diversity and inclusion in the sciences, for we cannot hope to solve the problems of the 21st century without the skills, knowledge, and ideas of all of society. We can expand our partnerships with governments, non-governmental organizations, and companies and collaborate with communities to make our science not just useful but used. And we can act individually and collectively to reduce our contribution to climate change by decreasing our own carbon footprints.

In this time of uncertainty, it is the passionate, generous spirit of the Earth and space science community that will help keep us connected.

Keywords: solutions, community, diversity, society, global, partnerships

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A new mission for the geosciences in an age of pandemics and beyond

*Alberto Montanari[1], Helen Glaves[2]

1. University of Bologna, 2. British Geological Survey, Environmental Science Centre

Geoscience aims to address key environmental challenges that are relevant to society. Some of these challenges, such as climate change, overexploitation of water resources and the water-food-energy nexus, have a global dimension. Recently science at large has been profoundly impacted by COVID-19. The tragedy of coronavirus, with more than 400, 000 deaths to date, is going to broadly change our lifestyle, including research avenues and the way we organize and manage scientific activities. Science will also be pivotal to ensuring a prompt recovery from the pandemic and transforming this crisis into an opportunity. Working for a brighter future is the most appropriate way to honour the memory of those who lost their life. In particular, I believe the expertise of geoscientists can support a synergetic approach to mitigating the risk of global crises. Strategies and actions to support economic recovery of countries during COVID-19 and beyond may also contribute to reducing the hazard and impact of other global threats that geoscientists are currently investigating. To reach this goal, we have to look at our research targets and organize our scientific activities with a new vision. The current crisis has created a window of opportunity to increase public trust in science and improve wider interaction between scientists and policy makers in general. In this talk we will discuss the conditions, strategies and attitude that may help geoscientists to achieve this target.

Keywords: COVID-19, Virtual networking, Geosciences

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A Borderless World of Geoscience in Asia after COVID-19… for Asia and the World

*David Laurence Higgitt[1]

1. Lancaster University College at Beijing Jiaotong University, Weihai, China

Rapid economic growth, massive R&D spending, technological innovation, high participation in STEM postgraduate education and an emerging number of top-ranked universities are characteristic of many Asian countries. The lifetime of AOGS (founded in 2003) has witnessed the rapid expansion of geoscience research in many Asian countries, growing confidence and internationalisation as well as a burgeoning amount of science output. Will the impact of COVID-19 be a road bump in the continuing rise of Asian geosciences or fundamentally adjust the relationships between science and society? The principal mission of Asia Oceania Geosciences Society is to promote the application of geosciences for the benefit of humanity. Asia is a continent of diversity with uneven access to resources between and within countries. In a region where natural hazards are prevalent, sharing an understanding of risk management through scientific, social and technological means is vital. Constraints on fieldwork and travel because of COVD-19 hinder international cooperation but also provide an opportunity for reimagining digital technologies, remote monitoring and adjusted responsibilities in research teams. Coupled with flashpoints of racial inequality how can an inclusive diverse and sustainable geoscience emerge from COVID-19. And (using the tagline for AOGS) how can geoscience in Asia serve Asia and the World?

Keywords: AOGS, Natural Hazards, Inclusivity, Diversity

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Borderless World of Geoscience after COVID-19 (Challenges for the future)

*Yue-Gau Chen[1]

1. Research Center for Environmental Changes, Academia Sinica

Now we are facing the international travel restrain, hindered international exchange of field survey, promotion of non-contact, remote and/or automatic operation technology, open data policy on the submission of experimental data on COVID-19, and other many issues such as health, education, equality, environment and international cooperation related to the infection. After COVID-19, it is highly likely that a new world will emerge without returning to the previous world. The Earth and Planetary Science is essential to the well-being of the humankind and sustainable environments. Therefore the session would like to discuss what kind of the challenges we should do for the future after overcoming the infection

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Contribution by JpGU to the future global development of Earth and Planetary Science –by overcoming COVID-19 -

*Hodaka Kawahata[1]

1. Atmosphere Ocean Research Institute, the University of Tokyo

The origins of the JpGU trace back to joint meetings held by 5 societies concerned with Earth sciences in Japan in 1990, when the first Western Pacific Geophysics Meeting (WPGM) of AGU was held in Kanazawa, shortly after the Japanese Association of Earth and Planetary Science Societies (JAEPSS) was formed. Closer relationship started to develop between AGU and JAEPSS through participation in biennial WPGM meetings. The chemistry of crossing the disciplinary borderlands and national borders seems to have worked to gain support from the communities. We share common cause with AGU in promoting Earth and space science in fundamental ways. And then JpGU was established in the fall of 2005 as the organization to represent all the Societies within Earth and planetary sciences in response to the renovation of the Science Council of Japan. It started as a general juridical person, Japan Geoscience Union on December 1, 2009 and developed to be as a public corporation 2 years later in 2011. In 2017, JaGU and AGU held its first joint Meeting in Chiba. Currently 51 societies with the total member of 13,000 join JpGU and around 8,000 participants attend annual meeting of JpGU at Makuhari Messe, Chiba in May. We aim to promote research activities, provide a platform for communications among the members, coordinate internationally, and reach out to the public by representing earth planetary science societies in Japan. Especially JpGU supports international discussion and exchange that contributes to moving forwards the leading of science and will help invigorate the global Earth and planetary science community.

Investments in Earth and Planetary science research and education have greatly benefited the economic well-being of nations by understanding of distractive environmental hazards, sustainable use of resources, safer and healthier environment for a changing world. Scientists and their partners from many countries has worked together, share ideas and data, which has established the international network of a variety of cultures. This will be vital in confronting the challenges facing humanity and the Earth in the coming years and decades. In particular, Japan is a country prone to various geo-hazards and it is necessary for us to make vital contributions in understanding and overcoming these calamities.

JpGU has concluded MOU with AGU, EGU and AOGS to promote mutual collaboration and exchange in information and co-organization of scientific conferences and to foster mutual cooperation. In addition, policymakers can maximize the positive impacts of Earth and Planetary science for economies, health, sustainability and security around the globe by investing in scientific research. This time JpGU-AGU will have a joint meeting 2020 "For a Borderless World of Geoscience". We firmly believe that the advancement and dissemination of Earth and Planetary science will contribute to the well-being of the humankind and sustainable environments. We will make further global progress through open and transparent scientific collaboration and clear and timely science communication globally.

Due to the global spread of the Corona virus and outbreak of COVID-19, JpGU-AGU 2020 is held as a virtual format using the internet. Even if we overcome the corona infection, we will encounter a new world without getting back where we started from. We would like to highlight some of the science-influenced phenomena caused by COVID-19: the relationship of panedemic infection with science, global cooperation, open science, Society (Economic crises against long-term issues), and Dystopia. We hope that the new corona epidemic will be an opportunity for all human beings to understand that global

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disruption poses a serious danger, as is clear from the case that everyone should cooperate in the development of vaccines.

The Corona virus problem may be a significant opportunity for us to think about current status of our world and future direction.

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[E] Oral | U (Union)：Union

Tue. Jul 14, 2020 10:45 AM - 12:15 PM JST | Tue. Jul 14, 2020 1:45 AM - 3:15 AM UTC | Ch.1

[U-02] Assessment and Accountability of Scientific Knowledge Creation

convener:Michiyo SHIMAMURA(Japan Agency for Marine-Earth Science and Technology), Yasuhiro Yamanaka(Faculty of Environmental Earth Science, Hokkaido University), Kiyoshi Suyehiro(Japan Agency for Marine-Earth Science and Technology), Brooks Hanson(American Geophysical Union), Chairperson:Michiyo SHIMAMURA(Japan Agency for Marine-Earth Science and Technology)

Scientific indices such as the number of citations or impact factor have been widely adopted in Japan and elsewhere to gauge scientific outputs without sufficient deliberations on their relationships to the true value of science and researchers' efforts or the harm and perverse incentives that result. If such disconnect exists, overreliance to these indices may lead to biases in research including in aiming for shorter-term goals. They are often requested by the solution-seeking stakeholders as well.

In the field of geoscience, a wide latitude of research styles exists and forms our community, from a focus on urgent societal needs to intellectual curiosity about our Earth. Such characteristics vary among fields making general comparisons across fields not straightforward. The adoption of simple evaluation indices as above may hinder the truly useful assessment of research. This trend influences gravely the research environment and thus the behavior of early-career researchers. What is the right direction for science and how should science be assessed?

In this session, we invite the members of the geoscience research community to discuss "ideal" science, recognize its diversity and identify the needs for changes. We welcome reports from different parts of the world and novel ideas to evaluate our own research activities that may lead to creating a culture that fulfills accountability to society. We envision this session to have infuse lively discussion and invite the audience to interactive exchanges.

10:45 AM - 10:50 AM JST | 1:45 AM - 1:50 AM UTC

Introduction

10:50 AM - 11:10 AM JST | 1:50 AM - 2:10 AM UTC

[U02-01] Research Evaluation in Japan: Basic and Solution-Oriented Science, Their Perceptions and Realities, and a Future Vision

★Invited Papers

*Tateo Arimoto[1] (1.Japan Science and Technology Agency)

11:10 AM - 11:30 AM JST | 2:10 AM - 2:30 AM UTC

[U02-02] The Critical Importance of Earth and Space Science, Public Perceptions, Global Funding, and What Societies and the Global ESS Community Can Do

★Invited Papers

Robin Elizabeth Bell[2], *Brooks Hanson[1] (1.American Geophysical Union, 2.Lamont-Doherty Earth Observatory of Columbia University)

11:30 AM - 12:15 PM JST | 2:30 AM - 3:15 AM UTC

[U02-03] Panel Discussion of the Session

*Michiyo SHIMAMURA[1], Yasuhiro Yamanaka[2], Kiyoshi Suyehiro[1], Brooks Hanson[3] (1.Japan Agency for Marine-Earth Science and Technology, 2.Hokkaido University, 3.AGU)

Research Evaluation in Japan: Basic and Solution-Oriented Science, Their Perceptions and Realities, and a Future Vision

*Tateo Arimoto[1]

1. Japan Science and Technology Agency

The research evaluation has been changing with the society in Japan. In this presentation, the value of the basic scientific research in the face of societal expectations and requirements, and its historical developments are overviewed, followed by a future perspective in the changing global landscape of science and technology.

Keywords: Basic Science, Solution-Oriented Science, Research Evaluation

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The Critical Importance of Earth and Space Science, Public Perceptions, Global Funding, and What Societies and the Global ESS Community Can Do

Robin Elizabeth Bell[2], *Brooks Hanson[1]

1. American Geophysical Union, 2. Lamont-Doherty Earth Observatory of Columbia University

Earth and Space Science is the critical science for the 21st Century. Nearly all major challenges we are facing locally to globally depend on robust Earth and space science and its convergence with other sciences—from addressing climate change and converting from fossil fuels, to feeding a world population that may reach 10 billion, to addressing health issues including clean air and water, to managing other resources on the Earth sustainably, to mitigating natural hazards. And all parts of our science are engaged in some way with these challenges and thus need to be nurtured, including for their curiosity. Public perception and awareness of these issues are growing, but larger, real engagement with the public is needed at all scales. In the U.S., the latest budget proposal would cut support for the sciences while these needs grow, and increased nationalism worldwide, which has also seen signs of expanding, is a persistent threat. AGU and other societies have a key role to play in leading and helping the global scientific community address both the core science and these important scientific and societal challenges. AGU has just developed a new strategic plan reflecting this awareness, based on broad input from the community, and we must as a community think of, develop, and leverage new connections with partners and the global public and policy makers and increase and scale up already successful efforts.

Keywords: Grand challenges, Scientific societies, Funding

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Panel Discussion of the Session

*Michiyo SHIMAMURA[1], Yasuhiro Yamanaka[2], Kiyoshi Suyehiro[1], Brooks Hanson[3]

1. Japan Agency for Marine-Earth Science and Technology, 2. Hokkaido University, 3. AGU

This session will be consisted from presesntations of invited speakers and panel discussion. Invited speakers and Ms. Nobuko Miyairi who is the ex president of ORCID Asia-Pacific, and Prof. Hodaka Kawahata who is the presiden of JpGU will make a active discussion with the floor participants based on questioner.

Keywords: Panel Discussion, Questioner

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[E] Oral | U (Union)：Union

Tue. Jul 14, 2020 9:00 AM - 10:30 AM JST | Tue. Jul 14, 2020 12:00 AM - 1:30 AM UTC | Ch.2

[U-15] Open Colloquium-NASA/JAXA: Earth Science focusing on Climate Change

convener:Yamaji Moeka(Japan Aerospace Exploration Agency), Kosuke Yamamoto(Japan Aerospace Exploration Agency), Paula S Bontempi(NASA Headquarters), Sandra Alba Cauffman(NASA Headquarters), Chairperson:Riko Oki(Japan Aerospace Exploration Agency), Sandra Alba Cauffman(NASA Headquarters), Paula S Bontempi(NASA Headquarters), Yamaji Moeka(Japan Aerospace Exploration Agency), Kosuke Yamamoto(Japan Aerospace Exploration Agency)

Climate Change brings us serious impacts in the form of droughts and floods in recent years. It is quite important to understand the nature of the Earth to evaluate and manage our limited resources. Spaceborne observations have provided fundamental information to understand the large-scale Earth environment.
In this session, we will introduce recent achievements and discuss future collaborations with researchers who play a central role in these fields from the U.S. and Japan, focusing on two of the key topics with respect to the Climate Change. One is "to what extent and where are gases causing Global Warming emitted?". The achievement by monitoring Green House Gases (GHGs) using OCO series by NASA and GOSAT series by JAXA will be presented. The other topic is "how can we predict more realistic impacts by the Climate Change?". One of the most uncertain factors in numerical prediction models is related to water cycles, such as aerosol-cloud-precipitation interactions. To better understand this topic, NASA and JAXA have jointly developed and operated the Global Precipitation Measurement (GPM) Mission following the successes of the Tropical Rainfall Measuring Mission (TRMM). Recently, NASA and JAXA have started the collaboration in a new mission called Aerosol, Cloud, Convection and Precipitation (ACCP). Status of the GPM and ACCP missions will be presented and discussed.

9:00 AM - 9:05 AM JST | 12:00 AM - 12:05 AM UTC

Introduction

9:05 AM - 9:25 AM JST | 12:05 AM - 12:25 AM UTC

[U15-01] Past, Current and Future NASA-JAXA Partnership in Earth System Observations from Space

★Invited Papers

*Arlindo da SIlva[1] (1.NASA Goddard Space Flight Center)

9:25 AM - 9:45 AM JST | 12:25 AM - 12:45 AM UTC

[U15-02] US-Japan collaboration toward accurate flux estimation of greenhouse gases from space: Intercomparison between US OCO and Japanese GOSAT

★Invited Papers

*Akihiko Kuze[1], David Crisp[2], Carol Bruegge[2], Laura Iraci[3], Florian Schwandner[3], Fumie Kataoka[4], Kei Shiomi[1], Nobuhiro Kikuchi[1], Hiroshi Suto[1] (1.Japan Aerospace Exploration Agency, 2.JPL CALTECH, 3.NASA AMES, 4.RESTEC)

9:45 AM - 10:05 AM JST | 12:45 AM - 1:05 AM UTC

[U15-03] JAXA-NASA collaborations toward a better understanding of the global water and energy cycle: From TRMM and GPM to ACCP

★Invited Papers

*Hirohiko Masunaga[1], Riko Oki[2], Moeka Yamaji[2], Kosuke Yamamoto[2] (1.Nagoya University, 2.Japan Aerospace Exploration Agency (JAXA))

10:05 AM - 10:30 AM JST | 1:05 AM - 1:30 AM UTC

[U15-04] Open Discussion

★Invited Papers

*Yamaji Moeka[1] (1.Japan Aerospace Exploration Agency)

Past, Current and Future NASA-JAXA Partnership in Earth System Observations from Space

*Arlindo da SIlva[1]

1. NASA Goddard Space Flight Center

NASA and JAXA have enjoyed a long standing partnership in earth observations from space. In this talk we will present science highlights from current and past key US-Japan joint endeavors such as AMSER-E/AMSR-2 on EOS platforms, carbon science missions (OCO-2/OCO-3/GOSAT/GOSAT-2), and the precipitation missions (TRMM, GPM). Going forward, the 2017 Decadal Survey (DS) highlighted Earth System Science themes, science and application questions, and several high priority objectives that have led to the inclusion of Aerosols (A) and Clouds-Convection-Precipitation (CCP) as *Designated Observables* (DOs). On July 17, 2018, several NASA centers (GSFC, LaRC, JPL, MSFC, GRC and ARC) submitted a joint Study Plan to the NASA Earth Science Division for the Aerosol (A) and Cloud, Convection, and Precipitation (CCP) Pre-formulation Study (A-CCP). In addition to NASA centers, ACCP includes strong international partnership with JAXA playing an important role on active remote sensing from space. We will conclude the presentation with a brief overview of the ACCP and the opportunities it offers for continued US-Japan collaboration.

Keywords: earth observations, nasa, jaxa

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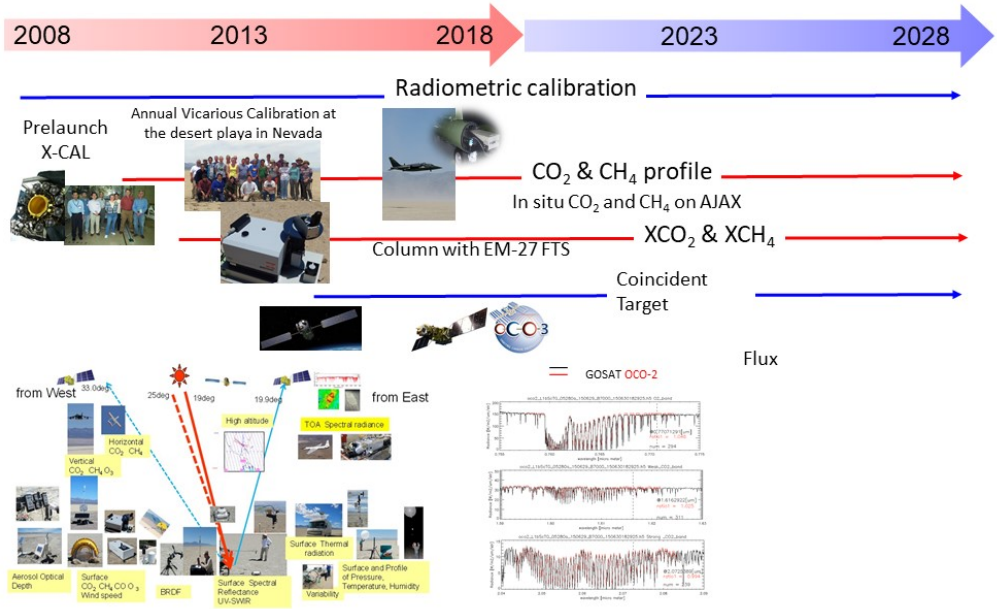
US-Japan collaboration toward accurate flux estimation of greenhouse gases from space: Intercomparison between US OCO and Japanese GOSAT

*Akihiko Kuze[1], David Crisp[2], Carol Bruegge[2], Laura Iraci[3], Florian Schwandner[3], Fumie Kataoka[4], Kei Shiomi[1], Nobuhiro Kikuchi[1], Hiroshi Suto[1]

1. Japan Aerospace Exploration Agency, 2. JPL CALTECH, 3. NASA AMES, 4. RESTEC

Since the beginning of OCO and GOSAT programs, US and Japan has been collaborating to demonstrate the effectiveness of greenhouse gases monitoring from space. Before OCO and GOSAT launch, we exchanged our radiometric standards to calibrate to calibrate OCO and GOSAT integrating spheres at the JPL and JAXA calibration laboratories in 2008. Since GOSAT launch in 2009, every summer near summer solstice, both teams have worked together in vicarious calibration campaigns at the Railroad Valley (RRV) playa. This field campaign has been improved by adding validation such as coincident spiral flight by NASA Alpha Jet and portable ground-based FTS. After OCO-2 launch, radiance spectra measured and CO_2 column amount retrieved from two independent measurements can now be compared. These data agree well within measurement uncertainties for both land and ocean. Our mission is to estimate anthropogenic emissions from different source sectors using satellite data. We will present our challenges how to validation global and local flux.

Keywords: GOSAT, OCO, intercomparison



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JAXA-NASA collaborations toward a better understanding of the global water and energy cycle: From TRMM and GPM to ACCP

*Hirohiko Masunaga[1], Riko Oki[2], Moeka Yamaji[2], Kosuke Yamamoto[2]

1. Nagoya University, 2. Japan Aerospace Exploration Agency (JAXA)

The Tropical Rainfall Measuring Mission (TRMM) was a joint US-Japan mission marking a milestone in the history of rainfall measurement from space. The TRMM satellite was launched in late 1997, carrying the Precipitation Radar, the first spaceborne radar to measure precipitation, provided by JAXA and other instruments including the TRMM Microwave Imager (TMI) by NASA. Unprecedented 17-year observations from the TRMM PR and TMI substantially updated our knowledge of tropical and mid-latitude rainfall and opened new pathways for the practical applications including numerical weather forecast and disaster prevention. The Global Measurement Mission (GPM) core observatory, with its operation started in 2014, has expanded the TRMM observational capability in many ways, for instance, the enhanced detectability of solid precipitation by the Dual-frequency Precipitation Radar (DPR) over a latitudinal coverage extended to 65˚S/N. A multi-satellite precipitation data product or the Global Satellite Mapping of Precipitation (GSMaP), developed as a part of the JAXA GPM program, is exploited for broad applications, most notably in aid of the infrastructure development and protection in the Asia-Pacific countries.

Meanwhile, the blueprint of new satellite missions is being developed in a NASA-led initiative called the Aerosol, Cloud, Convection, and Precipitation (ACCP). The ACCP teams are looking into a range of possibilities in the satellite instrumentation optimal for advancing our understanding of the physical processes involved in the atmospheric water and energy cycle. The science goals of ACCP are highly multi-disciplinary, bridging the gap among past and current satellite programs such as TRMM, GPM, CloudSat, and CALIPSO. JAXA has been working with their science team to discuss a next-generation spaceborne precipitation radar with enhanced (e.g., Doppler) capabilities, whose unique potential is being renewed in light of the scientific and technological demands of ACCP. In this talk, we will present selected scientific achievements from recent satellite observations and discuss the new horizon of scientific knowledge expected to be opened by ACCP.

Keywords: Satellite Remote Sensing, Climate Change

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Open Discussion

*Yamaji Moeka[1]

1. Japan Aerospace Exploration Agency

The Climate Change brings us serious impacts in the form of droughts and floods in recent years. It is quite important to understand the nature of the Earth to evaluate and manage our limited resources. Spaceborne observations have provided a fundamental information to understand large-scale Earth environment.

In this session, we will introduce the recent achievements and discuss the future collaborations with researchers who play a central role in this fields from the U.S. and Japan, focusing on two of the key topics with respect to the Climate Change. One is “how much is the substance causing the Global Warming emitted?”. The achievement by monitoring Green House Gases (GHGs) using OCO series by NASA and GOSAT series by JAXA will be presented. The other topic is “how can we predict more realistic impact by the Climate Change?”. One of the most uncertain factors in numerical prediction models is related to water cycles, such as aerosol-cloud-precipitation interactions. Toward the better understanding of this topic, NASA and JAXA have jointly developed and operated Global Precipitation Measurement (GPM) Mission following the successes of Tropical Rainfall Measuring Mission (TRMM). Recently, NASA and JAXA has started the collaboration in the new mission called Aerosols, Clouds, Convections and Precipitation (ACCP). Status of the GPM and ACCP will be presented and discussed.

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[E] Oral | U (Union)：Union

Tue. Jul 14, 2020 10:45 AM - 12:15 PM JST | Tue. Jul 14, 2020 1:45 AM - 3:15 AM UTC | Ch.2

[U-19] A deep dive into planetary habitability as related to subsurface architecture, energy, and water.

convener:Graham Heather Valeah, Vlada Stamenkovic(Jet Propulsion Laboratory), Shino Suzuki(Japan Agency for Marine-Earth Science and Technology), Atsuko Kobayashi(Earth-Life Science Institute), Chairperson: Heather Valeah

Investigations of the three-dimensional structure of the Earth and other planetary bodies are transforming our understanding of the distribution and age of water, fluxes of elements like carbon in and out of the subsurface, character and density of energy and the nature of habitability and its limits. We are poised to frame the important fundamental questions concerning the complexities of chemical, physical, and biological interactions in the Earth's subsurface, and by inference planetary bodies like Mars and Europa. This session considers questions related to the subsurface architecture of planets by exploring geophysical and geochemical results from experiments and observations in deep mines and boreholes as well as modeling efforts. This session addresses the nature and diversity of crustal subsurface environments and our understanding of how the subsurface changes with geographic location and depth. this could encompass studies on the variability and cycling of carbon, water, and subsurface volatiles including brines, ices, clathrates, salts, methane, and oxidants. Of particular interest are studies related to the physical and chemical controls on planetary subsurface architecture that determines the storage, transport, and interaction of fluids and gases in the interiors of Earth and other moons and planets. We also invite contributions on models of the novel subsurface energy systems required to sustain life as well as studies exploring the origin, evolution, and dispersal of subsurface life (microbial, viral, and multicellular) as compared with the surface biosphere. We welcome abstracts that consider the potential for extant life in subsurface conditions as well as the preservation of biosignatures

10:45 AM - 11:00 AM JST | 1:45 AM - 2:00 AM UTC

[U19-01] Recurring slope lineae on Earth: Implications for hydrological cycles and potential habitability on Mars

★Invited Papers

*Yasuhito Sekine[1], Maya Nakamura[1], Davaasuren Davaadorj[2], Daigo Shoji[1], Koki Morida[3], Keisuke Fukushi[3], Noriko Hasebe[3], Shawn E McGlynn[1] (1.Tokyo Institute of Technology, 2.National University of Mongolia, 3.Kanazawa University)

11:00 AM - 11:15 AM JST | 2:00 AM - 2:15 AM UTC

[U19-02] **Prospects for Subsurface Energy, Water, and Life on Mars**

★Invited Papers

*Joseph Michalski[1,2] (1.Division of Earth and Planetary Science, University of Hong Kong, Hong Kong, 2.CIFAR, Toronto, Canada)

11:15 AM - 11:30 AM JST | 2:15 AM - 2:30 AM UTC

[U19-03] Life on serpentinized setting on the Earth and beyond

★Invited Papers

*Shino Suzuki[1] (1.Japan Agency for Marine-Earth Science and Technology)

11:30 AM - 11:45 AM JST | 2:30 AM - 2:45 AM UTC

[U19-04] Subseafloor biosphere in the ancient Earth: constraint from multiple S isotopes records

★Invited Papers

*Aoyama Shinnosuke[1] (1.Yokohama National University)

11:45 AM - 12:00 PM JST | 2:45 AM - 3:00 AM UTC

[U19-05] **International Center for Deep Life Investigation: A global platform for the entire deep life community**

★Invited Papers

*FengPing Wang[1,2] (1.School of Oceanography, Shanghai Jiao Tong University, Shanghai, China, 2.State Key Laboratory of Microbial Metabolism, School of Life Sciences and Biotechnology, Shanghai JiaoTong University, Shanghai, China)

12:00 PM - 12:15 PM JST | 3:00 AM - 3:15 AM UTC

[U19-06] Opportunities and Exploration: A Panel Discussion on Planetary Subsurface Science

*Heather Valeah Graham[1], Vlada Stamenkovic[2], Shino Suzuki[3], Ken Takai[3], Tomohiro Usui[4] (1.NASA Goddard Space Flight Center, 2.NASA Jet Propulsion Laboratory, 3.Japan Agency for Marine-Earth Science and Technology, 4.Japan Aerospace Exploration Agency)

Recurring slope lineae on Earth: Implications for hydrological cycles and potential habitability on Mars

*Yasuhito Sekine[1], Maya Nakamura[1], Davaasuren Davaadorj[2], Daigo Shoji[1], Koki Morida[3], Keisuke Fukushi[3], Noriko Hasebe[3], Shawn E McGlynn[1]

1. Tokyo Institute of Technology, 2. National University of Mongolia, 3. Kanazawa University

Knowledge on dynamics and cycles of water on present-day Mars is central to understand the surface environments and habitability of this planet. The present study focuses on recurring slope lineae (RSL). Recurring slope lineae are dark, narrow features that appear on steep slopes in warm seasons and fade in cold seasons. Although the formation mechanism of RSL remains in debate, RSL could provide unique insights into dynamics and cycles of water on Mars. Unlike the previous studies that analyzed remote sensing data of RSL, the present study constrains the formation mechanism of RSL based on search, classification, and field survey of terrestrial RSL analogues. Based on the investigations of the terrestrial RSL analogues, we aim to constrain the dynamics and cycles of water on Mars.
We first search for terrestrial RSL analogues in a global scale using available satellite images. We first discover twelve RSL analogues, which exhibit similar morphological features to Martian RSL, in cold and (semi-)arid areas on Earth. These analogues are classified into three types (types A, B, and C) based on their morphological characteristics. We then conduct the field survey for these terrestrial RSL analogues near the Khangai mountains in Mongolia, where all type of the terrestrial RSL analogues appears. We find that the type-A RSL analogue is formed by exposure of dark soil through removal of surface bright sand grains due to transient surface runoff in warm seasons. The type-B RSL analogue is generated by continuous surface runoff possibly due to melting of subsurface ice in warm seasons. The type-C RSL analogue is formed due to physical weathering of bedrocks on the slopes. We suggest that the type-A RSL analogue can explain all of the characteristics of Martian RSL, including the absence of infrared absorption due to liquid water on RSL and their appearance on steep slopes. To form type-A RSL on Mars, transient surface runoff with high flow velocity needs to occur in warm seasons. Based on modeling of upwelling groundwater from aquifer through rock fractures, we suggest that such surface runoff can occur if aquifer is located at ~500 m below the surface or deeper with a volume less than ~10^4 m^3. This suggests that RSL would be supported by a small, localized water source, rather than a large, global-scale groundwater source. RSL sites could be a potential habitat for chemo-autotrophic microbial life. Our results of microbial community structure analysis for terrestrial RSL analogue suggest that chemoautotrophic methanotroph could exist in the RSL sites. The measured number density of methanotroph in the terrestrial RSL analogue in warm seasons is detectable using existing life-detection techniques for Mars missions. Recurring slope lineae could be a promising target for landing in future missions to find extraterrestrial life.

Keywords: Mars, hydrological cycles, space mission

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Prospects for Subsurface Energy, Water, and Life on Mars

*Joseph Michalski[1,2]

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From the perspective of a terrestrial geologist, Mars is a planet with familiar features including polar caps, glaciers, volcanoes, and a vast sedimentary rock record, as well as dried river beds, ancient lake basins, and evidence for long lost seas. Given the richness of the geologic record exposed to remote sensing instruments, it is easy to focus our attention and exploration efforts on that 2D surface world. But, small glimpses of subsurface materials and environments in terrains exhumed by impact craters, in addition to theoretical models and simple deductive geologic work all point to a vast and perhaps more intriguing subsurface environment on Mars. The upper (~10 km of) crust is likely composed of relatively porous volcaniclastic and impactite rocks and, because of the planet's lower surface gravity (38% of Earth's), a large amount of pore volume probably exists to much greater depth than occurs on Earth. This vast, 3D subsurface environment contains subsurface water and ice, and would have been (or still is) an excellent environment for the interaction between reactive rocks with various types of fluids, both containing various nutrients and possibilities for energy sources to drive a subsurface biosphere. In fact, the subsurface environment has probably always been the most habitable part of Mars since the magnetic field shut off c.a. 4.1 billion years ago, exposing the surface to an intense batch of UV radiation, solar energetic particles and cosmic rays. Life may have never had the chance to get started at the Martian surface and if it did, it might have retreated necessarily to the subsurface environment. It is not unreasonable to suggest that microbial life could survive or thrive there even today. But the subsurface is not critical for microbial life only –it could be the key to human exploration as well. When humans colonize Mars, we will require many natural resources, chief among them H_2O. One of the driving factors for planning future human missions is proximity to water resources in 3D space. Surface water resources are too high latitude (i.e. the poles), but subsurface ice exists to much lower latitudes. In addition, hydrated rocks in the shallow crust (e.g. hydrous sulfates, clays and carbonates) could provide huge amounts of extractable water. A key element of future mission planning will be resolving how to choose a site for major exploration build-up in a location that meets the requirements for resource extraction, but also honors the most inspiring science agenda possible.

Keywords: Deep Biosphere, Subsurface Life, Mars

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Life on serpentinized setting on the Earth and beyond

*Shino Suzuki[1]

1. Japan Agency for Marine-Earth Science and Technology

Almost all the microbial ecosystems on present-day Earth are supported by photosynthesis including the subsurface biosphere. Organic carbons from the photosynthesis have been accumurated and delivered into the deep subsurface ecosystem. Oxygen and oxidative compounds also have distributed everywhere on the Earth through the water and contributed to creating chemical gradients that can support microbial energy metabolisms. Therefore, opportunities are rare to address microbial ecosystems that are isolated from the effects of photosynthesis, but those are canceled in several settings, one of which includes a serpentinized ecosystem.

Serpentinization is a process whereby water interacts with reduced mantle rock called peridotite to produce a new suite of minerals (e.g., serpentine), a highly alkaline fluid, and hydrogen. The hydrogen and carbon dioxide present in the system are thought to react under the highly reducing and alkaline conditions, leading to the formation of methane and hydrocarbons and the concomitant production of carbon monoxide, formate, formaldehyde and methanol. Given that the reduced compounds delivered from the water-rock reaction can support microbial energy metabolisms, such serpentinization systems have been viewed as potential habitats for early life or the other planetary bodies.

Studies of serpentinizing environments to date have shown that these ecosystems host extremely low-abundance microbial communities, which is presumably attributed to the multiple extremes: 1) the highly-alkaline condition of the fluid; 2) the extremely low concentrations of oxidants (electron acceptors); and, 3) the low levels of and nutrients (available carbon and phosphate). The Cedars located in northern California is one of the active terrestrial serpentinization sites. While there are about a hundred of springs in The Cedars area with a variety of differences in geochemistry (Figure 1), spring waters discharged from The Cedars generally have extremely high pH (11-12), very low Eh (−900 mV - −550 mV) values and are rich in Ca^{2+} (~1 mM), hydrogen and methane gas, and contain low levels of dissolved organic carbon, total inorganic carbon, ammonium, phosphate and electron acceptors (oxygen, nitrate, sulfate)
Here I present a diversity of unusual metabolisms and life strategies seen in the early Earth or other planetary bodies' analogue sites, those of which have been identified through the studies of geochemistry, microbial cultivation, genome centric metagenomics of The Cedars microbial communities. Furthermore, I discuss the constraints and driving forces lying in the deep subsurface serpentinized settings to make a living.

Keywords: serpentinization, microbial ecosystem, astrobiology

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Subseafloor biosphere in the ancient Earth: constraint from multiple S isotopes records

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Subseafloor environment linked to hydrothermal systems has been proposed as the cradle of life, though the ancient activity of the subseafloor biosphere is poorly understood. Furnes et al., (2004) reported micrometer-scale mineralized tubes in ca. 3.5 Ga pillow lava rims from the Barberton Greenstone Belt, South Africa, which putatively trace microbial activity below Archean seafloor. However, these textures may also originate from metamorphic processes; thus, their microbial origin is still being debated (e.g., Lepot et al., 2011). Moreover, the putative microbial textures may have been produced on the seafloor. Therefore, such structure may not be useful for the subseafloor biosphere.
Microbial sulfate reduction (MSR) is a metabolism in which sulfate is reduced into sulfide and among the most ubiquitous metabolic processes on earth. Traditionally the activity of MSR was detected by sulfur isotopes (delta-S-34) because MSR is characterized by large sulfur isotopic fractionation up to −65‰ (Sim et al., 2011). Microbial cultivation studies reported not only the traditional delta-S-34 but also minor sulfur isotopes (capital-delta-S-33&36) are useful for MSR (e.g., Johnston et al., 2007). The oldest activity of MSR was evidenced by multiple sulfur isotopes of sulfate and sulfide minerals deposited on the ancient seafloor from ca. 3.5 Ga Dresser Formation in the North Pole area of Pilbara Craton in Western Australia (Ueno et al., 2008).
To verify the activity of MSR below the ancient seafloor, multiple sulfur isotopic compositions of sulfide minerals within hydrothermally altered seafloor basalt and basaltic komatiite collected from the ca. 3.5 Ga North Pole area were analyzed. The results suggested (1) capital-delta-S-33 values of the sulfide minerals were non-zero negative, demonstrating that sulfate reduction occurred below the Archean seafloor, (2) sulfate below seafloor before reduction was different from seafloor sulfate (i.e., barite deposit), and more rich in a mass-dependent component which was probably produced by local hydrothermal processes and (3) The maximum delta-S-34 fractionation between the putative substrate sulfate and the observed sulfide minerals was −35‰, suggesting MSR was involved below ca. 3.5 Ga seafloor. In this case, MSR may have occurred ~1000 meters below the Archean seafloor based on the geologically reconstructed depth below seafloor.

Keywords: Subseafloor biosphere, Archean, microbial sulfate reduction, multiple sulfur isotopes

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International Center for Deep Life Investigation: A global platform for the entire deep life community

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Life persists and thrives in the dark subsurface of the Earth in the absence of surface light energy. More than 50 years of investigations on the so-called “Deep Life” (or the “deep biosphere”) has revolutionized various aspects of our understanding of life and its origin and evolution. Still, large research gaps remain, e.g. what are the fundamental mechanisms of deep life persisting and evolving in the low-energy environments? What are the relationship and Interaction of deep life with the surface life and the environment? What are the ecological fundamentals governing the origin, distribution, and dispersal of the deep life? Aiming to resolve these large research questions through international joint efforts, the Deep Life community announced the inauguration of the **I**nternational **C**enter for **D**eep **L**ife **I**nvestigation (**IC-DLI**) on October 2018 (https://icdli.sjtu.edu.cn/). The **IC-DLI** will seek domestic and international funding resources to assist researchers to organize projects related to Deep Life within the scope of the Deep Carbon Research beyond 2020. The **IC-DLI** is an open platform that welcomes constructive ideas and suggestions that will lead to a world-class hub for Deep Life investigators from around the world.

Keywords: deep life, extremophiles, subsurface, low energy, life limit, high pressure

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Opportunities and Exploration: A Panel Discussion on Planetary Subsurface Science

*Heather Valeah Graham[1], Vlada Stamenkovic[2], Shino Suzuki[3], Ken Takai[3], Tomohiro Usui[4]

1. NASA Goddard Space Flight Center, 2. NASA Jet Propulsion Laboratory, 3. Japan Agency for Marine-Earth Science and Technology, 4. Japan Aerospace Exploration Agency

Investigations of the three-dimensional structure of the Earth and other planetary bodies are transforming our understanding of the distribution and age of water, fluxes of elements like carbon in and out of the subsurface, character and density of energy and the nature of habitability and its limits. We are poised to frame the important fundamental questions concerning the complexities of chemical, physical and biological interactions in the Earth’ s subsurface, and by inference planetary bodies like Mars and Europa. This panel seeks to explore questions related to the subsurface architecture of planets by exploring geophysical and geochemical results from experiments and observations in deep mines and boreholes as well as modeling efforts. This panel discussion addresses the nature and diversity of crustal subsurface environments and our understanding of how the subsurface changes with geographic location and depth. This cencompasses studies on the variability and cycling of carbon, water, and subsurface volatiles including brines, ices, clathrates, salts, methane, and oxidants. Our panel will also discuss studies related to the physical and chemical controls on planetary subsurface architecture that determines the storage, transport, and interaction of fluids and gases in the interiors of Earth and other moons and planets.

Keywords: subsurface exploration, planetary science, astrobiology

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[E] Oral | U (Union)：Union

Tue. Jul 14, 2020 2:15 PM - 3:45 PM JST | Tue. Jul 14, 2020 5:15 AM - 6:45 AM UTC | Ch.2

[U-20] "Open Colloquium" Exploring the Earth's interior using cutting edge science and technology

convener:Hiroko Watanabe(Research Center for Neutrino Science, Tohoku University), William F McDonough(Department of Earth Science and Research Center for Neutrino Science, Tohoku University, Sendai, Miyagi 980-8578, Japan), Kenta Ueki(Japan Agency for Marine-Earth Science and Technology), Eiichiro Araki(Japan Agency for Marine-Earth Science and Technology), Chairperson:Hiroko Watanabe(Research Center for Neutrino Science, Tohoku University)

New advances in technology are being used to explore the Earth. These include, but are not restricted to, neutrino geophysics, drilling the deep oceanic biosphere, and drilling to the Moho. Application of these new technologies to studies of the Earth provide critical new constraints and hopefully, new and unimagined insights. Recent technological advances, as well as advances in experimental and theoretical studies are revealing clues of how the Earth operates at a wide range of scales (microns to mega-meters). We seek to understand links from the core to atmosphere that connects the biosphere and geosphere through time. Near-future exploration of the Earth's interior with these new technologies will provide much-needed data on the internal structure of our planet and potentially its habitability. We anticipate presentations on recent advances in science and technologies that provide insights into physical, chemical, and biological processes and structures on and in the Earth. We welcome contributions from science and engineering.

2:15 PM - 2:30 PM JST | 5:15 AM - 5:30 AM UTC

[U20-01] Undestanding the Earth's deep interior with geo-neutrino measurements

★Invited Papers

*Hiroko Watanabe[1] (1.Research Center for Neutrino Science, Tohoku University)

2:30 PM - 2:45 PM JST | 5:30 AM - 5:45 AM UTC

[U20-02] Deep seafloor cable observation technologies towards future ocean bottom neutrino detector experiment.

★Invited Papers

*Eiichiro Araki[1], Taichi Sakai[2], Hiroko Watanabe[2], Takashi Yokobiki[1] (1.Japan Agency for Marine-Earth Science and Technology, 2.RCNS, Tohoku Univ.)

2:45 PM - 3:00 PM JST | 5:45 AM - 6:00 AM UTC

[U20-03] Direct sampling and measurement at deep crust through scientific ocean drilling

★Invited Papers

*Shin'ichi Kuramoto[1] (1.Japan Agency for Marine-Earth Science and Technology)

3:00 PM - 3:15 PM JST | 6:00 AM - 6:15 AM UTC

[U20-04] Hadean geodynamo origin and Ediacaran inner core growth preserved Earth’s habitability

★Invited Papers

*John Anthony Tarduno[1,2], Rory D Cottrell[1], Francis Nimmo[3], Hirokuni Oda[4], Axel Hofmann[5] (1.University of Rochester, Department of Earth and Environmental Sciences, Rochester, New York, United States, 2.University of Rochester, Department of Physics and Astronomy, Rochester, New York, United States, 3.University of California – Santa Cruz, Department of Earth and Planetary Sciences, Santa Cruz, California, United States, 4.National Institute of Advanced Science and Technology, Geological Survey of Japan, Tsukuba, Ibaraki, 305-8567, Japan, 5.University of Johannesburg, Department of Geology, Johannesburg, South Africa)

3:15 PM - 3:30 PM JST | 6:15 AM - 6:30 AM UTC

[U20-05] Earth's deep interior revealed by high-pressure experiments

★Invited Papers

*Kei Hirose[1,2] (1.Earth-Life Science Institute, Tokyo Institute of Technology, 2.Dept. Earth and Planetary Science, The University of Tokyo)

3:30 PM - 3:45 PM JST | 6:30 AM - 6:45 AM UTC

[U20-06] **Imaging subducted slabs in the mantle through inversion of seismic waveforms**

★Invited Papers

*Kenji Kawai[1], Anselme F. E. Borgeaud[1,2], Yuki Suzuki[1], Robert J. Geller[1] (1.Department of Earth and Planetary Science, School of Science, University of Tokyo, 2.Academia Sinica)

Undestanding the Earth's deep interior with geo-neutrino measurements

*Hiroko Watanabe[1]

1. Research Center for Neutrino Science, Tohoku University

Anti-neutrinos emitted from radioactive isotopes inside the Earth, geo-neutrinos, bring unique and direct information on the Earth’s composition, which relate to the fundamental mysteries of its heat balance and thermal evolution. KamLAND has been stably observing geo-neutrinos with highest sensitivity since it made the world’s first observation in 2005. Understanding of the Earth using geo-neutrinos is a research field that is originally started and has been led by Japan. To date, we have set limits on the global flux of geo-neutrino that has in turned constrained the range of acceptable models for the Earth’s composition, but distinguishing the mantle flux by current detectors, which are all locate on the crust is a challenge, as the crust signal is about 70 % of the total flux plus uncertainties. Given that the oceanic crust is thin and simple, geo-neutrino detector in the ocean makes it sensitive to geo-neutrinos originating from Earth’s mantle. Ocean bottom geoneutrino detector represents a breakthrough, which goes beyond the impossibilities of the modern land-based detector, providing transformative insights into the deep Earth. In this presentation, current situation and future prospects of experimental studies will be dicscussed.

Keywords: geo-neutrinos, understanding Earth's deep interior, Radiogenic heat in mantle

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Deep seafloor cable observation technologies towards future ocean bottom neutrino detector experiment.

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1. Japan Agency for Marine-Earth Science and Technology, 2. RCNS, Tohoku Univ.

Long-term neutrino observation at the bottom of deep ocean will open the window to investigate the neutrino source in deep earth’ s interior by escaping from the effect of sources in continental crust and those from anti-neutrinos from reactors. Ocean Bottom neutrino Detector (OBD) was first conceived in University of Hawaii to realize such a geoneutrino observation in the ocean floor in 2005, though only conceptual study and preliminary tests were conducted, and its feasibility is yet remain very uncertain. We now formed a joint research group with collaborators with background of deep seafloor cabled observation network development (such as off-Japan coast DONET seafloor cabled network for earthquake and Tsunami monitoring) and geoneutrino detector in Kamioka (KamLAND), trying to establish a new OBD concept and put it into practice in the future.
From our initial preliminary study of new OBD concept, three stage plans are suggested to develop matured scientific ocean bottom detector with scintillator volume of 10-50 k tons as the third and final stage. The first step is 1-10 tons OBD to demonstrate element technologies for OBD systems. The second stage 1.5 k tons OBD is aiming the first detector to achieve estimation of mantle geo-neutrinos from 3 years observation expecting 8.5 geo-neutrino events a year.
To facilitate long-term multi-year continuous observation in near the deep seafloor, necessitated from the small number of the mantle geo-neutrino events a year, we consider a seafloor cable connection as an indispensable part of the OBD system. There are existing cable technologies designed for long-term observation for earthquake and Tsunamis (DONET: Dense Ocean-floor Network for Earthquake and Tsunamis). In DONET, seafloor sensors distributed in 100 km+ wide area are linked to a submarine cable, which feeds electric power and precision time reference to each seafloor sensors. The cable also supports two-way high-speed communication to each sensor for command and data link. Power distribution is one of key important technical features in seafloor cable network if multiple stations are to share the same submarine cable. In DONET, each 8 sensors can receive up to 45 W power distributed from the Node equipment, which receives 500 W power from the submarine cable. In recent development, we developed a new Node equipment to accommodate more power hangry sensors, which can deliver each 250 W power to four individual sensors. In the current estimation, 1.5 tons OBD will need a lot more power than that, although low power PMT driver and ADC development would make the power demand closer to the ~ 10kVA limit of power feeding by telecom standard land equipment, if the OBD receives all power without any power distribution mechanism. In the new Node equipment, users can connect to seafloor sensors via a fiber optic link which can give 1 Gbps speed and very high precision time synchronization, which would support communication needs for OBD system.
We are currently planning for seafloor experiment of a 1-10 tons class OBD to demonstrate technical elements for the first stage. Primary candidate site for such demonstration experiment is 1100 m deep seafloor in Sagami Bay, Japan, where submarine cable connection is available to that deep seafloor. The technical elements to be demonstrated include PMT detector package that functions at high ambient pressure (10~60 MPa) in deep seafloor, high performance liquid scintillator in low temperature and high ambient pressure, as well as reliable and low power data acquisition and telemetry system which support OBD operation for many years. With the demonstration OBD in the deep seafloor, we also expect to obtain in-situ seafloor environmental information necessary to design a larger scale OBD, such as the flux of neutron and muon in deep sea as well as radioactive material concentration in deep seawater. For the

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planned 1-10 tons class detector, we also estimated the level of expected neutron background for different structure of the detector vessel.

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Direct sampling and measurement at deep crust through scientific ocean drilling

*Shin'ichi Kuramoto[1]

1. Japan Agency for Marine-Earth Science and Technology

The Kola superdeep borehole is well known as the deepest scientific drilled hole on our planet locates at Kola peninsula, Russia. It took about 20 years and reached approximately 12km deep in the crust. High temperature and pressure refused the drilling operation. KTB drilling project reached about 9km deep in Germany in 1994. Both projects have set a monumental milestone in scientific onshore drilling, and also showed the limitation of drilling technology at the same time. The technological difficulties are caused by borehole instability and high temperature even using drilling fluid circulation. However, ocean drilling is much difficult than onshore drilling. Because ocean drilling is conducting unstable conditions using a floating platform/vessel. Therefore, vertical drilling depth may have some limitations around 10km deep and temperature may lower than 300℃ in general.

The scientific ocean drilling vessel Chikyu has been started scientific ocean drilling operation since 2005 and reached about 3.3km below the seafloor in 2019. It is the current world record of the deepest borehole as scientific ocean drilling conducted at the Nankai accretionary wedge. Achieving mantle drilling by “Chikyu” that has never reached humanity is her next challenge. In addition, a mantle observation and experiment system using boreholes will be planned. The Mantle drilling will provide a fundamental understanding of the Earth system, such as the compositional distribution from the oceanic crust to the upper mantle, rheology, life and chemical evolution processes, and the behavior of thermal and environmental variables. Deepwater and deep penetration technology are under development. We are discussing the first target of Mantle drill at off Hawaii where relatively low temperature and reachable depth to the upper-most mantle by ocean drilling. Scientific drilling cut core samples and measure and/or monitor physical/chemical properties in the borehole. That is the only way to do material science and in-situ high-resolution measurements and monitoring, and it is the uniqueness of ocean drilling.
Chikyu has been completed relatively shallow depth drilling campaigns to understand the mechanism of large earthquakes and Tsunamis, the deep life under extreme conditions and the marine mineral resources so far. The scientific results will be presented in addition to future technology developments for the deep drilling into our planet.

Keywords: Ocean Drilling, Chikyu, Mantle Drilling, Borehole Monitoring, Borehole Experiment

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Hadean geodynamo origin and Ediacaran inner core growth preserved Earth’s habitability

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In a complex balance between deflection and capture of charged particles (Tarduno et al., PEPI, 2014; Blackman and Tarduno, MNRAS, 2019), the geomagnetic field provides net shielding of the solar wind which might otherwise erode the atmosphere and lead to a long-term drying of the planet, threatening habitability. Here we discuss two intervals when core chemical processes and their relationship to powering the geodynamo were crucial for preserving a habitable Earth: i. Hadean-Eoarchean times when solar winds were most intense and ii. the Ediacaran, when a thermally-driven geodynamo had become inefficient. Defining the oldest geodynamo is arguably the greatest technical challenge for paleomagnetism: only single crystal paleointensity (SCP) - the use of silicate crystals bearing magnetic inclusions - is suitable, and this requires use of the world’s most sensitive SQUID magnetometers. The recent optical and electron microscope documentation of primary magnetite inclusions in Jack Hills zircons (Tarduno et al., PNAS, 2020), previously predicted by paleomagnetic unblocking temperatures, together with microconglomerate test results, Pb-Pb radiometric age data and Li-diffusion constraints support a geodynamo as old as 4.2 billion-years-old. High paleofield values recorded by these zircons of Late Hadean age (ca. 4.0 Ga) may be a signal of core chemical precipitation. After the Paleoarchean, field strengths from global data show a long-term decrease spanning some 2 billion years. Ultralow field strengths, some 10 times lower than those of the modern, at ca. 565 Ma (Bono et al., Nat. Geo., 2019) are defined by SCP analyses and attest to a near collapse of the geodynamo. However, this appears to be the time of nucleation of the inner core which provided a new energy source for the geodynamo, rejuvenating magnetic shielding just as changes in composition were making the atmosphere increasingly more vulnerable to solar wind erosion.

Keywords: geodynamo, habitability, Hadean-Eoarchean, Ediacaran, paleointensity

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Earth's deep interior revealed by high-pressure experiments

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The interior of the Earth is under high pressure and temperature (*P*-*T*). Static compression experiments using a laser-heated diamond-anvil cell (DAC) can generate high *P*-*T*conditions, greater than 364 GPa and ~5000 K that correspond to the condition at the center of the Earth. Using such DAC techniques, we are now able to synthesize any materials that are possibly present inside our planet. Combining a DAC with synchrotron x-rays, crystal structures and phase transitions that occur in the deep Earth have been extensively explored up to inner core conditions. Sound velocities of liquid and solid, mantle and core materials have been also obtained by these high *P*-*T*experiments as well as recent theoretical calculations. These results on phase change and seismic wave velocities tell about structures and chemical compositions inside the Earth. In addition, chemical evolution of the mantle and the core has been of great interest in recent DAC studies. After melting experiments in a DAC, tiny samples (10–100 μm scale) were recovered and examined for textures and chemical compositions, demonstrating liquidus phase relations and element partitioning between coexisting liquid and solid. On the basis of these melting studies, I will discuss 1) exsolution of oxides from liquid core, which may have driven core convection and geodynamo since early Earth, and 2) the formation of bridgmanite-enriched ancient mantle structures (BEAMS) upon solidification of a deep magma ocean, which could still be present in the present-day lower mantle.

Keywords: high pressure, lower mantle , core

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Imaging subducted slabs in the mantle through inversion of seismic waveforms

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1. Department of Earth and Planetary Science, School of Science, University of Tokyo, 2. Academia Sinica

Seismic tomographic studies (e.g., Romanowicz 2002; Dziewonski et al. 2010) have inferred the three-dimensional seismological structure of the Earth’s deep interior. Some subducted slabs have been found to be stagnant above or below the 660 km discontinuity, while others fall through into the lower mantle and reach the core-mantle boundary (CMB) (Fukao et al. 2009), suggesting whole-mantle convection rather than layered mantle convection. Recent seismic waveform inversion studies with better resolution, especially for low velocity anomalies, have found vertically continuous low-velocity columns in the lower mantle and suggested that thermochemical plumes rooted in the D" region are associated with prominent hotspots (French and Romanowicz 2015). Hence, seismic tomographic studies have contributed much to understanding mantle convection.

It has been, however, difficult to estimate how long it takes for material in the Earth’s mantle to migrate between the Earth’s surface and the CMB, since seismic tomography studies provide information only on the current Earth’s deep interior. In order to better understand the Earth’s evolution and dynamics, dating inside the Earth is essential. Therefore, we have inferred the detailed seismic velocity structure in the mantle transition zone and D" region beneath Central America and the Northern Pacific, where continuous subduction of oceanic plates beneath the North and South American plates has been taking place since more than 200 Ma (Muller et al. 2016). We investigate the fate of subducted oceanic lithosphere and the thermal and chemical evolution of the Earth.

Waveform inversion studies

Our group’s waveform inversion studies were conducted as follows. The events used are deep- and intermediate-focus events recorded at broadband seismic stations of the USArray, Canadian Northwest Experiment (CANOE), Global Seismographic Network (GSN-IRIS/USGS), Southern California Seismic Network (SCSN), Pacific Northwest Seismic Network (PNSN), Berkeley Digital Seismic Network (BDSN), and Canadian National Seismograph Network (CNSN). The data are filtered in the period range of 8 or 12.5 to 200 s using a Butterworth bandpass filter. The 3D model is obtained by linearized inversion with respect to a spherically symmetric initial model.

We formulated the inverse problem of waveform inversion for localized 3-D seismic structure, computing the partial derivatives of waveforms with respect to the elastic moduli at arbitrary points in space for anisotropic and anelastic media using the methods of Geller and Hara (1993). We applied our methods to the assembled dataset to invert for 3-D shear wave structure. The methods used were presented by Kawai et al. (2014) and refined in our groups’ subsequent papers.

The inferred model shows the presence of two distinct slabs at the CMB beneath Central America and Venezuela and one prominent slab beneath the Northern Pacific due to subduction ~200 Ma (Muller et al. 2016). These slabs appear to modulate the formation of passive upwelling (called “passive plume”) of

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hot basal mantle material (Suzuki et al. 2016; Borgeaud et al. 2017; Suzuki 2020). High-resolution seismic images (Borgeaud et al. 2019) show that such plumes interact with slabs subducting in the upper mantle and that some tearing of the subducted slab is taking place.

The inferred images beneath Central America enable us to date the slab at various depths, taking into account the geological events investigated based on plate reconstructions. We estimate a viscosity contrast between the upper and lower mantle of 9-12, which is about 5 times smaller than that estimated from post-glacial rebound (Hager 1984; Forte and Mitrovica 2001). This implies that subduction from the Earth’s surface down to the base of the mantle affects the surface environment in two ways. 1) Intermittent and localized subduction to the base of the mantle cools the CMB, influencing convection in the outer core, and thus the geodynamo and geomagnetic field. Increased heat flux from the core to the mantle might trigger geomagnetic reversals. 2) Subduction to the CMB modulates the formation of passive plumes which, if they reach the Earth’s surface, can lead to volcanism that can affect the composition of the atmosphere and the temperature of the Earth’s surface. These results suggest the importance of coupling between the Earth’s deep mantle and the Earth’s surface.

Keywords: Seismic waveform inversion, Subducted slab, Mantle convection

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[E] Oral | U (Union)：Union

Wed. Jul 15, 2020 9:00 AM - 10:30 AM JST | Wed. Jul 15, 2020 12:00 AM - 1:30 AM UTC | Ch.1

[U-01] Great Debate: Geoscience and societal leadership in support of planetary stewardship

convener:Fumio Inagaki(Japan Agency for Marine-Earth Science and Technology), William F McDonough(Department of Earth Science and Research Center for Neutrino Science, Tohoku University, Sendai, Miyagi 980-8578, Japan), Susanne Buiter(Geological Survey of Norway), Chairperson:Fumio Inagaki(Japan Agency for Marine-Earth Science and Technology), William F McDonough(Department of Earth Science and Research Center for Neutrino Science, Tohoku University, Sendai, Miyagi 980-8578, Japan)

Since its emergence some 4.6 billion years ago, the Earth has experienced remarkable environmental changes. Life on this planet has adapted and evolved to these changes, maintaining itself despite several catastrophic perturbation events. Compared to the long history of the planet and life, humanity's brief history (Homo sapiens), about 300,000 years, represents a quasi-instantaneous event. Further, with the development of civilization and its agricultural and industrial revolutions, and in particular, since the 18th century with the use of fossil fuels as the primary energy source, the atmosphere, oceans, cryosphere, and biosphere have all changed at an unprecedented rate. This latter era -the Anthropocene- documents an epoch of change in the global system that is irrevocably recorded in the geological record of the planet. What will happen to our future, because the planet will continue to evolve? The geoscience community must continue and enhance its connections with society as it integrates fundamental knowledge into the stewardship of the Earth. Likewise, industrial leaders have a great responsibility in the stewardship of the planet, particularly in shaping policies and human response. The Great Debate will provide a range of viewpoints and disciplines the opportunities to discuss the global planetary stresses that are imposed on humans. We will address questions that focus on the role (code) of geoscience and society in planetary stewardship. Participants will be invited to share their latest knowledge, views, and perspectives on these questions. Please actively contribute to this interdisciplinary discussion during the JpGU-AGU Joint Meeting 2020.

9:00 AM - 9:30 AM JST | 12:00 AM - 12:30 AM UTC

[U01-01] Challenges of the Anthropocene

*Will Steffen[1] (1.Climate Council of Australia)

9:30 AM - 9:40 AM JST | 12:30 AM - 12:40 AM UTC

[U01-02] Climate change: from security perspectives

*Yasuko Kameyama[1] (1.National Institute for Environmental Studies, Japan)

9:40 AM - 9:50 AM JST | 12:40 AM - 12:50 AM UTC

[U01-03] Multiscale stewardship for water-food-energy nexus

*Makoto Taniguchi[1] (1.Research Institute for Humanity and Nature)

9:50 AM - 10:00 AM JST | 12:50 AM - 1:00 AM UTC

[U01-04] Planetary Stewardship in AGU

*Robin E Bell[1] (1.American Geophysical Union)

10:00 AM - 10:30 AM JST | 1:00 AM - 1:30 AM UTC

[U01-05] Great Debate: Geoscience and societal leadership in support of planetary stewardship

*Fumio Inagaki[1], William F. McDonough[1], Susanne Buiter[2], Guy Brasseur[3], Fumiko Kasuga[4], William Steffen[5], Makoto Taniguchi[6], Yasuko Kameyama[7], Robin E. Belll[8], Alberto Montanari[9], Hodaka Kawahata[10] (1.JpGU-AGU Joint Meeting 2020 Program Committee Chair, 2.EGU General Assembly 2020 Program Committee Chair, 3.AGU Fall Meeting 2020 Program Committee Chair, 4.Future Earth Japan Global Hub, 5.Australian National University, 6.Research Institute for Humanity and Nature, 7.National Institute for Environmental Studies, 8.AGU President, 9.EGU President, 10.JpGU President)

Challenges of the Anthropocene

*Will Steffen[1]

1. Climate Council of Australia

The Anthropocene is a unique point in time, where human history collides with Earth history. This talk will explore the origins of the Anthropocene, both as a concept and a term. Using Earth System and geological/stratigraphic frameworks, we’ ll outline the trajectory of the Anthropocene in the context of recent and longer term Earth history, with a focus on both the physical climate system and the biosphere. However, it is humanity that now plays the dominant role in the trajectory of the Earth System, which demands an exploration of the human dimensions of the Earth System. As we look to possible future directions of the planet in the Anthropocene, a clear picture is yet to emerge. Where on Earth are we going?

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Climate change: from security perspectives

*Yasuko Kameyama[1]

1. National Institute for Environmental Studies, Japan

Climate change is widely recognized as one of the most serious threats to human beings and ecosystems. As our understanding of the climate change problem has increased, we have also witnessed a vast increase in the use of terms “climate security” by experts and practitioners worldwide. Numerous publications have addressed the issue of climate security, and many other studies have aimed at categorizing definitions and approaches of climate security. Four types of approaches emerged by reviewing existing literature; (1) long-term irreversible planetary changes, (2) short-term abrupt risks to individuals, (3) cause of conflict and violence, and (4) impacts on military and defense organizations. Table1 summarizes what is assumed as threat and what is assumed to be protected from the threat so that the differences become clearer. The four approaches also send different messages on how insecure conditions can be mitigated.The first approach considers the long-term climate change to be a serious threat, not to the national security of any one country, but to future generations and the global ecosystem. Advocates of this approach are worried that the progression of climate change could render Earth uninhabitable. The only way to avoid the crisis is to mitigate climate change by reducing GHG emissions. The long-term temperature goal such as 2˚C needs to be achieved from the viewpoint of this approach. The second approach considers extreme weather events and other impacts of climate change at the regional level as a threat to individuals. Extremely high temperatures and epidemics of diseases could have serious health implications, and the food and water supply could be limited by serious droughts. All these concerns are less relevant to national security and much more related to human security, food security, and water security. Adaptation actions are required to improve the situation. The third approach focuses on the interactions between the impacts of climate change and conflict between people. With this approach, “threat” originates from people outside of your own community. Displaced people may immigrate due to damages caused by climate change, and the immigration could raise tensions between various groups of people. As the impacts of climate change do not always lead to conflict, regions need to increase social stability by improving the level of governance and building resilience to natural hazards. The fourth approach employs a narrower definition of security, one in which national security is conducted by the military. National security has been concerned with other countries’ armed forces to a nation state. With “climate security”, however, the threat has been expanded to include a wide variety of impacts of climate change. To avoid these losses, those using this approach emphasize the importance of military and national security strategies to take into account the impacts of climate change.Categorization of climate security concept is useful to recognize various types of threats we need to take into account, and to check if each country is well prepared for them.

Keywords: climate change, security, conflict, social instability

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Table 1: Summary of the four categories of climate security discourse

Category	Threat	Objects of protection	Means to improve level of security
Long-term irreversible planetary changes	Global changing climate, warming world	The planet, human beings, and the ecosystem	GHG emission reduction at global level
Short-term abrupt climate change risks	Extreme weather events and other impacts of climate change to individuals	People's daily life, including stable supply of basic human needs	Adaptation measures, building resilience
Cause of conflict and violence	Migration and other causes of conflict between groups	Own group	Reduction of social instability
Military and defense implications	Long- and short-term damages (i.e. sea level rise, extreme weather events)	National territory, military facilities, and defense forces	Adaptation in the area of defense and other military operations

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Multiscale stewardship for water-food-energy nexus

*Makoto Taniguchi[1]

1. Research Institute for Humanity and Nature

Water, energy, and food are fundamental resources for human beings and sustainable society with livelihood including agriculture and industries, and these resources are interlinked each other beyond the boundaries of single resource management. Therefore, integrated management and governance for water-energy-food (WEF) nexus is important by increasing synergies and reducing trade-offs among the three resources, environment/society/economy factors, and local/national/global scale. However, there are many disconnections of governances between not only three resources and different spatial scales, but also between sectors of production and consumption, and agencies of protection of environment and development of economy. Who should take responsibility of stewardship for multiscale water-food-energy nexus ? How to manage the tradeoff between carbon footprint as global environmental impact and water footprint as local environmental impact through multiscale WEF nexus ? Belmont Forum SUGI project “METABOLIC” has been analyzing the multiscale WEF nexus for sustainable resources management. Scenario and impact assessments by using system dynamics model and footprints analyses have been made for understanding how each area is inter- and intra- connected on WEF nexus by using three databases of resources, interlinkage, and scenario in multi-spatial scale. Analyses of the change in WEF nexus structure also have been made, and assessments of the changes in three resources, carbon emission, environmental and economic impacts are analyzed. These analyses with stakeholders can help to make future policies for sharing the roles of governance, land intensive policy and others to increase synergy for sustainable future.

Keywords: water-energy-food nexus, tradeoff and synergy, multiscale stewardship

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Planetary Stewardship in AGU

*Robin E Bell[1]

1. American Geophysical Union

Society today is facing many challenges, and opportunities, that critically depend on the Earth and space sciences. Planetary stewardship is intertwined throughout these topics as many of the challenges and opportunities in the 21st century are at the global scale. Societies, by catalyzing, leveraging, and engaging members the our science, play a key role in addressing these. Leadership is needed through strategic efforts, mobilizing our science, policy positions, programming, communication and engaging the public in new ways, expanding our scientific community and providing a welcoming culture that rewards planetary stewardship, and also developing partnerships with new stakeholders. Examples at AGU include our new strategic plan; position statements, for example on Addressing Climate Change and on Open FAIR data; and programs such as the Thriving Earth Exchange, Ethics, and Voices for Science.

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Great Debate: Geoscience and societal leadership in support of planetary stewardship

*Fumio Inagaki[1], William F. McDonough[1], Susanne Buiter[2], Guy Brasseur[3], Fumiko Kasuga[4], William Steffen[5], Makoto Taniguchi[6], Yasuko Kameyama[7], Robin E. Belll[8], Alberto Montanari[9], Hodaka Kawahata[10]

1. JpGU-AGU Joint Meeting 2020 Program Committee Chair, 2. EGU General Assembly 2020 Program Committee Chair, 3. AGU Fall Meeting 2020 Program Committee Chair, 4. Future Earth Japan Global Hub, 5. Australian National University, 6. Research Institute for Humanity and Nature, 7. National Institute for Environmental Studies, 8. AGU President, 9. EGU President, 10. JpGU President

Since its emergence some 4.6 billion years ago, the Earth has experienced remarkable environmental changes. Life on this planet has adapted and evolved to these changes, maintaining itself despite several catastrophic perturbation events. Compared to the long history of the planet and life, humanity’ s brief history (Homo sapiens), about 300,000 years, represents a quasi-instantaneous event. Further, with the development of civilization and its agricultural and industrial revolutions, and in particular, since the 18th century with the use of fossil fuels as the primary energy source, the atmosphere, oceans, cryosphere, and biosphere have all changed at an unprecedented rate. This latter era—the Anthropocene—documents an epoch of change in the global system that is irrevocably recorded in the geological record of the planet. What will happen to our future, because the planet will continue to evolve? The geoscience community must continue and enhance its connections with society as it integrates fundamental knowledge into the stewardship of the Earth. Likewise, industrial leaders have a great responsibility in the stewardship of the planet, particularly in shaping policies and human response. The Great Debate session during the JpGU-AGU Joint Meeting 2020 will provide a range of viewpoints and disciplines the opportunities to discuss the global planetary stresses that are imposed on humans. We will address questions that focus on the role (code) of geoscience and society in planetary stewardship.

Keywords: Planetary Stewardship, Anthropocene, Geoscience, Sustainability, Resilience, Co-evolution

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[E] Oral | U (Union)：Union

[U-03] Sustainable global groundwater management for human security

convener:Yoshihide Wada(International Institute for Applied Systems Analysis), Makoto Taniguchi(Research Institute for Humanity and Nature), Chairperson:Yoshihide Wada(International Institute for Applied Systems Analysis), Chairperson:Makoto Taniguchi(Research Institute for Humanity and Nature)

Sustainable management of water resources is an overwhelming task, when faced with a growing population that is increasing its demand for food, energy and water. Except frozen ice, groundwater is world's largest fresh water resource, but increasing over-exploitation of groundwater resources has been reported over intensely irrigated regions. Groundwater is the prime source for drinking water supply and irrigation, hence critical to global water, food and energy security contributing to human security. But also for sustaining low flow requirements and ecological values of groundwater dependent ecosystems, the contribution by groundwater flow is essential. Groundwater therefore needs to be managed wisely, protected and especially sustainably used. In itself this is a challenge, however under a changing environment including climate, land use, population growth, this task becomes a challenge especially in the light of limited data availability and consequential uncertainties. From arid over humid to arctic regions, in every type of climate changing environmental conditions become apparent and have very different effects. In this session we invite contributions, which report on research on the consequences of a changing environment for future management, protection, and sustainable use of groundwater. Methodologies, strategies, case studies as well as quantitative techniques for dealing with uncertainty and limited data availability are of interest for this session. We welcome studies describing how groundwater resources benefit from an Integrated Water Resources Management approach. Furthermore, contributions describing case studies and new techniques for active management and protection of groundwater resources such as artificial recharge and conjunctive use are welcome.

[U03-01] Groundwater governance for global sustainability

★Invited Papers

*Makoto Taniguchi[1], Sanghyun Lee[1], Naoki Masuhara[1] (1.Research Institute for Humanity and Nature)

[U03-02] **Global Economic Limits of Groundwater used for Irrigation**

★Invited Papers

*Marc FP Bierkens[1,2], Inge E.M de Graaf[3], Scott Jasechko[4], Debra Perrone[4], Rens L.P.H van Beek[1] (1.Utrecht University, 2.Deltares, 3.University of Freiburg, 4.University of California at Santa Barbara)

[U03-03] Net inflow – a key quantity for defining pathways towards sustainability in heavily stressed aquifers

★Invited Papers

*James J Butler[1], Geoffrey C Bohling[1], Donald O Whittemore[1], Blake B Wilson[1] (1.Kansas Geological Survey, University of Kansas, Lawrence, KS USA)

[U03-04] **Human-groundwater interactions in a changing environment: modeling stressed global aquifer systems**

★Invited Papers

*Yadu Pokhrel[1], Farshid Felfelani[1], Sanghoon Shin[1], Tamanna Kabir[1] (1.Michigan State University)

[U03-05] Global salinization risk in irrigated areas

*Sayaka Yoshikawa[1], Kota Higashiyama[1], Shinjiro Kanae[1] (1.Tokyo Institute of Technology)

[U03-06] Gender differences in water insecurity

*Kaoru Kakinuma[1,2], Yoshihide Wada[3] (1.Shanghai University, 2.Tohoku University, 3.International Institute for Applied Systems Analysis)

Groundwater governance for global sustainability

*Makoto Taniguchi[1], Sanghyun Lee[1], Naoki Masuhara[1]

1. Research Institute for Humanity and Nature

Groundwater governance is important, in particular in Asia, for global sustainability, because more than 70 percent of groundwater depletion occurs in Asia, and more than 55 percent of groundwater footprint for food production is produced in Asia. Groundwater, energy and food are interlinked each other beyond the boundaries of each shed as well as trans-spatially through the food and energy trades. Interactions between groundwater-food-energy nexus under the limited land and climate change, and environmental/economical/social impacts, are analyzed in terms of multi-scale integrated management and governance of the nexus by increasing synergies and reducing trade-offs. An integrated model for decision support is developed to analyze the nexus and assess environmental and economic impacts, with three databases of resources, interlinkage, and scenario in multi-spatial scale. Tradeoffs are analyzed between economy and environment as well as local and national scale.

Keywords: groundwater-energy-food nexus, multi spatial scale, tradeoff and synergy

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Global Economic Limits of Groundwater used for Irrigation

*Marc FP Bierkens[1,2], Inge E.M de Graaf[3], Scott Jasechko[4], Debra Perrone[4], Rens L.P.H van Beek[1]

1. Utrecht University, 2. Deltares, 3. University of Freiburg, 4. University of California at Santa Barbara

Under pressure of population growth and increasing food demand, irrigated agriculture has expanded into semi-arid areas with limited surface water resources. As a consequence, irrigation has become increasingly dependent on groundwater, which has resulted in high rates of aquifer depletion in many aquifers around the globe. As groundwater decline leads to increasing costs of groundwater pumping, an important question is at which groundwater depth pumping costs will exceed revenues from crop production. Here, we assess globally the maximum economic depth of groundwater extraction for the irrigated areas overlying productive aquifers under current crop cover and current climate. To this end we combine globally available data on crop cover, crop yield and crop prices with crop water requirements and groundwater level estimates from a global hydrological and groundwater model. The estimating maximum economic depths are consistent with well depths obtained from a rich well dataset over the U.S. Our results show that the maximum economic depth greatly varies between regions with times to reach this depth varying greatly as well. We estimate the global volume of economically extractable groundwater, which is only a small fraction of the estimated fresh groundwater resources underlying irrigated areas, but nevertheless represents a significant economic value. Although globally the time to complete economic depletion is large, the remaining value of economically recoverable groundwater shows a sharp decline over the coming decades. Our results provide a global time horizon for transformation to a more sustainable use of groundwater resources.

Keywords: Groundwater, Sustainability, Depletion, Economic, Depth, Aquifer

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Net inflow –a key quantity for defining pathways towards sustainability in heavily stressed aquifers

*James J Butler[1], Geoffrey C Bohling[1], Donald O Whittemore[1], Blake B Wilson[1]

1. Kansas Geological Survey, University of Kansas, Lawrence, KS USA

The depletion of aquifers that support irrigated agriculture is a pressing problem across the globe. A frequently asked question is how to redirect these heavily stressed systems on to more sustainable paths. If alternative water supplies are not available, the only viable option for the near term (few to several decades) is to reduce pumping. The key issues therefore become how much should pumping be reduced to significantly extend the lifetime of an aquifer and what is the likelihood of attaining a sustainable state for the system. We have developed a new water-balance approach to glean insights into these issues and give water managers a convenient tool for application in seasonally pumped aquifers supporting irrigated agriculture. This approach, which can be used to assess the impact of pumping reductions and to chart pathways towards more sustainable states, shows that the response to pumping reductions heavily depends on the net inflow (all inflows to the aquifer minus all outflows except pumping) component of an aquifer’ s water budget, both in terms of its magnitude and how it changes with time in response to the reductions. The net inflow will decrease in response to pumping reductions; prospects for sustainability will depend on the proportion of the various components making up the net inflow (e.g., how much is natural recharge versus how much is irrigation return flow) and their sensitivity to the reductions. If a pumping reduction leads to a pumping rate that is above the net inflow at the time of the reduction, the aquifer lifespan can often be extended by a factor of two or more but depletion will be the final outcome. If a reduction results in a pumping rate equal to the net inflow, the aquifer lifespan will be extended further but again depletion will be the end result. In contrast, if a reduction results in a pumping rate below (>10-15%) the net inflow at that time, sustainability may be achievable. At the very least, there will be a lengthy period of apparent sustainability during which water levels remain above the level at the time of the reduction. In any case, the aquifer lifespan will be lengthened to such an extent that other options, such as large-scale water transfers, may become viable. These concepts will be demonstrated using examples based on data from an ongoing large-scale (256 km^2) experiment in pumping reductions in the High Plains aquifer in the state of Kansas in the central United States; the role of climate change will be incorporated into the analysis using regional-scale projections. These results indicate that field monitoring of net inflow and its changes through time must become a higher priority for the water resources community. As we have shown in earlier work (Butler et al., GRL, 2016), this can be readily done when reliable pumping and water-level data are available. Although efforts to parse out the individual contributors to net inflow will ultimately provide the clearest picture of what the future holds, many useful insights of practical importance can be obtained through greater attention to this quantity.

Keywords: aquifer sustainability, pumping reductions, net inflow, High Plains aquifer

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Human-groundwater interactions in a changing environment: modeling stressed global aquifer systems

*Yadu Pokhrel[1], Farshid Felfelani[1], Sanghoon Shin[1], Tamanna Kabir[1]

1. Michigan State University

Groundwater storages in many of the world’ s major aquifer systems have been declining at an alarming rate. While in-situ measurements and satellite observations provide crucial information on the past changes, hydrological models serve as indispensable tools for attributing the observed changes to climate variability and human actions, and thereby better predicting future dynamics under climate change. Concerted efforts have been made by the hydrologic sciences community over the past decade in better understanding evolving aquifer dynamics in response to climate change and increased groundwater use by humans; however, imperfect or missing groundwater parameterizations in large-scale hydrology models still pose critical challenges in realistically simulating climate-human-groundwater interactions, hindering path forward to sustainable management of groundwater resources. This study presents improved simulations of groundwater flows and storages in the major global aquifer systems using multiple global hydrological models including the Community Land Model version 5 (CLM5). Simulations are conducted at 5km grids over the contiguous United States considering lateral groundwater flow, surface water-groundwater interactions, and aquifer pumping, and at 50km grids globally under simplified settings. Changes in water table depth and terrestrial water storage (TWS) are analyzed and validated using a synthesis of ground- and satellite-based datasets including those from the gravity Recovery and Climate Experiment (GRACE) satellite mission. Results suggest that groundwater depletion in the stressed aquifer systems can be better simulated when lateral flow is represented, especially in models that operate at relatively fine grid sizes (~5km). Further, results from future projections suggest that TWS in many of the stressed global aquifer systems will reduce under future climate, exacerbating groundwater sustainability issues in many regions.

Keywords: Hydrology, Modeling , Groundwater depletion

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Global salinization risk in irrigated areas

*Sayaka Yoshikawa[1], Kota Higashiyama[1], Shinjiro Kanae[1]

1. Tokyo Institute of Technology

Building a sustainable agricultural production system might be necessary for increasing population in the future. In this study, we focused on salinization which is one of the factors that threaten sustainable agricultural production in cropland, especially irrigated area. Throughout literature review in terms of salinization mechanism, we determined five factors which are soil type, dryness, irrigation method, groundwater use and groundwater level. Then risk areas of salinization were clarified. The high risk was shown more than 20% areas in irrigated areas. In almost 80% of the irrigated areas, there are some risk. Comparing with previous study, more detailed and more accurate risk of salinization were identified.

Keywords: climate change, food shortages

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Gender differences in water insecurity

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1. Shanghai University, 2. Tohoku University, 3. International Institute for Applied Systems Analysis

Universal and equitable access to safe water for all is central to achieving the 2030 Sustainable Development Goals (SDGs). Billions of people have gained access to basic water services since 2000, but around 600 million people still don’ t have adequate accesses to safe water. Moreover, impacts of water insecurity, that defined as the limited or uncertain availability of safe water, are different by gender. For example, water collections are often tasks for women especially in many parts of rural Africa, and they often spend more than 30 minutes per day for collecting water. Thus gender information are important to assess impacts of water insecurity on societies and livelihoods. However, there are often gaps between water resource assessments and gender researches. Most research that focus on gender differences in water access are conducted at local scales while most global water resource assessments don’ t include gender information. On the other hand, recent developments of population datasets enable us to use detail population distribution information that include gender and age in the world. Here we integrate these population datasets into water resource assessments to examine the gender differences in water insecurity around the globe. Our interdisciplinary approach between hydrology and demography would contribute to assess social impacts of water insecurity in the world.

Keywords: water access, water scarcity, population

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[E] Oral | U (Union)：Union

[U-03] Sustainable global groundwater management for human security

convener:Yoshihide Wada(International Institute for Applied Systems Analysis), Makoto Taniguchi(Research Institute for Humanity and Nature), Chairperson:Yoshihide Wada(International Institute for Applied Systems Analysis), Chairperson:Makoto Taniguchi(Research Institute for Humanity and Nature)

Sustainable management of water resources is an overwhelming task, when faced with a growing population that is increasing its demand for food, energy and water. Except frozen ice, groundwater is world's largest fresh water resource, but increasing over-exploitation of groundwater resources has been reported over intensely irrigated regions. Groundwater is the prime source for drinking water supply and irrigation, hence critical to global water, food and energy security contributing to human security. But also for sustaining low flow requirements and ecological values of groundwater dependent ecosystems, the contribution by groundwater flow is essential. Groundwater therefore needs to be managed wisely, protected and especially sustainably used. In itself this is a challenge, however under a changing environment including climate, land use, population growth, this task becomes a challenge especially in the light of limited data availability and consequential uncertainties. From arid over humid to arctic regions, in every type of climate changing environmental conditions become apparent and have very different effects. In this session we invite contributions, which report on research on the consequences of a changing environment for future management, protection, and sustainable use of groundwater. Methodologies, strategies, case studies as well as quantitative techniques for dealing with uncertainty and limited data availability are of interest for this session. We welcome studies describing how groundwater resources benefit from an Integrated Water Resources Management approach. Furthermore, contributions describing case studies and new techniques for active management and protection of groundwater resources such as artificial recharge and conjunctive use are welcome.

[U03-07] Development and enhancement of a global hydrological model to better contribute to the sustainable groundwater management and human water security

★Invited Papers

*Naota Hanasaki[1], Julien Eric Boulange[1], Zhipin Ai[1], SARITHA PADIYEDATH GOPALAN[1], Kumiko TAKATA[1] (1.NIES National Institute of Environmental Studies)

[U03-08] **Impacts of Global Groundwater Depletion to Regional Hydroclimatology in 37 Major Aquifers**

★Invited Papers

*Pat J.-F. Yeh[1], Chong Zhang[2], MinHui Lo[3], Yoshihide Wada[4], James S. Famiglietti[5] (1.School of Engineering, Monash University, Malaysia, 2.Beijing Normal University, China, 3.Department of Atmospheric Sciences, National Taiwan University, Taipei, Taiwan, 4.International Institute for Applied Systems Analysis, Laxenburg, Austria, 5.School of Environment and Sustainability and Global Institute for Water Security, University of Saskatchewan, Saskatoon, Canada)

[U03-09] **Divergent effects of climate change on future groundwater availability in key mid-latitude aquifers**

★Invited Papers

*Min-Hui Lo[1], Wen-Ying Wu (1.National Taiwan University)

[U03-10] Uncertainty of global hydrologic simulations: associated with data and physics including groundwater capillary flux

★Invited Papers

*Hyungjun Kim[1], Sujan Koirala[2] (1.The Univ. of Tokyo, 2.Max Planck Institute for Biogeochemistry)

[U03-11] Higher-resolution mapping of regional aquifer storage parameters using a GRACE spherical harmonic inversion method

*Yun Pan[1], Yalin Ma[1], Pat J.-F. Yeh[2], Huili Gong[1] (1.Capital Normal Univ., 2.Monash Univ. Malaysia)

[U03-12] Potential misrepresentation of hydrological extremes using transient climate rather than stabilized climate given identical levels of global warming

*Julien Eric Boulange[1], Naota Hanasaki[1] (1.National Institute for Environmental Studies)

Development and enhancement of a global hydrological model to better contribute to the sustainable groundwater management and human water security

*Naota Hanasaki[1], Julien Eric Boulange[1], Zhipin Ai[1], SARITHA PADIYEDATH GOPALAN[1], Kumiko TAKATA[1]

1. NIES National Institute of Environmental Studies

Groundwater is an important water resource in the world. In recent decades, the observation of excessive groundwater depletion raised public concerns in many areas, highlighting the urgent need for sustainable management of groundwater resources. The over reliance on groundwater resources is primarily due to excess in water demand for recharge rate and limitation in alternative water source options. Therefore, in order to solve the groundwater problem, it is necessary to understand not only groundwater but also the entire hydrological cycle, including overall water use and surface water dynamics. The Global Water Resources Model H08 has been developed over the past 15 years to elucidate the overall picture of global water use and hydrological cycle. In this presentation, we will introduce some of the latest research achievements of H08 that will be potentially beneficial toward sustainable groundwater management. Then we will describe the prospects for the development and application of global water resources models.

H08 is currently focusing on the following research themes. The first is reservoir operation. Reservoir operation reduces the seasonal and interannual variability in surface water availability, but its expression in global hydrological models is still in infancy. After intensive investigation, we have succeeded in combining a global hydrological model with a global flood inundation model which brings us to the new horizon of expressing global surface water dynamics including human interventions. The second theme is agricultural productivity and irrigation. Most of the world's water is used for irrigation, hence estimating the requirement and understanding the effects of irrigation is key to global water resources modeling. We have focused on the productivity of biofuel crops and their irrigation and succeeded in expressing them in H08 which enables us to investigate the trade-offs among social decarbonization (bioenergy production), terrestrial ecosystem conservation (land use), and sustainable water use. The third theme is the enhancement of the accuracy and spatial resolution of the model. As many previous studies have suggested, in application to specific basins, the reproducibility of global water resources models is significantly poorer than that of basin-based hydrological models. By preparing high-precision input data and performing parameter calibration, in the Chao Phraya River in Thailand and other multiple basins in various climate zones, we have succeeded in achieving good performance of H08 which satisfy practitioners. Based on these research results, I would like to describe how the global water resources models can contribute to the solution of groundwater problems and enhancing water security, and what should be added in the future.

Keywords: reservoir operation, irrigation, high spatial resolution

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Impacts of Global Groundwater Depletion to Regional Hydroclimatology in 37 Major Aquifers

*Pat J.-F. Yeh[1], Chong Zhang[2], MinHui Lo[3], Yoshihide Wada[4], James S. Famiglietti[5]

1. School of Engineering, Monash University, Malaysia, 2. Beijing Normal University, China, 3. Department of Atmospheric Sciences, National Taiwan University, Taipei, Taiwan, 4. International Institute for Applied Systems Analysis, Laxenburg, Austria, 5. School of Environment and Sustainability and Global Institute for Water Security, University of Saskatchewan, Saskatoon, Canada

Global groundwater pumping (GWP) introduces dormant fossil waters into the active land-atmosphere-ocean water cycle and alters the combined land and atmosphere water budgets. Despite its adverse environmental impacts on regional water resources management and global seas level rises have been well recognized, the underlying physical mechanisms and paths are poorly understood due to the lack of large-scale GWP and long-term global hydrometeorological data to estimate these impacts. In this study, two sets of global-scale model simulations conducted for the 1900-1999 period by a fully-coupled climate-hydrologic model, one with GWP and one without, are used to investigate the effects of GWP in affecting the land and atmospheric water budgets over 37 major aquifers worldwide. The internally-consistent simulated water budget components, includ precipitation, evaporation, runoff, atmospheric vapor convergence, and water storage changes in land, ocean and atmosphere, are analyzed and their differences between two simulations are considered as the effects in changing regional hydroclimates due to long-term GW depletion. The analyses ranging from monthly to decadal timescales are focused on estimating the pumping sensitivity on various hydrologic stores and fluxes over these 37 aquifers. Lastly, the contribution of GWP to global sea level rise (GSLR) as a result of the changes in the land and atmospheric water budgets is also estimated via (1) the direct R contribution from land to ocean and (2) the indirect C contribution via atmospheric interactions.

Keywords: Groundwater Depletion, Combined Land-Atmosphere-Ocean Water Budgets, Global Major Aquifers, Regional Hydroclimate Changes, Global Sea Level Rise

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Divergent effects of climate change on future groundwater availability in key mid-latitude aquifers

*Min-Hui Lo[1], Wen-Ying Wu

1. National Taiwan University

Groundwater provides critical freshwater supply, particularly in dry regions where surface water availability is relatively limited. Climate change impacts on groundwater storage could affect the availability and sustainability of freshwater resources. Here, we used a fully-coupled climate model to investigate changes in groundwater storage over seven critical aquifers that have been identified as significantly distressed by satellite observations. We assessed the potential climate-driven impacts on groundwater storage changes throughout the 21st century under the business-as-usual scenario (RCP8.5). Results show that the climate-driven impacts on GWS (groundwater storage) changes do not necessarily reflect the long-term trend in precipitation; instead, the trend may result from changes in transpiration, enhancement of evaporation, and reduction in snowmelt, which collectively lead to divergent responses of GWS across different aquifers. While two of them (the Southern Plains and the Middle East) are projected to become more stressed with climate change, our results also suggest the potential for enhanced future groundwater use in some of the currently most overstressed aquifers. Finally, we compare the climate-driven and anthropogenic pumping impacts. The reduction in GWSs is mainly due to the combined impacts of over-pumping and climate effects; however, the contribution of pumping could easily far exceed the natural replenishment.

Keywords: groundwater withdrawal, natural climate variability

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Uncertainty of global hydrologic simulations: associated with data and physics including groundwater capillary flux

*Hyungjun Kim[1], Sujan Koirala[2]

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Numerical simulation has three major sources of uncertainty: 1) boundary conditions, 2) model physics, and 3) physical parameters. In this study, we introduce a few examples of uncertainty estimations from those aspects. First, it was shown how the uncertainty in forcing data translates into evapotranspiration and runoff calculations. To quantify the uncertainty, ensemble simulation was carried out using five different observational precipitation datasets, and the uncertainty was estimated based on Omega index which quantifies relative similarity of ensemble members. The uncertainty in the boundary condition was relatively amplified and damped in runoff and evapotranspiration calculations, respectively. Second, as an example to estimate the uncertainty associated with model physics, the simulation sensitivity due to parameterizations of the GW capillary flux and depth of interaction interface were tested. It has been found that the capillary flux parameterization affects the magnitude of GW-supported ET and GW recharge significantly, and the biggest sensitivities were related with the dependency of the capillary flux simulation on water table depth. Third, we tested the effect of soil texture classification on the partitioning of the water balance components. The sensitivity test concluded that the uncertainty associated with soil parameters mainly affects partitioning of sub-components rather than the first order water balance. In other words, the balance between transpiration-evaporation and surface-subsurface runoff were changed significantly, while the changes in the balance between evapotranspiration and runoff were negligible.

Keywords: Global Hydrologic Simulation, Simulation Uncertainty, Groundwater Capillary Flux

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Higher-resolution mapping of regional aquifer storage parameters using a GRACE spherical harmonic inversion method

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The aquifer storage parameter, i.e. the specific yield (storativity) for unconfined (confined) aquifers, is crucial for estimating groundwater storage changes, and for hydrological and land surface model simulations. Despite that it can be quantified through pumping test or ground gravity measurement at local scale, obtaining distributed values at large scale is still of great challenge. In this study, we propose a GRACE (Gravity Recovery and Climate Experiment) spherical harmonic inversion (SHI) method, which reconciles GRACE and in situ groundwater level observations and enables distributed estimation of the storage parameters with higher-resolution at large scales. Through a case study in the plain area (346, 000 km^2) of the Yellow River basin, Huaihe River basin, and Haihe River basin (YHH), with a validation dataset of 120 pumping test data, we demonstrate that the overall performance (the R between SHI and pumping test) can reach 0.75 at the resolution of 1 km×1 km, though major limitations still exist in the uncertainties associated with selecting the best (true) one from multiple inversion results. Our study provides a potential new solution for estimating aquifer storage parameters at large scale, and highlights the additional value of spherical harmonic data on higher-resolution studies related with groundwater storage changes.

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Potential misrepresentation of hydrological extremes using transient climate rather than stabilized climate given identical levels of global warming

*Julien Eric Boulange[1], Naota Hanasaki[1]

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The Paris Agreement aims to limit global warming well below 2˚C and encourage participants to pursue effort to further limit global warming to 1.5˚C. Models combining energy–economy–environment systems have provided crucial insight to how the future could evolve and how present decisions could affect long-term global warming. However, while many scenarios attempted to limit end-of-century radiative forcing to specific levels (e.g. +1.5˚C, +2˚C), these stabilized levels of global warming were frequently temporally exceeded during the mid-21st (Fig. 1A), owning to strong reduction in greenhouse gas emissions (Fig. 1B).

Such scenarios were used extensively to identify the different options available for limiting climate change and informing international climate policy. However, since stabilized levels of global warming for the end-of-century were not always available due to time requirements for stabilizing global warming, most analysis were conducted given a 30-year period centered on the year the global temperature exceed a specific levels (Fig. 1A)[1]. While the level of global warming for this 30-year period is identical to the stabilized global warming, it is not clear if the variables used in previous analysis behave identically between the two periods, hereinafter referred to as transient and stabilized climates.

In this study, using the ISIMIP2b[2] framework which provides outputs for various global hydrological models forced by the same bias corrected GCMs in a consistent manner, we extract extreme hydrological events obtained in the two climates and assess (i) whereas a statistical difference can be detected at the global scale, and (ii) if specific regions are more susceptible to being misrepresented by using solely the transient period in an analysis.

Our results (Fig. 2) indicate that while a statistical difference in extreme discharge obtained for the transient and stabilized climates could be detected globally, the difference was generally small. Overall, on average, significant differences in low and high discharges obtained in the transient and stabilized climates were identified for 6.82 and 3.27% of the land grid cells, respectively. Note that these findings were robust to the choice of indices. The extreme discharges in central Asia and the Amazon regions were consistently highlighted by the ensemble members as behaving differently in the transient and stabilized climate given identical level of global warming. For such regions, the conclusions drawn from previous analysis using only the transient climate may not be applicable in the far future exhibiting a stabilized climate.

To better understand the reasons behind the differences among GHMs in extreme discharge behaving differently for the transient and stabilized periods, it might be important to pay close attention to processes related to snow. Last two additional GHMs are currently being processed to further increase the number of members in the ensemble.

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2. Warszawski, L. *et al.* The Inter-Sectoral Impact Model Intercomparison Project (ISI–MIP): Project framework. *Proc Natl Acad Sci USA* **111**, 3228 (2014).

Keywords: Hydrology, Climate change, ISIMIP2b, Discharge

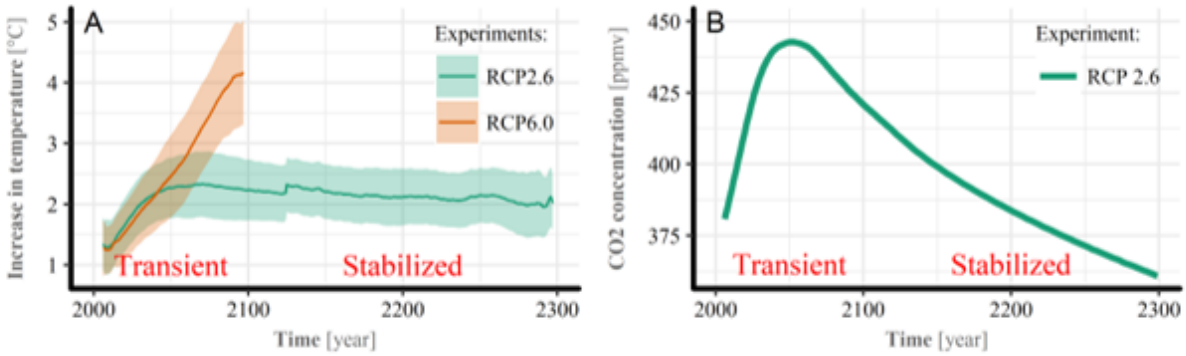

Fig. 1: Trend of (**A**) the average global temperature given by an ensemble of global circulation models (GCMs) and (**B**) the associated CO_2 emission during 2005-2300

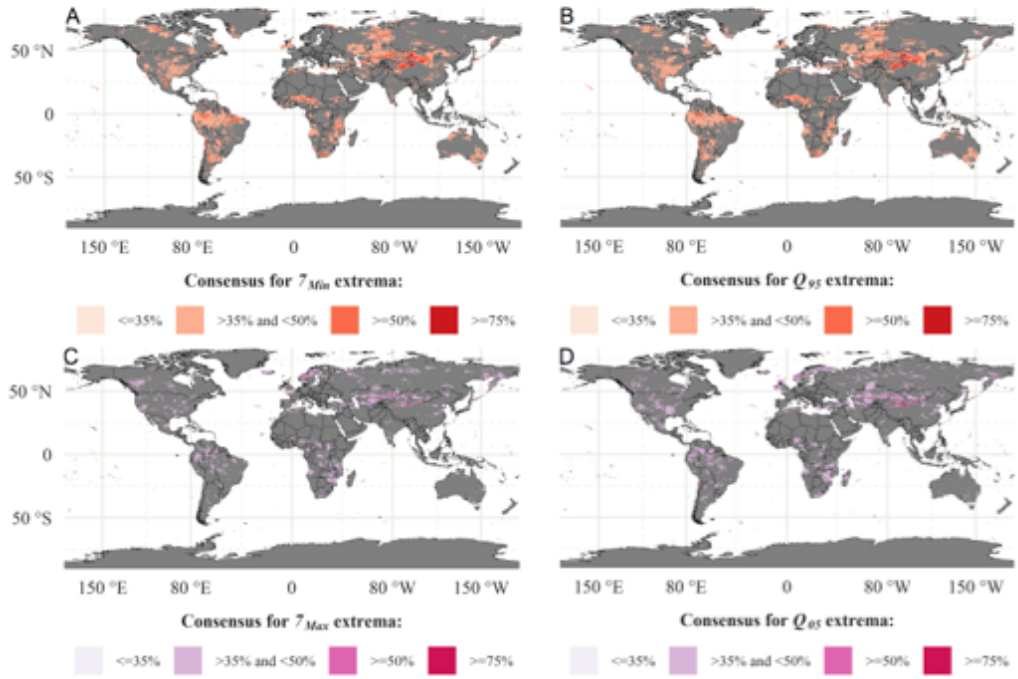

Fig. 2: Grid cells (0.5°×0.5°) where the ensemble of GCMs and GHMs indicated a consensus regarding statistical differences between (A and B) low discharge indices and (C and D) high discharge indices between the transient and stabilized climates

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[E] Oral | U (Union)：Union

[U-04] International Efforts Supporting Global Navigation Satellite System-Enhanced Tsunami Early Warning

convener:Rundle John B(University of California Davis), Kazuyoshi Nanjo(University of Shizuoka), Eiichi Fukuyama(Kyoto University / National Research Institute for Earth Science and Disaster Resilience), Chairperson:Kazuyoshi Nanjo(University of Shizuoka), Chairperson:John B Rundle(University of California Davis), Chairperson:Eiichi Fukuyama(Kyoto University / National Research Institute for Earth Science and Disaster Resilience)

With little to no warning more than 230,000 lives were lost to the Great Indian Ocean Tsunami of December 26, 2004. This devastating loss of life focused the efforts of scientists, engineers and politicians to strengthen tsunami early warning systems beginning with an accurate and rapid estimate of tsunami potential. A combined network of seismic and geodetic sensors quickly emerged as an accurate, efficient, and cost effective enhancement to tsunami early warning systems for those at risk communities nearest the earthquake epicenter. In the months following the Great Indian Ocean Tsunami, geophysicists demonstrated that analysis the GPS network of the Global Geodetic Observing System could have provided warning within 15 minutes after the Sumatran earthquake if the network data were available in real time. On March 11, 2011, the Tohoku-oki earthquake and tsunami unleashed another terrible tragedy upon the Japanese people and posed great challenges to the Japanese government. The Tohoku-oki earthquake occurred off shore from the world's most advanced GPS network, the GEONET, designed and operated by The Geospatial Information Authority of Japan (GSI). The Tohoku-oki earthquake did underscore the potential and extraordinary societal value of Global Navigation Satellite Systems (GNSS) to tsunami warning systems. Several retrospective studies of the Tohoku-oki earthquake deformation captured by the GEONET demonstrated that accurate tsunami inundation predictions could be provided within 5 minutes of the earthquake occurrence.

In this session, we solicit papers on topics related to the realization of such a system, including instrumentation, data collection and availability, modeling, forecasting/nowcasting, and software development, as well as capacity building and linkages to international organizations, the Sendai Framework for Disaster Risk Reduction, and UN Sustainable Development Goals.

[U04-01] Operation of REGARD: Real-Time GNSS analysis system in Japan

*Hiroki MURAMATSU[1], Satoshi ABE[1], Satoshi KAWAMOTO[2], Yusaku Ohta[3] (1.GSI of Japan, 2.Cabinet Office of Japan, 3.Research Center for Prediction of Earthquakes and Volcanic Eruptions, Graduate School of Science, Tohoku University,)

[U04-02] Tsunami early warning system in Japan and plans towards practical uses of GNSS data to tsunami warning operation of the JMA

★Invited Papers

*NISHIMAE Yuji[1], ISHIKAWA Norihiko[2] (1.Japan Meteorological Agency, 2.Geospatial Information Authority of Japan)

[U04-03] GNSS Tsunami Early Warning: Implementing the Sendai Framework for Disaster Risk Reduction

★Invited Papers

*John L LaBrecque[1], Diego Arcas[2], Gerald Bawden[3], Allison B. Craddock[4], Lorraine Hwang[5], Shunichi Koshimura[6], Basara Miyahara[7], Yasuku Ohta[8], John Rundle[9] (1.Chair, IUGG Commission on Geophysical Risk and Sustainability (GeoRisk Commission), 2.NOAA Center for Tsunami Research , 3.NASA Headquarters, Natural Hazards Research and GNSS Science Team, 4.Director, Central Bureau IGS & Jet Propulsion Laboratory, 5.Director Computational Infrastructure for Geodynamics, Univ. Californinia, Davis, 6.International Research Institute of Disaster Science, Tohoku University, 7.President, Global Geodetic Observing System & Director, Space Geodesy Div. , Geospatial Information Authority of Japan , 8.Graduate School of Science, Tohoku University, 9.Professor, Univ. California, Davis)

[U04-04] Coupled Earthquake-Tsunami-TEC Simulator in a Parallel HPC Environment

*John B Rundle[1], David Grzan[1], John Wilson[1], Kasey Schultz[1], Steven Ward[2] (1.University of California Davis, 2.University of California Santa Cruz)

[U04-05] GNSS Total Electronics Contents tsunami measurements and tsunami height inversions.

*Philippe Henri Lognonné[1], Lucie Rolland[2], Giovanni Occhinpinti[1], Elvira Astafeyva[1], Mala Bagiya[3], Khaled Khelfi[4], Virgile Rakoto[4] (1.Université de Paris, Institut de physique du globe de Paris, CNRS, 2.Laboratoire Géoazur - Université de Nice Côte d'Azur Bureau 208 - Bâtiment 4 250 rue Albert Einstein 06560 Valbonne - France, 3.Indian Institute of Geomagnetism, Sector 18, Near Kalamboli Highway New Panvel(W), Navi Mumbai, 410218 India , 4.formerly at Université de Paris, Institut de physique du globe de Paris, CNRS)

[U04-06] GNSS-TEC-based tsunami early warning system: Tsunami ionospheric hole identification, 2D initial tsunami height estimation, and tsunami simulation

★Invited Papers

*Masashi Kamogawa[1], Toshiyasu Nagao[2] (1.Global Center for Asian and Regional Research, University of Shizuoka, 2.Institute of Oceanic Research and Development, Tokai University)

Operation of REGARD: Real-Time GNSS analysis system in Japan

*Hiroki MURAMATSU[1], Satoshi ABE[1], Satoshi KAWAMOTO[2], Yusaku Ohta[3]

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The displacement data produced by GNSS observations never saturate for large earthquakes in contrast to seismometer data that has a limitation of instrument saturation. Geospatial Information Authority of Japan (GSI) and Tohoku University developed a real-time GNSS analysis system named REGARD (Real-time GEONET Analysis System for Rapid Deformation monitoring), which estimated finite fault models based on the Japanese nationwide GNSS CORS network named GEONET.

REGARD has three subsystems: (1) the real-time positioning subsystem, (2) the event detection subsystem and (3) the fault model inversion subsystem. This system always conduct real-time kinematic analysis of ~1200 stations of GEONET. If REGARD receives an earthquake information from earthquake early warning system managed by the Japan Meteorological Agency or detect large displacement using RAPiD algorithm (Ohta et al., 2012), the inversion subsystem is started. Two types of finite-fault model are automatically estimated by a single rectangular fault model, which is available for both inland and subduction zone earthquakes and slip distribution model, which is suitable for grate subduction zone earthquakes. Estimated Mw from each fault model are sent to the relevant people.

REGARD has already detect several earthquake events. 2016 Kumamoto earthquake (Mw 7.0 (GCMT)) was the first time to estimate GNSS-based fault model in real-time in Japan. The system estimated Mw 6.96 and VR 96.2% within 5 minutes after the event occurred. Although REGARD could not estimate approximate fault model because of the small displacement, it successfully detected crustal deformation in many events. This system is useful for monitoring crustal deformation as well as estimating fault parameter.

Although REGARD shows potential for estimating fault model supporting early tsunami warning, the system has not yet been optimized. We keep trying to improve REGARD for operating under less cost and robustness conditions.

Keywords: GNSS

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Tsunami early warning system in Japan and plans towards practical uses of GNSS data to tsunami warning operation of the JMA

*NISHIMAE Yuji[1], ISHIKAWA Norihiko[2]

1. Japan Meteorological Agency, 2. Geospatial Information Authority of Japan

A tsunami warning must be issued immediately after occurrence of an earthquake because many earthquakes occur near coasts and a tsunami hits coasts in a short time in Japan. The Japan Meteorological Agency (JMA) issues a tsunami warning in about three minutes. Numerical tsunami simulation is a powerful tool to predict a tsunami. Numerical tsunami simulation takes a long time and the time are not adequate to terminate calculation up to issuance of a tsunami warning. For this reason, the JMA calculates a lot of tsunami simulations to various source models in advance and creates a database of tsunami scenarios. And when an earthquake actually occurs, the closest scenario are chosen from the database based on the hypocenter and magnitude of the earthquake, and a tsunami warning can be issued in about 3 minutes. The magnitude called JMA magnitude (Mjma) is used the first warning to ensure issuance of a tsunami warning in about 3 minutes. The amplitude of seismic waves with short periods is used for quick estimation of Mjma. Mjma based on the short-period waves is saturated in case of a huge earthquake. As a result, the size of the earthquake is likely underestimated. Actually, in case of the Great East Japan Earthquake, the JMA could quickly obtain Mjma and could issue a tsunami warning in about 3 minutes. The estimated Mjma was 7.9 and it was by far smaller than moment magnitude (Mw) of 9.0 and that led underestimation of the tsunami heights. The JMA have developed several methods how to evaluate underestimation of Mjma. And if underestimation of Mjma is evaluated using those methods, the JMA will issue a tsunami warning based on the largest assumed tsunami heights or the largest size of the earthquake in the region. And then, after the accurate Mw will be obtained by CMT analysis or W-phase analysis, the tsunami warning will be updated. The JMA have also updated or lifted the tsunami warning using sea level changes observed by offshore and coastal tide gauges besides the earthquake data. The Meteorological Research Institute of the JMA developed the new method called tsunami Forecasting based on Inversion for initial sea-Surface Height (tFISH) to predict more accurate tsunami heights. tFISH is a method for predicting tsunami heights along coasts from distributions of initial tsunami heights at the tsunami source estimated by inverse analysis of tsunami waveforms observed at offshore tsunami meters. tFISH has been used to update a tsunami warning since March 2019.

The Geospatial Information Authority of Japan (GSI) has operated GNSS Earth Observation Network System (GEONET) which consists of more than 1000 GNSS sites. The GSI recently developed the REal-time GEONET Analysis system for Rapid Deformation monitoring (REGARD) (Kawamoto et al., 2017). REGARD can rapidly and automatically estimate a rectangular fault model or slip distributions on plate boundaries based on permanent displacements which are generated at the GNSS sites by an earthquake. In post-evaluation of the Great East Japan Earthquake, REGARD could estimate Mw 8.8 in about three minutes (Kawamoto et al., 2017). If Mw by REGARD could be obtained in time up to issuance of a tsunami warning, the Mw might be used for evaluation of underestimation of Mjma.

The JMA has considered criteria and procedures for utilization of Mw by the REGARD in cooperation with the GSI and has used to update tsunami warning as a trial in tsunami warning operation since March 2019 if solutions of all of CMT analysis are estimated in low quality. The JMA has plan to use a rectangular fault model or slip distributions estimated by REGARD as the initial source of real-time numerical tsunami simulation. The JMA is now exploring potential for abovementioned utilizations of REGARD.

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REGARD: A new GNSS-based real-time finite fault modeling system for GEONET, J. Geophys. Res. Solid Earth, 122, 1324-1349, 2017

Keywords: tsunami, GNSS, tsunami warning, REGARD

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GNSS Tsunami Early Warning: Implementing the Sendai Framework for Disaster Risk Reduction

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1. Chair, IUGG Commission on Geophysical Risk and Sustainability (GeoRisk Commission), 2. NOAA Center for Tsunami Research , 3. NASA Headquarters, Natural Hazards Research and GNSS Science Team, 4. Director, Central Bureau IGS & Jet Propulsion Laboratory, 5. Director Computational Infrastructure for Geodynamics, Univ. Califorinia, Davis, 6. International Research Institute of Disaster Science, Tohoku University, 7. President, Global Geodetic Observing System & Director, Space Geodesy Div. , Geospatial Information Authority of Japan , 8. Graduate School of Science, Tohoku University, 9. Professor, Univ. California, Davis

The GTEWS 2017 workshop reported that Global Navigation Satellite Systems (GNSS) will enhance tsunami early warning systems with an accurate and sustainable system that could bring additional economic benefits to coastal societies and island nations of the Indo-Pacific region. GNSS analysis systems can provide an accurate estimate of earthquake magnitude and the associated finite fault displacement within 2 minutes of a major earthquake. This information can be used to predict the likelihood and the scale of a resulting tsunami within 5 minutes of the earthquake occurrence. Within ten to fifteen minutes of the earthquake occurrence, GNSS based ionospheric imaging can identify and track tsunami development from onset to propagation across the ocean basin. Implementation of GNSS Tsunami Early Warning Sensor (GTEWS) enhancement to existing systems will bring accuracy, affordability and sustainability to tsunami risk reduction for the Indo-Pacific.

Though seventeen agencies of twelve nations have endorsed GTEWS enhancement within the Global Geodetic Observing Systems Geohazards Initiative, there is much to be done to take full advantage of this new technology for the Indo-Pacific region. The challenges to GTEWS implementation include national policies on data sharing, commercial and agency programmatic decisions, communications and computing resource allocations, and the technical challenges of integrating GTEWS into existing tsunami warning systems. The Group on Earth Observations has adopted GTEWS enhancement as a goal of its Geodesy4Sendai community activity in response to the UNDRR call to implement the recommendations of the Sendai Framework for Disaster Risk Reduction. This presentation will discuss the recommendations of the GTEWS 2017 workshop and the follow-on GTEWS 2020 workshop focused upon the implementation of GTEWS for the Indo-Pacific.

Reference: GTEWS 2017 Workshop Report, 2019, LaBrecque, J.; Rundle, J. et al. Global navigation satellite system enhancement for tsunami early warning systems. Contributing Paper to GAR 2019 (https://www.preventionweb.net/publications/view/66779)

Keywords: Tsunami, GGOS, GTEWS, GNSS

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Coupled Earthquake-Tsunami-TEC Simulator in a Parallel HPC Environment

*John B Rundle[1], David Grzan[1], John Wilson[1], Kasey Schultz[1], Steven Ward[2]

1. University of California Davis, 2. University of California Santa Cruz

We describe the implementation of a tsunami simulator code in a parallel High Performance Computing environment using the Tsunami Squares method first proposed by SN Ward. Due to the destructive nature of tsunamis, early warning systems are necessary to avoid loss of human life. This talk outlines the groundwork for such a system that will link Total Electron Content signatures of tsunamis detected by GNSS satellites to maps of inundated areas along the coast. The tsunami simulator that will be used for this early warning system is called Tsunami Squares, a simulator that utilizes a numerical method of solving the shallow water approximation equations over a grid of cells. To validate its accuracy, it was compared to the Regional Ocean Modeling System tsunami simulator, a simulator that solves the Navier-Stokes equations using a finite-difference method. The two simulation techniques showed good agreement over a variety of tests using several different initial conditions. As a preliminary step to creating the early warning method, many earthquakes off the coast Japan were simulated and from those earthquakes, tsunamis were simulated. From the simulated tsunamis, the runup heights along the coast were averaged and mapped, giving us a catalog of earthquakes and inundated locations. Examples of simulation movies for both Pacific Basin-wide and local inundation on the Sanriku coast are available. Unlike purely hydrodynamic codes, Tsunami Squares has the advantage that inundation and runup can be computed directly.

In future works, we plan to combine these methods with our earthquake and tsunami nowcasting methods to enable forecasting of both tsunami occurrence in tsunamigenic zones, as well as forecasting of potential coastal runups.

Keywords: Earthquake and Tsunami Simulation, Earthquake and Tsunami Nowcasting, Geodesy4Sendai

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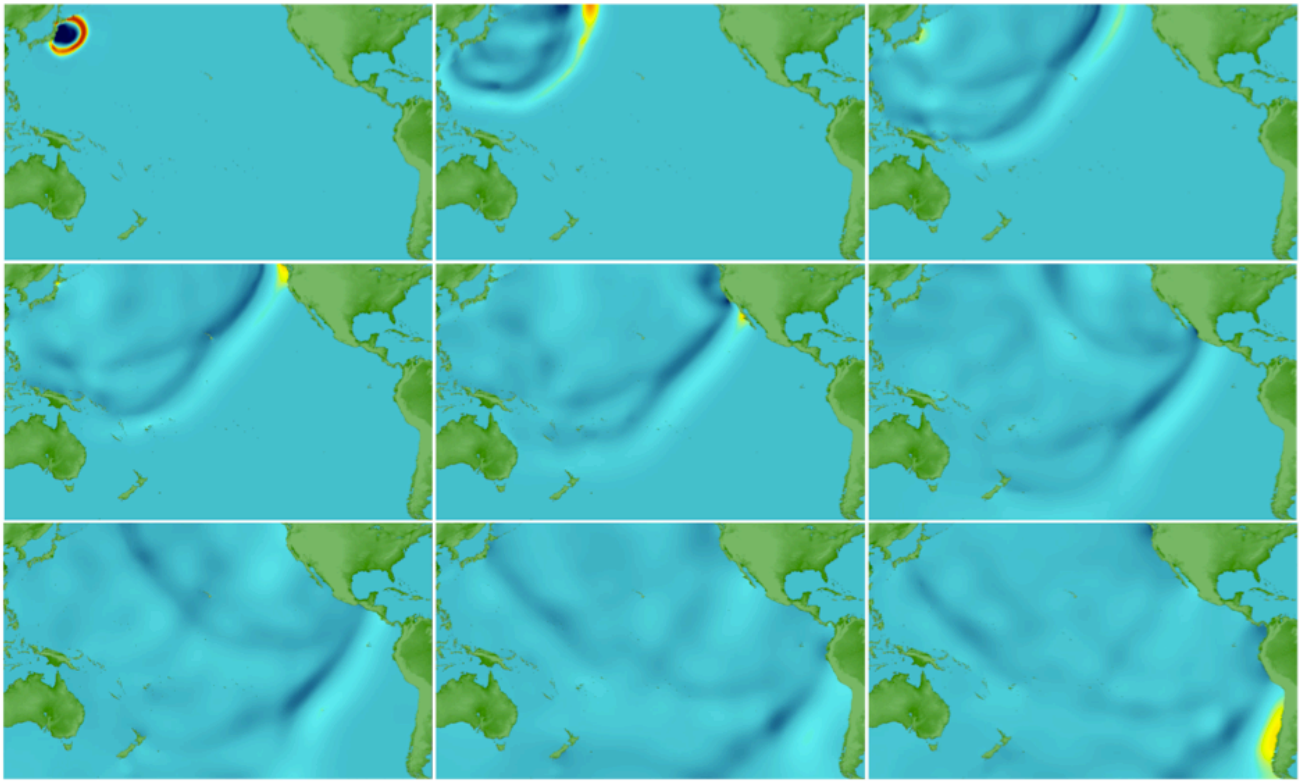

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GNSS Total Electronics Contents tsunami measurements and tsunami height inversions.

*Philippe Henri Lognonné[1], Lucie Rolland[2], Giovanni Occhinpinti[1], Elvira Astafeyva[1], Mala Bagiya[3], Khaled Khelfi[4], Virgile Rakoto[4]

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GNSS Total Electronic Content (TEC) measurements provide an additional coverage of GNSS ground motion measurements to estimate the tsunami risk and tsunami amplitude off-shore. Geometrically, the ionospheric TEC measurements (sounding the ionosphere at 300 km of altitude along the station-satelite ray-path, so called ionospheric piercing points) extents the monitoring zone up to two thousands of km from the physical location of the GNSS ground stations enabling therefore remote measurements offshore. In addition, theories and modeling of the ionospheric signals have now reached a maturity to allow estimation of oceanic displacement produced by the tsunami, with errors of about 10%. Those results include moderate tsunamis with less than 5 cm of oceanic displacement. GNSS TEC measurements are therefore complementing nicely land-surface, sea-surface and sea-floor seismic, geodetic and pressure networks. Additionally, to extend the coverage, GNSS stations can be easily installed on airbornes, vessels or buoys as dual frequency ionospheric sounding are not sensitive to the displacement of the GNSS receiver .

We review first the state of the art of observations, for both ground based GNSS networks and space GNSS occultations (e.g., COSMIC), as well as the efficiency in the to reproduce the tsunami sisgnature in the ionosphere. Numerical modeling are shown with various technics, such as tsunami normal modes summation or spectral elements methods, compared to data and then used to estimate the sea-level height waveform, with excellent waveform matching compared to those recorded by DARTs.

We present observations and modeling close to the epicenter –where the ionospheric TEC perturbation is visible at 7 minutes after the rupture- in order to estimate the tsunami risk; as well as in the far-fiel, off-shore, where we show that the TEC measurement can strongly support the tsunami high estimation during oceanic propagation. We discuss also the impact of the ionospheric dynamics in the signal to noise ratio. We finally conclude by the perspectives offered by TEC measurements in the improvements of oceanic monitoring and tsunami warning systems.

Keywords: tsunami, ionosphere, TEC

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GNSS-TEC-based tsunami early warning system: Tsunami ionospheric hole identification, 2D initial tsunami height estimation, and tsunami simulation

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Tsunami-generated ionospheric plasma disturbances have been measured by the total electron content (TEC) between a satellite and its ground-based receivers in Global Navigation Satellite System (GNSS). TEC depression lasting for a few minutes to tens of minutes, i.e., tsunami ionospheric hole (TIH), is formed above the tsunami source area. According to Kamogawa et al. [Scientific Reports, 2016], the quantitative relationship between the maximum initial tsunami height and the TEC depression rate caused by the TIH was shown. In addition, the largest TEC depressions appeared 10 to 20 minutes after the main shocks. These imply that the TIH measurement using the existing ground GNSS receiver networks were potentially used in an early warning system for near-field tsunamis. Applying our knowledge to space-based early warning system, we are developing the feasible warning system.

In the presentation, we show the procedure of our systems: 1) Identification of TIH from the tsunami-generated ionospheric plasma disturbances. 2) Estimation of 2-D initial tsunami height from 2-D TEC depression rate in the TIH. 3) Tsunami simulation based on the estimated initial tsunami height. In our tsunami calculation, we used JAGURS code [Baba et al., Pure Appl. Geophys., 2015].

Keywords: Tsunami, Ionosphere

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[E] Oral | U (Union)：Union

[U-05] Advanced understanding of Quaternary and Anthropocene hydroclimate changes in East Asia

convener:Chuan-Chou Shen(High-Precision Mass Spectrometry and Environment Change Laboratory, Department of Geosciences, National Taiwan University), Yusuke Yokoyama(Atmosphere and Ocean Research Institute, University of Tokyo), Kaoru Kubota(Graduate School of Human Development and Environment, Kobe University), Li Lo(Department of Geosciences, National Taiwan University), Chairperson:Chuan-Chou Shen(High-Precision Mass Spectrometry and Environment Change Laboratory, Department of Geosciences, National Taiwan University), Chairperson:Yusuke Yokoyama(Atmosphere and Ocean Research Institute, University of Tokyo), Chairperson:Kaoru Kubota(Kochi Institute for Core Sample Research, JAMSTEC), Chairperson:Li Lo(Department of Geosciences, National Taiwan University)

For the sustainability of biosphere and human society, it is crucial to in-depth understand Earth climate system changes on different timescales in Quaternary. Anthropogenic forcing is also strongly affecting different aspects of human living environments, natural ecological through physical and chemical climatic perturbations, especially in East Asia with swift economic takeoff in the recent decades. We welcome climate and environmental reconstructions based on natural archives, proxy data, numerical simulations especially on the topics of monsoon, precipitation belt shifting, typhoon, and drought histories in Quaternary and Anthropocene. Atmospheric and oceanic interactions, greenhouse gases radiative forcing and anthropogenic forcing impact from regional to global scale are also welcomed.

[U05-01] Meaning of stalagmite oxygen isotopes
★Invited Papers

*Akihiro Kano[1] (1.Graduate School of Science, The University of Tokyo)

[U05-02] **Late-Holocene anthropogenic impact on tropical climate**
★Invited Papers

*Yair Rosenthal[1], Samantha Claudia Bova[1], Zhengyu Liu[2], Mi Yan[3] (1.Rutgers University, 2.Ohio State University, 3.Nanjing Normal University)

[U05-03] Evolution of meridional and zonal sea surface temperature gradients in the Pacific Ocean during the Quaternary period
★Invited Papers

*Takuya Sagawa[1], Risako Makino[2], Yukimi Kubota[2], Yoshimi Kubota[3], Yair Rosenthal[4] (1.Institute of Science and Engineering, Kanazawa University, 2.School of Science and Engineering, Kanazawa University, 3.National Museum of Nature and Science, 4.Rutgers University)

[U05-04] How do marine microplankton survive during global warming?
★Invited Papers

*Yurika Ujiie[1], Kyoko Hagino[1], Tatsuhiko Hoshino[2], Jeremy R. Young[3], Ian Probert[4], Richard Jordan[5] (1.CMCR, Kochi University, 2.JAMSTEC, 3.University College London, 4.Roscoff Biological Station, 5.Yamagata University)

[U05-05] Periodical enhancements of multi-decadal hydroclimate variations in central Japan and its implication for the 2600-year East Asian history
★Invited Papers

*Takeshi Nakatsuka[1] (1.Nagoya University)

[U05-06] Benthic biotic response to Quaternary climate changes in the Sea of Japan and other Asian regions
★Invited Papers

*Moriaki Yasuhara[1] (1.University of Hong Kong)

Meaning of stalagmite oxygen isotopes

*Akihiro Kano[1]

1. Graduate School of Science, The University of Tokyo

Stalagmite oxygen isotope records have been reported from elsewhere in the world, and explained by intensity of the monsoonal rainfall during Late Quaternary. For example, the records from China where it rains mainly in summer indicate the variability in East Asian summer monsoon (EASM). However, there has been counterstatements that other factors certainly reflect on the stalagmite oxygen isotopes.

Well-dated stalagmites collected from Hiroshima, Gifu and Mie prefectures in Japan appear a similar trend but much smaller amplitude of oxygen isotopic ratio than the Chinese stalagmite. A prominent feature of the 83 kyr record of Mie stalagmite is a long-term trend that follows the change in seawater oxygen isotopes. This is because the seawater is the main moisture source of the meteoric water for the Mie stalagmite. Considering the change in the seawater oxygen isotope, the residual variability can be ascribed to a presumable temperature change in the last 83 kyr. Estimated difference between the mid-Holocene and the last glacial maximum and cooling of Heinrich events were 9ºC and < 3ºC, respectively (Mori et al. 2018). Thus, the intensity of EASM was rather a minor factor for the oxygen isotopes of the Japanese stalagmite.

Stalagmites from Niigata prefecture reveal another example showing importance of the seawater oxygen isotopes. The cave at Itoigawa where moisture from the Japan Sea delivers heavy snow in winter, is unique in an aspect of the stalagmite records. Unusually low oxygen isotopic ratio during the last glacial cannot be explained by lowered temperature neither by intensified East Asian winter monsoon. The most likely factor is the lowered oxygen isotope of the Japan Sea surface water during the last glacial, which has been suggested in the marine isotopic records. Comparison with the Pacific side records, the evaluated amplitude of the lowering was around 3‰.

Control of the monsoonal intensity, i.e. the amount effect is disputable for the Japanese stalagmites, and it should be re-examined for the Chinese records. An understated factor for the oxygen isotopes of the Chinese stalagmite is continentality, i.e. the distance from coast. Because the Chinese coast side of the East China Sea is a shallow shelf, the continentality of the Chinese caves is sensitive to the sea-level change, which amplifies the changes in stalagmite isotopes.

Keywords: stalagmite, oxygen isotopes, paleoclimate

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Late-Holocene anthropogenic impact on tropical climate

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Climate models indicate that rising *preindustrial* greenhouse gas (GHG) levels since 7 ka caused increase in mean annual temperatures (MAT) comparable to that observed since the industrial revolution. However, geochemical temperature proxies offer inconsistent evidence, which was termed “*The Holocene Conundrum*”. Specifically, Mg/Ca records in planktonic foraminifera from the Western Pacific warm pool (WPWP) record cooling in direct opposition to alkenone derived temperature records from the South China Sea and to simulated trends. Here, we present a new, centennially resolved record of planktic foraminifer (*G. ruber ss*) Mg/Ca-derived sea surface temperatures (SSTs) spanning the current*and* last interglacial (LIG) periods from the WPWP and compare these data to two transient climate simulations. Taking advantage of a stronger seasonal contrast during the LIG, we demonstrate that Mg/Ca-derived SSTs reflect late Fall SSTs, rather than mean annual. Applying this seasonal relationship to the Holocene, we reconcile the proxy record with model output, assess the WPWP SST sensitivity to GHGs, and ultimately confirm that preindustrial warming has doubled the anthropogenic total. We will also examine possible effects on precipitation in the Western Pacific warm pool.

Keywords: Quaternary, Holocene, tropics

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Evolution of meridional and zonal sea surface temperature gradients in the Pacific Ocean during the Quaternary period

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Long-term change of meridional and zonal temperature gradients in the Pacific Ocean is key to understanding the evolution of the global climate change. The asymmetric zonal SST pattern in the modern tropical Pacific, i.e. warm pool in the west and cold tongue in the east, has been gradually evolved since the Plio-Pleistocene climate transition. This zonal SST gradient has been attributed to a strengthening of the Walker Circulation. Here, we conduct planktonic foraminiferal Mg/Ca temperature reconstruction in the western Pacific warm pool (WPWP) using two species, Globigerinoides ruber sensu stricto and Trilobatus trilobus. In the modern tropical Pacific, both species calcify in mixed layer and show similar Mg/Ca temperature with a bit deeper signature in T. trilobus. Our temperature reconstruction using T. trilobus is consistent with that of ODP806, which is also in WPWP region, indicating regional representativeness. Temperature reconstruction using G. ruber is significantly higher than that using T. trilobus before 1.7 Ma, suggesting a deepening of the western thermocline at that time. This vertical temperature gradient change is accompanied by SST drop in the eastern equatorial Pacific. Therefore, our data support the strengthening of the Walker Circulation. Further, both northern and southern subpolar SST dropped at similar timing, which indicates a steepening of the meridional temperature gradient. We infer that the strengthening of the Walker Circulation at 1.7 Ma was induced by the steepening of meridional temperature gradient in the course of Northern Hemisphere Glaciation.

Keywords: Sea surface temperature, Pacific Ocean, Quaternary

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How do marine microplankton survive during global warming?

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1. CMCR, Kochi University, 2. JAMSTEC, 3. University College London, 4. Roscoff Biological Station, 5. Yamagata University

Global warming has been accelerating since the 1990s and has dynamically changed the global environment, often leading to climate hazards. Marine microplankton, particularly phytoplankton, play important roles in driving biogeochemical cycles because they are CO_2consumers in the atmosphere–ocean CO_2 exchange, and exporters of organic and inorganic compounds in the water column through the biological pump. There is growing concern that global warming significantly modifies the habitats of microplankton, and so their biogeochemical functions could be impaired resulting in reduced CO_2 absorption by the marine ecosystem. However, the impact of anthropogenic climate change on marine microplankton has been poorly investigated based on actual measurements. The present study enables us to directly observe the photic biosphere before the acceleration of global warming. The Okada & McIntyre collection of filter (0.8–64 μm) samples from ~6000 sites across the world ocean in the 1960–1970s represents a unique resource for the investigation of microplanktic diversity from half a century ago. We are employing both morphological and molecular techniques to these collections to unveil species diversity. Extracted DNA from the filter samples are enough quality to be used for Next Generation Sequencing (NGS) metabarcoding. This metabarcoding can be compared with those of the TARA-Oceans expeditions, which provided the database of the current genetic diversity of plankton communities in the world ocean.
Our first priority is to study the calcifying phytoplankton coccolithophores among the microplankton, because they crucially contribute to the carbon, nitrogen and other cycles via the calcification of coccoliths and their symbiotic relationship with bacteria. Morphological studies of modern coccolithophores have provided knowledge on their ecology, physiology, and geochemical roles. A comprehensive survey of morphological-genetic approaches can reveal the changes of species composition and geographic distribution of coccolithophores in the late Anthropocene. These changes will be related to the actual response of marine microplankton to global warming and will help to improve our prediction of the future impact of climate change on the marine biosphere.

Keywords: anthropogenic climate change, marine diversity, phytoplankton, biogeochemical role

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Periodical enhancements of multi-decadal hydroclimate variations in central Japan and its implication for the 2600-year East Asian history

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In general, it is not easy to extract low-frequency climate signals from tree rings because they usually overlap with biological age trends. Although oxygen isotope ratio ($\delta^{18}O$) of tree-ring cellulose, a novel proxy of summer hydroclimate in monsoonal Asia, is often free from the age effect, conifer trees sometimes show significant $\delta^{18}O$ age trends. Here, we propose a new method to reconstruct past hydroclimate variations seamlessly from annual to millennial time scales by integrating tree-ring cellulose oxygen and hydrogen ($\delta^{2}H$) isotope ratios (Nakatsuka et al., 2020; https://doi.org/10.5194/cp-2020-6). By analyzing many old conifers, we have found that there are always positive correlations between short-periodicity $\delta^{18}O$ and $\delta^{2}H$ variations and sometimes negative correlations between long-periodicity $\delta^{18}O$ and $\delta^{2}H$ variations, reflecting climatological and physiological factors, respectively. Because the gradual $\delta^{18}O$ decrease and $\delta^{2}H$ increase can be explained by growth-related physiological changes, we can cancel the physiological effect and extract the climatological component ($\Delta\delta^{18}O_{cel(climate)}$) in tree-ring cellulose $\delta^{18}O$ by solving simultaneous equations of $\delta^{18}O$ and $\delta^{2}H$. We apply this procedure to a 2600-year chronology of tree-ring $\delta^{18}O$ and $\delta^{2}H$ made of 67 samples of excavated wooden artifacts, old architectural woods, and naturally buried logs in addition to old living trees in central Japan and demonstrate that long-periodicity variations in $\Delta\delta^{18}O_{cel(climate)}$ agree well with multi-millennial summer hydroclimate variations reconstructed by other global and regional low-frequency proxies. It indicates that the $\Delta\delta^{18}O_{cel(climate)}$ can be a seamless proxy of long- and short-periodicity summer hydroclimate variations in East Asia.

So far, the short-periodicity climate variations in ancient eras have been seldom discussed either from natural or historical viewpoints. Because the $\Delta\delta^{18}O_{cel(climate)}$ chronology may contain many undiscovered information in all frequencies, it is worth analyzing its short-periodicity variations in the distant past. Here, we propose a new analytical framework to identify vulnerability of historical societies against climate changes with special focus on climate periodicity. First, we make a simple model to describe "climate-production-storage-population" dynamics for pre-modern agricultural societies and propose a working hypothesis that multi-decadal climate variations are most critical for human societies because neither crop storage nor demographic adjustment can function for the multi-decadal variations. Second, we investigate periodicity of the 2600-year $\Delta\delta^{18}O_{cel(climate)}$ chronology in central Japan and find that multi-decadal variations are enhanced every 400 years, possibly caused by multi-centennial solar cycles, corresponding to the so-called dynastic cycle in China and the quasi-simultaneous political regime shifts in surrounding countries like Japan and Korea. Third, we compare the chronology with various historical societal parameters in East Asia (yearly data on agricultural productions, famines and peasant uprisings during 16-19th CE centuries in Japan and decadal frequency on internal wars during 3rd BCE –20th CE centuries in China). Statistical analyses on the climate-society relationships clearly demonstrate that crop failures due to large multi-decadal hydroclimate variations actually caused famines and social conflicts and often resulted in political regime shifts in East Asia. There are also substantial exceptions where people could avoid social collapse due to the multi-decadal hydroclimate variations, from which we can extract important lessons, applicable to contemporary global environmental issues, by spatiotemporal comparisons of social vulnerability against hydroclimate variations in the long East Asian history.

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Keywords: East Asia, multi-decadal climate variation, tree ring, oxygen isotope ratio, hydrogen isotope ratio, history

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Benthic biotic response to Quaternary climate changes in the Sea of Japan and other Asian regions

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1. University of Hong Kong

The Sea of Japan is a marginal sea, connecting to adjacent seas by four shallow straits (water depths <130 m). Marginal seas are ideal for studying biotic responses to large-scale environmental changes as they often are sensitive to glacial-interglacial and stadial-interstadial climatic cycles. However, only a limited number of studies cover time periods beyond the last two glacial-interglacial cycles. In this presentation, I will show long Quaternary records of benthic biotic response to paleoceanographic changes in the southern Sea of Japan, covering many glacial-interglacial cycles, based on ostracode assemblages at the Integrated Ocean Drilling Program (IODP) Site U1427 and U1426. The results indicate that orbital-scale oxygen variability in the bottom water has been the major control impacting the marginal-sea biota, and secular-scale faunal transitions are likely associated with the mid-Brunhes event (~0.43 Ma) and the onset of the Tsushima Warm Current (~1.7 Ma). Benthic ecosystems in marginal seas are sensitive and vulnerable to both short- and long-term climatic changes, and the mid-Brunhes event is suggested to be a global biotic event affecting benthic ecosystems substantially. I will also introduce other recent examples of Asian biotic response studies.

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[E] Oral | U (Union)：Union

[U-06] Open Access, Open Data, and FAIR Data in Geosciences

convener:Hirokuni Oda(Institute of Geology and Geoinformation, Geological Survey of Japan, AIST), Hodaka Kawahata(Atmosphere Ocean Research Institute, the University of Tokyo), Brooks Hanson(American Geophysical Union)

Scientific products including journal publications, reports and data are invaluable resources for human beings. These days, open access, open data, and FAIR data policies are becoming more and more important for sustainable society and research developments. In the proposed session, we discuss the topics in Geosciences following the presentations by the keynote speakers invited from leading organizations.

[U06-01] Open access and open data: the publisher perspective

★Invited Papers

*Paola Teti[1], Toby Charkin[1], Samuel Winthrop[1] (1.Springer Nature)

[U06-02] Enabling FAIR Data in the Earth, Space, and Environmental Sciences: Encouraging all Researchers to Document, Share, and Cite Scientific Data

★Invited Papers

*Shelley Stall[1] (1.American Geophysical Union)

[U06-03] Preprint is ready, data sharing is still difficult, what scholarly community should do in 2020's?

★Invited Papers

*Kazuhiro Hayashi[1] (1.National Institute of Science and Technology Policy)

[U06-04] An Attempt to Discuss Scientific Outputs including papers and digital data in the Open Science scene

★Invited Papers

*Yasuhiro Murayama[1] (1.Strategic Program Produce Office, National Institute of Information and Communications Technology)

Discussion

Discussion

Open access and open data: the publisher perspective

*Paola Teti[1], Toby Charkin[1], Samuel Winthrop[1]

1. Springer Nature

The publishing landscape is going through many changes in policy and culture. The future of research development is based on the concept of open research, aiming to publish research results with immediate open access in a transparent and economically sustainable way.

Many initiatives have been undertaken to facilitate the transition of journals to open access. Transformative agreements embraced by funders, research institutions, publishers and scientific societies, will ultimately enable researchers to publish their work openly through sustainable models that take into account different policies and market influences.

Another key component of this transformation towards open research is ‘open data’. In 2019 a Springer Nature white paper (Lucraft et al. 2019), based on a survey of more than 11,000 international researchers, set out key challenges in data management and data sharing. While data sharing is increasing, and the majority of researchers see data sharing as important and a priority, the majority of researchers are not yet managing or sharing data in ways that make them FAIR (Findable, Accessible, Interoperable, and Reusable) - a growing requirement for many global research funders.

In this presentation we will discuss the initiatives publishers are launching to help researchers in this journey towards open research, and the measures they are taking to make data sharing the norm.

Keywords: open access, open data, open science, open research, data sharing, research data

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Enabling FAIR Data in the Earth, Space, and Environmental Sciences: Encouraging all Researchers to Document, Share, and Cite Scientific Data

*Shelley Stall[1]

1. American Geophysical Union

AGU’ s data position statement, recently updated, affirms that **“Earth and space science data are a world heritage, and an essential part of the science ecosystem. All players in the science ecosystem—researchers, repositories, publishers, funders, institutions, etc.—should work to ensure that relevant scientific evidence is processed, shared, and used ethically, and is available, preserved, documented, and fairly credited.”**
(https://www.agu.org/Share-and-Advocate/Share/Policymakers/Position-Statements/Position_Data)

The statement includes key objectives for the Geosciences:
Champion Open and Transparent Data Enable a Robust Science Ecosystem Create Effective Culture Change
Our research ecosystem is diverse and interconnected involving researchers, publishers, editors, repositories, institutions, librarians, societies, funders and more. The effort to evolve practices for open and FAIR data sharing in support of Open Science requires all participants.

At the American Geophysical Union we are convening and encouraging adoption of updated data practices across the ecosystem to support open and FAIR data and the resources needed by researchers to comply with this updated guidance. The Enabling FAIR Data Commitment Statement gives a path specific to each stakeholder to support progress.
(https://copdess.org/enabling-fair-data-project/commitment-statement-in-the-earth-space-and-environmental-sciences/)

With JpGU, EGU, and AOGS as partners in this effort, we continue to steadily make progress toward making open and FAIR data a common practice in the Geosciences. We will share the current progress and provide recommendations for how participants can encourage incremental actions in their own organizations.

Keywords: Open Science, Open Data, FAIR Data

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Preprint is ready, data sharing is still difficult, what scholarly community should do in 2020’s?

*Kazuhiro Hayashi[1]

1. National Institute of Science and Technology Policy

Open Science is aiming digital transformation of Science, Society including Industry, and Science and Society. Open Science Policy has encouraged researchers to share their data as much as possible to accelerate their research, collaboration, and innovation. However, current activities are lack of incentives to drive research data sharing directly, it also needs some time to have them change their culture. For example, the 2nd survey of NISTEP in 2018 with comparison of 2016 to monitor research data sharing revealed that Japanese researchers are still reluctant to share research data, while they promote open access to share their research papers.

While research data sharing is still difficult to implement, current established scholarly communication based on journal and article is changing significantly. Especially, preprint server is now getting popular even in the medical field to get their priority. Furthermore, as series of publication regarding Coronavirus (COVID-19) indicates, preprint on preprint server is having a certain impact to both of research community and society, casting many issues to scholarly community especially on quality control.

It is obvious that Scholarly journals must be compatible with preprint server and data sharing scheme as of evidence of the paper. However, in 2020’s, scholarly journals is getting more into re-designing whole framework of journal publishing itself, setting preprint as more authorized publishing, changing the process of when and how the preprint should be filtered, and also who should filter it. It also changes the role of editing. These trials could be a transition state towards digital native scholarly communication which is currently understandable but not accepted to all researchers.

Keywords: Scholarly communication, preprint server, peer review, journal publishing, Open Science

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An Attempt to Discuss Scientific Outputs including papers and digital data in the Open Science scene

*Yasuhiro Murayama[1]

1. Strategic Program Produce Office, National Institute of Information and Communications Technology

Today's Open Science movement is to re-consider research outputs (papers, data etc.), in particular in the form of digital information in this era with the Internet infrastructure. Traditional styile, culture and scholarly community norm of conducting scientific research, publishing research outputs and evaluating/rewarding their results have been successful in advancing science, technology and innovation. In the change concerned, from the printing technology to the electronic (and often digital) infrastructure, we will be able to conduct science in different ways. This doesn't mean necessarily a mandate for scientists to change their daily lives while efficiency and sustainability in an economical and scientific sense would be to a moderate encouragement and better motivation fo scientists to change the way of science. The author's intention is to discuss and promote Open Science in the international policy scene, science academies, and learned societies in order to optimize the way of science to enable better lives of scientists and citizens in the global community.

Keywords: open science, research data sharing, science policy

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[E] Oral | U (Union)：Union

[U-07] Diversity and equality - Where do we stand on gender equality or equity in the geosciences?

convener:Chiaki T. Oguchi(Institute for Environmental Science and Technology, Graduate School of Science and Engineering, Saitama University), Rie Hori, S.(Department of Earth Science, Faculty of Science, Ehime University), Claudia Jesus-Rydin(European Research Council), Hodaka Kawahata(Atmosphere Ocean Research Institute, the University of Tokyo), Chairperson:Rie Hori, S.(Department of Earth Science, Faculty of Science, Ehime University), Chairperson:Claudia Jesus-Rydin(European Research Council)

In the last decades efforts have been made to raise awareness on the under-representation of women in the geosciences. Numerous actions were initiated and supported by geosciences societies across the world, such as AGU, EGU and JpGU. Despite this, the progress is slow and the barriers complex, and the underrepresentation of women remains a reality.
Gender equality is not only a fundamental human right, but a necessary foundation for our society that must tap the potential of every talented mind to develop solutions for a sustainable future. The existence of under-representation of different groups (cultural, national, and gender) remains a reality and a threat to getting maximal value from research investment across STEM fields around the world, including the geosciences.
Professional societies have a privileged position to catalyse change by setting the tone and leading by example. Promoting fairness and inclusion, in a safe environment, to all members are common goals, which require effective concerted actions.
In this session, speakers will present and discuss data showing the evolution of women representation retrospectively. Furthermore, concrete examples of successful actions and future initiatives to bridge the gender gap in the geosciences are presented.

[E] Oral | U (Union)：Union

[U-08] Special session for a borderless World of Geoscience (GEOethics)

convener:Hodaka Kawahata(Atmosphere Ocean Research Institute, the University of Tokyo), Brooks Hanson(American Geophysical Union), Takashi Furumura(Earthquake Research Institute The University of Tokyo), Eiichi Tajika(Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo), Chairperson:Hodaka Kawahata(Atmosphere Ocean Research Institute, the University of Tokyo), Chairperson:Takashi Furumura(Earthquake Research Institute The University of Tokyo)

JpGU-AGU will have a joint meeting 2020 "For a borderless World of Geoscience". This symposium will present the viewpoint of leaders from the major geoscience societies (JpGU, AGU, EGU and AOGS), which are partner unions, who are also leading scientists representing exciting geoscience fields. The Earth and space science is essential the well-being of the humankind and sustainable environments. Some of the discussion topics will include: How shall we establish more reliance between Earth and planetary science and society ? A joint action plan/communique' is a desired outcome of this symposium.

[U08-01] The key role of Scientific Societies
★Invited Papers

*Brooks Hanson[1] (1.American Geophysical Union)

[U08-02] Climate science and social values
★Invited Papers

*Seita Emori[1] (1.National Institute for Environmental Studies)

[U08-03] How can we effectively utilize atmospheric forecasts that include uncertainties?
★Invited Papers

*Hisashi Nakamura[1] (1.Research Center for Advanced Science and Technology, University of Tokyo)

[U08-04] Communicating uncertainty of geoscience for the disaster risk reduction -Geoscience, the ambiguous, and ourselves-
★Invited Papers

*Satoko Oki[1] (1.Faculty of Environment and information Studies)

[U08-05] Transdisciplinary research on geoscience in society
★Invited Papers

*Makoto Taniguchi[1] (1.Research Institute for Humanity and Nature)

[U08-06] Geodiversity and its conservation as a framing guideline for Geoethics in 21st Century
★Invited Papers

*Abhik Chakraborty[1] (1.Wakayama University)

[U08-07] The AGU GeoHealth and Thriving Earth Exchange Programs: Engaging our Geoscience Community for a Sustainable Future
★Invited Papers

Brooks Hanson[1], Janice Lachance[1], *Billy M Williams[1] (1.American Geophysical Union)

The key role of Scientific Societies

*Brooks Hanson[1]

1. American Geophysical Union

Forming a borderless world of geoscience is critical for benefiting humanity and forming a vibrant sustainable future. Earth, environmental, and space science are critical for many societal challenges and for guiding decisions on these issues. AGU has recently developed a new strategic plan that includes recognition of the need for deeper engagement with society and the public for a sustainable future and expanded partnerships worldwide. We’ ll discuss the implications for scientific societies and the broader scientific community.

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Climate science and social values

*Seita Emori[1]

1. National Institute for Environmental Studies

The Future Earth, a currently operating international platform of sustainability science, calls for trans-disciplinarity, meaning co-designing and co-producing science with various non-academic stakeholders in the society. The need of trans-disciplinarity is justified from three perspectives: the logic of accountability, the logic of impact and the logic of humility (van der Hel, 2016). The logic of humility, which is often overlooked, essentially means that scientists should reflect on their own perceptions and values, which may be biased in various ways, and should appreciate diverse values of various stakeholders in the society.

For example, when we observe climate debates in the society, different opinions based on different values over risk perceptions of climate change or various mitigation options can be identified. The climate issue is inevitably value-laden and climate science cannot be free from values as well. Observational research might look relatively value free, but what to measure and where to measure, for example, already involve some kind of value judgment. Also, continuous measurement needs stable fund, which leads to a situation that research might be influenced by the values of funders.

Typologies and recommendations on how scientists behave in such value-laden research environment have been discussed by social scientists (e.g., Honest Broker, Pielke, 2003). Here I present the idea of Reflective Advocacy (Asayama et al., 2017), which is characterized by transparency, anticipation, reflection, deliberation and responsiveness.

Keywords: climate science, social values

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How can we effectively utilize atmospheric forecasts that include uncertainties?

*Hisashi Nakamura[1]

1. Research Center for Advanced Science and Technology, University of Tokyo

Today weather forecasts provide useful information for our daily life. The numerical weather forecast was one of the first applications of a computer invented more than 70 years ago. Since then, in addition to the rapid advance of computing resources, expansion of global satellite measurements and advance of data assimilation methods have contributed to the great improvement of the forecast skill. Today, operational centers offer not only daily weather forecasts but also weekly, monthly and seasonal forecasts, and a weather forecast system has thus become a fundamental infrastructure for the modern society.

The atmospheric circulation system is a highly nonlinear complex system with super high dimensions, and its behavior is therefore essentially chaotic. Thus, tiny observational errors in the initial field can gradually amplify, which will severely degrade the forecast skill within 10 days or so. For the extended or seasonal forecasts the ensemble forecast method therefore becomes essential, where parallel forecasts are performed from a number of slightly different initial fields into which tiny errors have been introduced artificially. The ensemble forecast is therefore probabilistic, and inter-member forecast spread as a measure of uncertainties of the forecast offers quite useful information to the users. The ensemble method is now being introduced even into daily forecasts, which today have high prediction skill but are by no means perfect in a deterministic sense. Furthermore, production of reanalysis data by assimilating observational data accumulated until today into a state-of-the-art forecast system can reproduce the atmospheric state four-dimensionally over the last several decades and thus provide useful data for assessing predictability of extreme weather events in the past.

For the effective risk reduction in case of an imminent disaster by a typhoon/hurricane, torrential rainfall or a snow storm, not only further improvement of forecast skill but also appropriate information of forecast uncertainty is necessary. It should be noted that prediction of behavior of pollutants once emitted into the atmosphere by volcanic eruption or a nuclear plant accident is basically a matter of atmospheric forecast. So, it becomes necessary for the society to understand the meaning and significance of forecasts that always include a certain level of uncertainties for their effective utilization. For this purpose, it is inappropriate to regard a forecast as perfect information by ignoring its uncertainties. It is also absolutely inappropriate to dismiss any forecasts simply because they contain uncertainties. With observations alone one cannot foresee what will happen in the future. Effective combination between observations and forecasts is of essential significance.

Keywords: forecast•prediction, uncertainties

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Communicating uncertainty of geoscience for the disaster risk reduction -Geoscience, the ambiguous, and ourselves-

*Satoko Oki[1]

1. Faculty of Environment and information Studies

In Japan, a large earthquake causing casualties occurs once every few years. The 2016 Kumamoto Earthquake, the 2018 Northern Osaka Earthquake, and the 2018 Eastern Iburi Earthquake occurred one after another, even after the 2011 Tohoku Earthquake caused more than 18,000 deaths and missing. In addition, damage from storms and floods, such as heavy rains and storm surges caused by rising sea levels, is also increasing these years. You can't tell where they point when you hear "disaster area" in Japan.

In such situation, geosciences are expected from the society for disaster risk reduction,and geosciences have also tried to meet this expectation. For example, seismology has been making efforts to publish the National Seismic Hazard Maps announced by the government every year since the 1995 Kobe Earthquake. Regarding meteorology or volcanology, they are committing to the introduction and operation of warning levels as well as the improvement of prediction accuracy.

Here I would like to report the results of a survey on how this information from geoscience is perceived by the public, taking the National Seismic Hazard Map as an example.
Since we have earthquake risk everywhere in Japan, it is not enough to make the hazard map of individual scenario earthquake. We therefore calculate the probability of a certain place to be affected by a ground motion of seismic intensity 6 or more within the next 30 years, then color it from yellow to brown on Japan map to overview the earthquake occurrence risk.
We investigated how the public perceives this map (Nagamatsu et.al., 2017) by comparing two groups in areas with low probabilities. Those people in one group are shown this map and the other not shown. The results showed that people seeing the map had lower risk perception. Earthquakes will occur everywhere in Japan, and in fact, some of damaging earthquakes have occurred at the low probability area. It is an ironic result that the map prepared by the government to encourage earthquake countermeasures reduce the public awareness of disaster prevention at least to those who live in areas with low probabilities.

When geoscience gives out useful information to society, it is always accompanied by uncertainty. To express this uncertainty, we introduce probability, but it does not seem to be a good communication to the public. How should we communicate uncertainty? I would like to introduce an activity called "disaster prevention novel" which is being conducted at a junior high school.

The "disaster prevention novel" was introduced into the Shimizu Junior High School in Kochi prefecture. It is the only junior high school in this city of Tosashimizu, which is facing the Pacific Ocean and told to face devastating tsunamis in the forthcoming Nankai-trough Earthquake. The “disaster prevention narratives" are written by the students provided the detailed date and time of the Nankai-trough Earthquake occurrence in about a month by the school teachers. The main characters are themselves, living in their

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actual neighborhood. Other characters are real people too. One important requirement is that the stories end with hope.

Let us review this "disaster prevention novel" in terms of communicating the uncertainty of an earthquake. The present earthquake science cannot accurately predict when an earthquake occurs. And, if "When" cannot be designated, the accompanied damage anticipation can also be ambiguous. For example, the degree of fire disaster depends on the time of the earthquake. The uncertainty of earthquake occurrence leads to the uncertainty of damage anticipation.

In the activity of "disaster prevention novel", the school designates the date and time of earthquake occurrence. Nobody thinks this is a true earthquake prediction. It is one of the educational considerations that one can think about his/her own evacuation behavior with the detailed occurrence time. In the novels, the way tsunamis inundate the town is depicted in different ways by students. Some students describe fires, and others write about landslides. The 90 students anticipate and express the damage in 90 ways. This expresses uncertainty and ambiguity of the forthcoming Nankai-trough Earthquake.
In the following year, students wrote the "disaster prevention novel" in different seasons, different times, and different weather settings. This led students, parents, and locals to come up with various assumptions. The unavoidable uncertainties from geosciences can be expressed in this way without introducing probabilities.

In the presentation, I would like to refer to a possible improved communication of geosciences.

Keywords: communication, uncertainty, earthquake, disaster

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Transdisciplinary research on geoscience in society

*Makoto Taniguchi[1]

1. Research Institute for Humanity and Nature

Global environmental issues such as global warming, decrease of biodiversity, global nitrogen contamination are wicked problems with involvement of many stakeholders, wide difference of interests, and some degrees of scientific uncertainties. To solve these wicked problems, global research communities such as Future Earth realize the importance of co-design/co-production/co-delivery with stakeholders in society as transdisciplinary research. As co-design with stakeholders including governors, media, industry, and citizen, Japanese Strategic Research Agenda (JSRA) for global environmental issues had been made, and identified 108 agendas which are important not only for scientists but also for society. These 108 agendas are categorized into ten groups, and prioritization of JSRA has been made in terms of necessity of trasdisciplinary research and character of Japanese research. Recursive and mutual learning with stakeholders are important for science in society. This JSRA are used in some Japanese associations on geoscience under JpGU for making a decision of future research directions.

Keywords: science in society, transdisciplinary research, Japanese Strategic Research Agenda, co-design

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Geodiversity and its conservation as a framing guideline for Geoethics in 21st Century

*Abhik Chakraborty[1]

1. Wakayama University

Geodiversity refers to the collective abiotic diversity of our planet. It is defined as the natural range (diversity) of geological and geomorphological features, including their assemblages, structures, and interactions that contribute to the heterogeneity of landscapes and sustain the evolution of life. However, geodiversity has been typically undervalued in existing sustianabililty literature as well as in conservation policy frameworks. There is ample evidence of recent pervasive anthropogenic change of key surface processes of our planet, and this phenomenon of humans as earth-movers will leave indelible marks on the fossil record. It therefore becomes imperative to understand that the heterogeneity of abiotic landforms/proceses and their integrity across geological time are fundamental factors underpinning all biodiversity and ecosystem services, and therefore are crucial for the sustenance of our civilization. This insight can be connected to the *intrinsic value* of geodiversity, which in turn should underpin any ethical framework for conserving the abiotic diversity of our planet. This paper posits the important argument for understanding, appreciating, and conserving the spatial and temporal integrity of geodiversity as the backbone for geoethics, and analyzes major challenges for conservation of dynamic earth proceses through insights derived from natural heritage landscapes (such as UNESCO World Natural Heritage Sites and UNESCO Geoparks).

Keywords: Geodiversity , Abiotic elements , Intrinsic value , Geoethics , World Natural Heritage

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The AGU GeoHealth and Thriving Earth Exchange Programs: Engaging our Geoscience Community for a Sustainable Future

Brooks Hanson[1], Janice Lachance[1], *Billy M Williams[1]

1. American Geophysical Union

The American Geophysical Union, a scientific society of more than 60,000 members worldwide, has undertaken important strategic initiatives to help address important GeoEthics related concerns and opportunities. AGU efforts such as its GeoHealth program and the Thriving Earth Exchange are two such critical initiatives designed to help promote GeoEthics-related needs, and specifically to help promote the well-being of humankind and sustainable environments. This presentation will discuss the progress, impacts and future opportunities in these two AGU programs, and other means to engage and promote Earth and space sciences and society.

Keywords: GeoEthics, Health, Sustainability, GeoHealth, Thriving Earth Exchange, Environment

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[E] Oral | U (Union)：Union

[U-09] Special session For a Borderless World of Geoscience (Challenges for the future)

convener:Hodaka Kawahata(Atmosphere Ocean Research Institute, the University of Tokyo), Robin Elizabeth Bell(Lamont Doherty Earth Observatory), Alberto Montanari(University of Bologna), David Laurence Higgitt(Lancaster University College at Beijing Jiaotong University, Weihai, China), Chairperson:Brooks Hanson(American Geophysical Union), Chairperson:Simon Richard Wallis(The University of Tokyo)

JpGU-AGU will have a joint meeting 2020 "For a Borderless World of Geoscience". This symposium will present the viewpoint of leaders from the major geoscience societies (JpGU, AGU, EGU and AOGS), which are partner unions, who are also leading scientists representing exciting geoscience fields. The Earth and space science is essential the well-being of the humankind and sustainable environments. Some of the discussion topics will include: What are the challenges for the future ? A joint action plan/communique' is a desired outcome of this symposium.

Introduction

Discussion

[E] Oral | U (Union)：Union

[U-10] Linking Education and Research Communities in Geosciences: Engaging the Public and Local Communities

convener:Vincent Tong(University College London), Takashi Oguchi(Center for Spatial Information Science, The University of Tokyo), Renee M Clary(Mississippi State University), Keiko Kuge(Department of Geophysics, Graduate School of Science, Kyoto University), Chairperson:Vincent Tong(University College London), Chairperson:Takashi Oguchi(Center for Spatial Information Science, The University of Tokyo), Chairperson:Keiko Kuge(Department of Geophysics, Graduate School of Science, Kyoto University), Chairperson:Renee M Clary(Mississippi State University)

Developing links between research and education is important for maximizing the impact of Earth and Space Sciences and for nurturing a global geoliterate community. Initiatives involving research, education and public engagement abound, building communities that bring educators, researchers and those with dual interests together is, however, not always straightforward. While many researchers are engaged in activities at national and international levels, educators may focus on projects primarily shaped by institutional and national priorities. In this session, we investigate the challenges and opportunities of advancing research-education synergies in Earth and Space Sciences through engaging the general public and local communities. We focus on success stories showcasing educational and outreach initiatives that aim to bring researchers and educators together. Ways of fostering collaborations, evidencing impact and developing leadership will be highlighted. Projects that address the UN Sustainable Development Goals (SDGs) are particularly welcomed.

[U10-01] Resilience and public engagement for advancing sustainability policy, research and education

★Invited Papers

*Mika Shimizu[1] (1.Kyoto University)

[U10-02] Japanese Activity in collaboration with the international ocean literacy survey

★Invited Papers

*Hiroshi Ichikawa[1], Noriko Imamiya[2], Akiko Tsuzuki[2], Geraldine Fauville[3], Craig Strang[4] (1.Ocean Literacy and Education Panel, Oceanographic Society of Japan, 2.Marine Learning Center, 3.Stanford University, 4.University of California, Berkeley)

[U10-03] Digital story-telling and video briefs as an approach to enhanced international collaboration and impact

★Invited Papers

*Brendan Francis Dominic Barrett[1] (1.Osaka University)

[U10-04] The International Geography Olympiad and Geography Education in Japan

★Invited Papers

*Yoshiyasu Ida[1] (1.Faculty of Human Sciences,University of Tsukuba)

[U10-05] Open Dialogue in Geoscience-based Policy Process: Linking Stakeholders and Researchers

★Invited Papers

*Hidenroi Nakamura[1] (1.Toyama Prefectural University)

[U10-06] A few points to be considered when we engaging with a local community for research and practice for sustainability

★Invited Papers

*Fumiko Noguchi[1] (1.United Nations University)

Resilience and public engagement for advancing sustainability policy, research and education

*Mika Shimizu[1]

1. Kyoto University

In seeking for pathway for overcoming sustainability challenges through policy, research and education, how we design the approach to address will affect our future sustainable society. For the design, given the complex systems around sustainability it is critical to take into account 1) all sustainability challenges are interlinked with the climate change directly or indirectly, and 2) the climate change impacts on human societies systemically, 3) while humans have driven pervasive decline of life on Earth.

Specifically, resilience approach, based on systems approach which recognizes inextricable links between complex and non-linear systems and is characterized by feedback loops and uncertainty (Berkes et al. 2003, is about enabling the capacity to create human, social and natural environments to adapt, recover, or transform even in facing challenges or adverse changes. This is best accomplished by looking at human, social and natural systems as a continuum. In other words, to nurture, strengthen, or create resilience within human, social, and natural systems, the interconnectedness of, or linkages among systems, is critical in operationalizing resilience where collaborative human actions can play a role. More operationally, the resilience approach is applicable for designing resilience, within and through the whole of organizations, communities and public policy, by looking at issues, resources or relevant systems in the context of at least four lenses, e.g. “Linkage”, “Temporal,” “Process” and “Scale” points of views(Shimizu & Clark, 2019).

The resilience approach is critical for addressing Sustainable Development Goals (SDGs) which covers a holistic challenge for human, social and natural systems with complexity and uncertainty. This kind of challenge cannot be addressed separately or through ad-hoc efforts, but requires transforming our human and social ways especially because humans have driven pervasive decline of life on Earth as mentioned in the above. While SDGs list all kinds of human, social and natural systems-related challenges whose holistic picture is critical especially because multiple issues for SDGs are interlinked, the operational approach which can address complex issues systemically and operationally is not provided in the SDGs. For this, the resilience approach can contribute to the operational aspects.

Especially since the resilience approach brings about the nexus views of human, social and natural systems, the views can result in raising public engagement level or creating “commons” at different scales and levels. For example, the author has designed to implement some educational programs or projects by using the resilience approach, such as ” Creating Kyoto Commons: Forests and Resilience toward Sustainability” which was designed to support Kyoto Resilient City (Kyoto City was chosen as one of among 100 resilient cities by the Rockefeller Foundation in 2017) with two-full day sessions. The sessions combined lectures, field work in forests and collaborative works for graduate students across

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different schools within Kyoto University, with the major goal of promoting systems views of or capacities for human, social and natural systems for sustainability challenges in SDGs. Although the example event was a small project, the questionnaires for the participants revealed the event influenced their mindsets and views to raise their engagement level in facing the challenges.

As such, the author will present with the focus on 1) what is resilience approach, 2) how the approach can be (or has been) practically linked with public engagement or creating “commons”, and 3) how the approach linked with public engagement or commons can be a pathway for overcoming sustainability challenges to advance policy, research and education for SDGs.

Keywords: Resilience, Sustainable Society, Public Engagement, SDGs, Commons

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Japanese Activity in collaboration with the international ocean literacy survey

*Hiroshi Ichikawa[1], Noriko Imamiya[2], Akiko Tsuzuki[2], Geraldine Fauville[3], Craig Strang[4]

1. Ocean Literacy and Education Panel, Oceanographic Society of Japan, 2. Marine Learning Center, 3. Stanford University, 4. University of California, Berkeley

The ocean plays important roles not only in the global climate system but also in the global material cycling through biogeochemical processes, and has close relationships with the daily lives of people through fisheries, marine energy and resources, ocean transportation, marine sports, ocean relaxation activities, and others. The Ocean Literacy movement began in the U.S. in the early 2000s, and has recently become international as shown by the Ocean Literacy Portal website operated by IOC/UNESCO. In Japan, the present national standard course of study at elementary school has not given any room for ocean education while the Oceanographic Society of Japan (JOS) and 34 other academic societies/committees gave a proposal entitled, “On the Setting up of a class named, ‘the role of Ocean’ in the national standard course of study for the 4th grade students in the elementary science education” to the Ministry of Education, Culture, Sports, Science and Technology (MEXT) in April 2016. In the U.S., aiming to serve as a community-based measurement tool that allows the comparison of levels of ocean knowledge across time and location, the International Ocean Literacy Survey (IOLS) project has been started since 2015. Fauville et al. (2018, https://doi.org/10.1080/13504622.2018.1440381) published the results from IOLS Version 2, and the English version IOLS Version 4 was finalized after reviewing the English IOLS Version 3 by IOLS Advisory Board consisting of international marine researchers, communicators, teachers, and psychometricians. The English version of the IOLS Version 4 was translated into 14 languages (Catalan, Chilean, Dutch, Greek, Italian, Japanese, Korean, Polish, Portuguese, Simplified Chinese, Spanish, Tagalog, Thai, and Traditional Chinese) and its field testing was conducted during February and March 2019 with nominal 6945 participants worldwide including nominal 567 participants from Japan. In collaboration with IOLS Version 4 field testing, JOS and the Marine Learning Center took part in correcting the original Japanese draft of IOLS Version 4, sponsored IOLS Version 4 field testing, and made a wide campaign to high-school teachers through sending recommendation letters to academic societies and other ocean-related organizations.

Keywords: Ocean literacy, ocean sciences education, community-based development, measure development

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Digital story-telling and video briefs as an approach to enhanced international collaboration and impact

*Brendan Francis Dominic Barrett[1]

1. Osaka University

Universities generate knowledge through qualitative and quantitative methods. This is shared with society primarily via scholarly articles in academic journals. Performative approaches (modelling experience through aesthetic and feeling) are an important part of creative practice in the arts. These two spheres tend to maintain a respectful distance. This presentation will share insights from close to a decade of experience by a small team trying to work across boundaries in an effort to communicate science via creative writing in an online magazine and video briefs (short 5-6 minute documentaries on scientific research generally in the field). The goal was to “create for impact” and to develop an extensive network of international collaborators involved in content production and dissemination. This was not without significant challenges, but it did reveal much broader realms of possibility for effective research communication than originally envisaged.

Keywords: digital story-telling, documentary production, science communication

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The International Geography Olympiad and Geography Education in Japan

*Yoshiyasu Ida[1]

1. Faculty of Human Sciences,University of Tsukuba

In Japan, the national curriculum was revised in 2018, and geogaraphy will be compulsory subject for high schools from 2022. Less than 50% of high school students had taken geigraphy for about 30 years in Japan. So it is hoped that high school geogarpy will be restored. The impact of the International Geography Olympiad(iGeo) is one of reasons why geography will be compulsory subject in high school in Japan. Traditional geogarphy education in Japan has focused on understanding the modern world, centered on regional geography and systematic geography. The geography education had been highly evaluated because all students acquire basic knowledge, but has been criticized as a memorable subject. The iGeo was one of the catalysts for curriculum change of school geogarphy in Japan.
In 2006, Japan launched an organization to participate in iGeo. The number of studentas participating in geography olympiad in Japan has increased. The quetions in iGeo test has been much different from those covered in geography education in Japan, following. At first, there are many questions for knowledge in Japan, but test of iGeo consist of quetions for logical thinking. Second, fieldwork test is much important in iGeo. Regarding fieldwork, it has been recommended in Japan, but the implementation rate is low. Third, the propotion of asking for phisical geography is high in iGeo. Because of difference of geography contents between iGeo and Japan, it is difficult for the Japanese team to rank high in iGeo test.
The major impact of iGeo on Japanese geography education is following; in new geography curriculum. the viewpoint, that is how to use geographical knowledge to think logically and consider about the future, is emphasis. The geography of new course of study in Japan incorporates theme learning and uses knowledge and skills to think logically, and aims at future-oriented geography. On the other hand, traditional processes of geography that is regional and systematic geography is emphasis on new curriculum. It is trying to built a new Japanese-style geography education.

Keywords: geogarphy education, the Internationl Geography Olympiad, Japan

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Open Dialogue in Geoscience-based Policy Process: Linking Stakeholders and Researchers

*Hidenroi Nakamura[1]

1. Toyama Prefectural University

To realize sustainable and resilient societies, an effective way to manage the complexity and uncertainty in contemporary society and scientific knowldge is needed.This is also the case in the policy process that requires geoscientific knowldge. I argue that researchers could play significant roles in geoscience-based policy process that engages local stakeholders and general public. Their contribution to open dialogue in the policy process with stakeholder/public engagement deals with the constraints of positionality and scientific uncertainty. Two case studies in post-disaster Japan are presented. One is on three-year long capacity development of local volcano disaster resilience and governance in three prefectures in central Japan after Mt Ontake eruption in 2014. The other is on five-year long random-sampling citizen dialogue on geological disposal of nuclear waste in two prefectures in central Japan after Fukushima Dai-ichi nuclear power plant accident in 2011. In the former case, researchers functioned as producers, coordinators, and facilitators of capacity development, in collaboration with local government. In the latter case, researchers played a role of science interpreters with differing views, reflecting dialogue among citizens. These studies suggest that explicit treatment of pluralistic positions and views among stakeholders and researchers would be a key for quality learning and deliveration in geoscience-based policy process.

Keywords: Plurarism, Poliphony, Action Research, Positionality, Uncertainty, Resilience

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A few points to be considered when we engaging with a local community for research and practice for sustainability

*Fumiko Noguchi[1]

1. United Nations University

Local community-based and multi-stakeholder approach are considered as essential in a research and practice for achieving sustainable development. This is because governmental policies and conference declarations can create the frame but local community is the only place where we can actually work on and change the things (Fien and Tilbury 2002). Also, many sustainability challenges root in multiple causes, which even are complexly twined. Diversity is required in search for the solution at local community level. People from different fields, sectors, generations, cultural and socio-economic and educational backgrounds should participate in search for the solution of challenges. They share their knowledges and experiences in that process, so that they co-create a new knowledge for making their community sustainable.

Then, how can be multi-stakeholder participation realised truly –not in a tokenism way but in a really inclusive way where everyone, including, the marginalised, has ownership, is empowered and controls over the decision making process? And what role should we, researchers, take there? In my presentation, I would like to look at a few examples of local community practice and discuss the key factors to make community engagement successful and a potential epistemological pitfall of ‘participatory approach’ when everybody is fully believing that they are taking a participatory approach. Finally, I will propose a framework that can facilitate multi-stakeholder participation effectively for further discussion.

Keywords: Multistakeholder and participatory approach, Multiple knowledges and learnings, Epistemological gap

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[E] Oral | U (Union)：Union

[U-14] Open Colloquium-NASA/JAXA: Planetary science on Mars driving current and future missions

convener:Shunichi Kamata(Faculty of Science, Hokkaido University), Go Murakami(Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency), Mitchell D Schulte(NASA Headquarters), Michael S Kelley(NASA Headquarters), Chairperson:Shunichi Kamata(Faculty of Science, Hokkaido University), Chairperson:Go Murakami(Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency), Chairperson:Mitchell D Schulte(NASA Headquarters), Chairperson:Michael S Kelley(NASA Headquarters)

Today a number of missions to Mars are ongoing or planned by NASA, JAXA, and their partners (Curiosity Rover, InSight, MMX, Mars2020, ExoMars, MRO, Odyssey, Mars Sample Return, etc.). Such missions and other activities are providing us with various kinds of and large amounts of high-quality data, revealing the present and past Mars. In this session, the new views of Mars based on recent missions as well as the scientific backgrounds that connects these missions are presented. Open discussion with speakers, participants, and science leads from NASA/JAXA will be included.

[U14-01] 50 Years of Mars Exploration: Past and Ongoing NASA Missions Pave the Way for Determining Whether There Was Life on Mars

★Invited Papers

*John A Grant[1] (1.Smithsonian National Air and Space Museum, Center for Earth and Planetary Studies, Washington DC)

[U14-02] MARS SAMPLE RETURN: A MISSION CAMPAIGN OF INTENSE SCIENTIFIC INTEREST

★Invited Papers

*David Beaty[1], Brandi L Carrier[1], Michael A Meyer[2], Elliot Sefton-Nash[3] (1.Jet Propulsion Laboratory/California Institute of Technology, 2.NASA Headquarters, 3.ESA ESTEC)

[U14-03] JAXA's Strategic Mars Exploration Program (JSMEP) for Understanding Origin, Evolution, Inventory of Water on Mars

★Invited Papers

*Tomohiro Usui[1] (1.Japan Aerospace Exploration Agency)

[U14-04] Open discussion

*Go Murakami[1] (1.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency)

50 Years of Mars Exploration: Past and Ongoing NASA Missions Pave the Way for Determining Whether There Was Life on Mars

*John A Grant[1]

1. Smithsonian National Air and Space Museum, Center for Earth and Planetary Studies, Washington DC

NASA’s 50-plus years of Mars exploration has revealed a planet once more Earth-like and habitable than today. Nevertheless, the Mariner 4 flyby mission in 1965 and the subsequent Mariner 6 and 7 flybys in 1969 imaged mostly cratered surfaces. Mariner 9 entered orbit in 1971, studied the atmosphere and surface, and was the first mission to confirm the diversity of landforms that included volcanoes and channels.

The Viking missions provided the first truly global view of Mars starting in 1976 and included the landing of Viking 1 in Chryse Planitia and Viking 2 in Uptopia Planitia. The orbiters took ~50,000 images and both landers acquired/analyzed soil samples that provided important data on composition and the potential for life. The Viking 1 lander survived until 1982.

Formation of NASA’s Mars Exploration Program in 1993 led to focus on whether life ever arose on Mars, characterizing the planet’s climate and geology, and preparing for human exploration. The first program mission was the Mars Global Surveyor (MGS) orbiter arriving in 1997 and operating until 2006. MGS studied the atmosphere, surface, and interior, and science highlights include global maps of topography and mineralogy, images of gullies and fluvial deltas, and detection of magnetic surface anomalies. Mars Pathfinder and the Sojourner rover also arrived in 1997, demonstrated the feasibility of airbag landing and the value of surface mobility, and characterized rock sizes and textures consistent with water-lain flood deposits. Mars Odyssey arrived in orbit in 2001 and further mapped surface composition, discovered widespread deposits of mid and high latitude ice, and characterized the near-space radiation environment.

The Mars Exploration Rovers (MER) Spirit and Opportunity landed on Mars using airbags in early 2004, with Spirit operating until 2010 and Opportunity end of mission occurring in 2019. MER focused on understanding the geology and role of water in shaping the surface around the landing sites: Spirit was targeted to Gusev Crater, site of a possible former lake in a large impact crater, and Opportunity landed at Meridiani Planum, where orbital detection of hematite at the surface by Odyssey suggested past water activity. Both rovers found evidence of past environments where water was once active at and below the surface and that may have been habitable.

The Mars Reconnaissance Orbiter (MRO) arrived in 2006, enabling a new phase of global, detailed mapping of surface composition, surface morphology, and the atmosphere. MRO is ongoing and results range from mapping clay-rich deposits around Mawrth Vallis to identifying probable polar geysers to characterizing small, recurring slope lineae. The high spatial and spectral resolution of MRO data sets opened a new era of landing site studies crucial to the assessment and certification of the landing site in Gale crater for the Mars Science Laboratory (MSL) Curiosity rover.

MSL landed in 2012 using a “sky crane” system with goals that included understanding past Martian climate and geology and determining whether the landing site ever harbored habitable conditions. Major discoveries include discovery of complex organic molecules and characterization of deposits whose

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chemistry and extent confirm the presence of a relatively long-lived lake and associated habitable conditions more than 3 Ga.
Other missions augment our understanding of the evolution of Mars: Phoenix landed in 2008 and explored high northern latitudes; Maven arrived in orbit in 2014 and continues to explore the upper atmosphere to understand climate evolution; and InSight landed in 2018 and is studying the deep interior of Mars. Odyssey, MRO, and Maven also provide data relay from MSL and InSight critical to increasing their science return. Collectively, these missions comprise an organized approach to Mars exploration that pave the way for future missions to cache and return samples and determine whether there was ever life on Mars.

Keywords: Mars, NASA, Missions

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MARS SAMPLE RETURN: A MISSION CAMPAIGN OF INTENSE SCIENTIFIC INTEREST

*David Beaty[1], Brandi L Carrier[1], Michael A Meyer[2], Elliot Sefton-Nash[3]

1. Jet Propulsion Laboratory/California Institute of Technology, 2. NASA Headquarters, 3. ESA ESTEC

Introduction. The transport to Earth of scientifically selected samples from Mars is of compelling scientific interest. This has led to the formulation of the MSR Campaign, which is planned to be carried out by means of a NASA-ESA partnership. This campaign, as it is currently envisioned, would result in the collection of martian samples by NASA's 2020 rover, and their return to Earth as early as 2031.

Technical. Several developments surrounding Mars Sample Return (MSR) have taken place over the past decade or so that have caused the scientific interest in martian samples to increase:
Advances in the study of martian meteorites. As the number of martian meteorites has now grown to well over 100, it has become apparent that of the types of samples which survive the ejection process and the absence of sample context will continue to constrain the insights that may be obtained using this pathway. New mission results from Mars. Fabulous new results have been obtained by the in-situ exploration program (of particular note, MSL and the expected results to come from ExoMars and M2020). These results have served to reinforce the additional value that would come from narrowing the spatial focus, and widening the diversity of instrumentation, both of which would happen by making Mars samples available to terrestrial laboratories. Human exploration. We have a greatly improved understanding of the ways in which the risks, performance, and cost of putting humans on Mars can be improved by acquiring advance information—especially sample-related information. Astrobiology. Although the search for extra-terrestrial life has been key driver of Mars exploration, we now have a much better understanding of the potential for preservation in the geologic record, the evolution of Mars as a planetary object, and (by means of the study of biochemistry on Earth) the details of biological processes. This allows for far more effective search strategies. Instrument developments. We are seeing unprecedented improvements in our collective ability to prepare and analyze very small samples in Earth laboratories. Highly visible examples are the work on Hayabusa asteroid samples (JAXA) and the Stardust comet samples (NASA). Engineering developments. Over the past decade there have been substantial improvements in the capability of the world's space agencies to acquire and preserve samples (most notably, the M-2020 sampling system), the development of the Mars Ascent Vehicle, and critical progress in breaking the chain of contact with Mars.

As recently summarized as the technical conclusion of the 2018 2nd International MSR Conference:

The scientific exploration of Mars and the search for extra-terrestrial life have advanced to the point Mars exploration. Capitalising on major engineering progress in recent years by the world's space agencies and industries, we are technically ready to start the development of the flight missions associated with retrieving the samples. In parallel, planning for the potential receipt and evaluation of the samples has started, and should accelerate, as well as for the processes associated with making the samples available to the world's science community. Given the nature and scope of the Mars Sample Return campaign, we expect that engaging the public early and keeping them involved throughout will be a particularly important component of this effort. We have the opportunity and the motivation to make the Mars Sample Return campaign an international endeavour and a reality for all humankind.

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References: [1] iMOST (2018), The Potential Science and Engineering Value of Samples Delivered to Earth by Mars Sample Return. *Meteoritics & Planetary Science*. https://doi.org/ 10.1111/maps.13232

Keywords: Mars sample return

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JAXA’s Strategic Mars Exploration Program (JSMEP) for Understanding Origin, Evolution, Inventory of Water on Mars

*Tomohiro Usui[1]

1. Japan Aerospace Exploration Agency

The Mars-moon system is a promising target for exploration in the broad field of planetary science: e.g., geology, geochemistry, astrobiology, and comparative planetology. The international Mars science community has set a long-term goal toward achieving Mars sample return (MSR) and human exploration. MSR will address questions on the origin (e.g., source of building blocks), interior evolution (e.g., crust-mantle differentiation and mantle dynamics), the potential biological history (e.g., nature and extent of habitability and preservation of biosignature), and geologic history of Mars with an emphasis on the role of water. Previous Mars exploration missions have provided compelling evidence for the presence of liquid water during the earliest geologic era (Noachian: >~3.9 Ga) of Mars. Observations of dense valley networks, evaporites (e.g., gypsum) and hydrous minerals (e.g., clays) that are commonly formed by aqueous processes imply that, at some time in the past, Mars had an Earth-like active hydrological cycle with lakes, oceans, possibly also aquifers and groundwater, and had the potential for life.

According to the international trend for Mars exploration and potential significance for understanding the current and past surface/subsurface aqueous environments, JAXA plans a strategic Mars exploration program (JSMEP). JSMEP starts with a Martian moon’s sample return mission (MMX: Martian Moons Exploration) in 2024-2029, followed by a Mars orbiter (MO) in later 2020s and a Mars lander/rover (ML/R) mission in early 2030s. JSMEP’s goals are 1) to address questions of water on Mars [origin and delivery (MMX), distribution and inventory (MO), and chemical evolution (ML/R)], 2) to ensure expansion of the areas of human activities by exploring habitable subsurface world, and 3) to acquires key technologies including EDL (entry-descent-landing) with aerodynamic control, drilling and sampling on the surface, deep space telecommunication, transportation to/from the Mars orbit, and planetary protection.

Keywords: Mars, JSMEP, water

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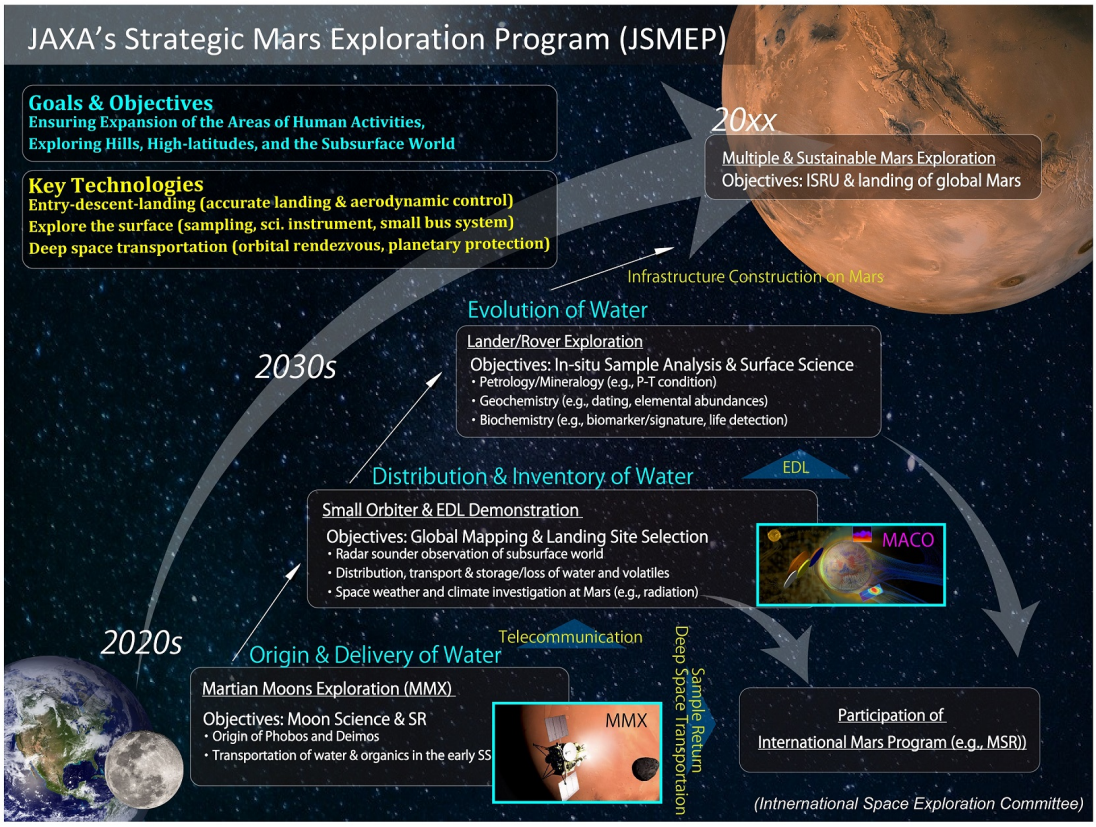

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Open discussion

*Go Murakami[1]

1. Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency

Open discussion slot for Mars science and future missions of NASA, JAXA, and others.

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[E] Oral | U (Union) : Union

[U-16] OC:Research Advances in Recent Disaster Studies Using Remote Sensing and Computational Methodologies

convener:Jun Matsumoto(Deaprtment of Geography, Tokyo Metropolitan University), Guido Cervone(Pennsylvania State University Main Campus), Chairperson:Jun Matsumoto(Deaprtment of Geography, Tokyo Metropolitan University), Chairperson:Guido Cervone(Pennsylvania State University Main Campus)

Every year, environmental hazards pose a constant threat to the development and sustainment of our civilization. A single catastrophic event can claim thousands of lives, cause damages for billions of dollars, and destroy natural landmarks. Such potential catastrophic consequences are due to the emergence of megacities, nuclear power plants and nuclear waste storage, and other facilities whose destruction pose an unacceptable risk of global reach.

In recent years, the advances in our ability to observe the Earth and its environment through the use of air, space and ground based sensors has led to the generation of large dynamic, and geographically distributed data. The rate at which geospatial data are being generated exceeds our ability to organize and analyze. New challenges arise from an unprecedented access to massive amounts of Earth science data that can be used to study the complementary nature of different parameters. These developments are quickly leading towards a data-rich but knowledge-poor environment.

This session focuses on the use of remote sensing and data mining techniques to study recent natural hazards, including but not limited to recent earthquakes, hydro-meteorological events, floods, landslides, tsunamis. Of particular interest are contributions that discuss the analysis of large data using novel methodologies. This session will be offered using the hyperwall. Only invited talks are allowed for oral presentations, but we welcome a wide ranges of poster presentations.

Introduction

[U16-01] Expanded Dimensionality Image Spectroscopy Via Machine Learning

★Invited Papers

*Guido Cervone[1], Mark Salvador, Fangcao Xu[1] (1.Pennsylvania State University Main Campus)

[U16-02] Detection of landslides and vegetation recovery from multitemporal UAV and satellite images

★Invited Papers

*Hitoshi SAITO[1,2], Shoichiro Uchiyama[2], Yuichi S. Hayakawa[3], Hiroyuki Obanawa[4] (1.Kanto Gakuin University, 2.National Research Institute for Earth Science and Disaster Resilience, 3.Hokkaido University, 4.National Agriculture and Food Research Organization)

[U16-03] Next-generation alerting system for natural disasters using ground network and micro-satellites

★Invited Papers

*Yukihiro Takahashi[1,2], Mitsuteru Sato[1,2], Hisayuki Kubota[1,2], Kozo Yamashita[3], Tetsuro Ishida[1,2] (1.Department of Cosmosciences, Graduate School of Science, Hokkaido University, 2.Faculty of Science, Hokkaido University, 3.Faculty of Engineering, Ashikaga University)

[U16-04] The Rise of the Crowd: An Assessment of Crowdsourced Data during Disasters

★Invited Papers

*Carolynne Hultquist[1] (1.Columbia University)

Discussion

Expanded Dimensionality Image Spectroscopy Via Machine Learning

*Guido Cervone[1], Mark Salvador, Fangcao Xu[1]

1. Pennsylvania State University Main Campus

The general goal of hyperspectral image analysis is to identify with confidence surface solid materials, liquids, or atmospheric gases. The current state-of-the science approach to hyperspectral imagery collection and exploitation is based on physics and engineering for the development and building of the sensors, and data science for the analysis of the data collected by the sensors. The algorithms and tools used to analyze the very large data collected were developed primarily in the early 1990s, and continues to pervade both operational and research and development.

These concepts and solutions have demonstrated operational success and their methods are ensconced in existing algorithms and software. While these existing solutions are based on sound physics, mathematics, and statistics, they lag behind the revolution in computational power, artificial intelligence, and agile sensors and platforms. Most importantly, they have been shown to fail under varied environmental conditions, obscuration, and target material conditions. Many simplifying assumptions are made in this process and it can be said that today's analysis is effective in performing material identification in optimal collection conditions. It can also be said that in non-optimal conditions, cloudy scenes, shadows, intimate mixtures of materials, liquid spills and residues, or any combination of the above, material identification of solids, liquids, or gases is ineffective, unrepeatable, or subject to unknown levels of uncertainty.

New spectral imagers are being integrated in or on agile collection platforms, such as gimbals, and they are becoming popular in unmanned aerial systems (UAS). This overcomes the fixed nadir looking geometries of past instruments. In addition to imaging a particular scene location, the agile sensor can also image the background and the atmosphere to improve the overall accuracy of the target classification. Additionally, while the previous generation of sensors have a scene revisit time of minutes to days, the current generation, and even more so the next, have a scene revisit time of as little as a few seconds. The ability of collecting rapid sequences of hyperspectral scans under different angles provides an unprecedented dataset. It is theoretically possible to advance the state of the science by developing a more complete and accurate solution by analyzing multiple hyperspectral images simultaneously.

We propose an expansion of the radiance equation to take advantage of multiple hyperspectral images and a solution of this expansion via Deep Learning. The characterization of the components of the radiance equation via the expansion would drive future hyperspectral sensor performance requirements and concepts of operations. The expansion and solution would enable identification of target materials in scenarios and environments that no current or planned hyperspectral image exploitation system is capable of.

At the basis of hyperspectral imaging is the fundamental radiance equation defining the reflective and emissive spectral radiance components of the image scene and its 3-dimensional surroundings. Current

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state of the science algorithms and tools analyze each hyperspectral image individually via a simplification of the radiance equation into a single spatial dimension. This individual image analysis was driven primarily by the limits of sensors and collection platforms with optimal scene collection consisting of a nadir looking scan of the target area.

Keywords: remote sensing, target detection, machine learning

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Detection of landslides and vegetation recovery from multitemporal UAV and satellite images

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1. Kanto Gakuin University, 2. National Research Institute for Earth Science and Disaster Resilience, 3. Hokkaido University, 4. National Agriculture and Food Research Organization

Heavy rainfall and earthquakes are major triggers of landslides. Recently, unmanned aerial vehicles (UAVs) have attracted great interest for use in the creation of high-resolution images for geoscientific studies. This study used this technique to examine the topographic characteristics of coseismic- and rainfall-induced landslides at the Aso volcano in Japan. The study area has frequently experienced coseismic- and rainfall-induced landslide events, such as those in 1990, 2001, 2012, and 2016. The study area is characterized by the typical grassy vegetation landscape of the region. Vegetation recovery at the landslide sites was also monitored using multitemporal UAV and satellite images. We obtained orthorectified images and digital surface models with a spatial resolution of 0.06 m based on UAV surveys conducted between 2014 and 2020. These high-spatial-resolution images show that the coseismic landslides, many of which were initiated near topographic ridges, were typically located on the upside hillslopes of the previous rainfall-induced landslide scars. The UAV and satellite images revealed strong vegetation recovery at both the rainfall-induced and the coseismic landslide sites. However, site-specific vegetation recovery was determined primarily by topographic parameters, such as slope angle and direction at the local scale.

Keywords: Landslides, UAV, Aso volcano

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Next-generation alerting system for natural disasters using ground network and micro-satellites

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1. Department of Cosmosciences, Graduate School of Science, Hokkaido University, 2. Faculty of Science, Hokkaido University, 3. Faculty of Engineering, Ashikaga University

It is not easy to predict the intensity and location of extreme weathers, such like torrential rainfall by individual thunderstorm or typhoon since low resolution and less coverage of the existing observational methods. We have been developing an observation system for extreme weather monitoring using of 50-kg micro-satellites and with ground network consisting of automated weather stations with ground-based lightning sensor in the projects of a SATREPS “ULAT” and e-ASIA under international cooperation among Japan, Philippines, Indonesia and other SE-Asian countries supported by JST, JICA, PHL-Microsat and other fundings.

We are installing totally 60 AWS stations with lightning sensor over nation-wide of Philippines and concentrating Metro Manila. We operate micro-satellites developed and controlled by our group in order to capture the 3 dimensional structure of the thunderstorms or clouds in typhoon eye by the on-demand operation of 50-kg micro-satellites, including the Philippine-developed satellites, based on real time weather data obtained by the ground based networks and other satellite imaging. Here we show the future strategy of the alerting system for the extreme weathers and other kinds of natural disasters.

Keywords: remote sensing, lightning, micro-satellite

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The Rise of the Crowd: An Assessment of Crowdsourced Data during Disasters

*Carolynne Hultquist[1]

1. Columbia University

Crowdsourcing is not new, but the scale of environmental monitoring activities is unprecedented due to technological advancements. Innovative technological applications enable the crowdsourcing of massive datasets in short periods of time under difficult disaster conditions. Crowdsourcing methods can prove useful during disasters when the content is confirmed to be of good quality and there is access to streaming sources in real-time. Crowdsourced data from established projects are proven to quantitatively align with environmental measurements from traditional collections and provide timelier information during disaster. Data from individuals may be used in aggregation for decision-making by the public, humanitarian organizations, and government institutions during disasters. However, there is no guarantee that these projects will be active during disasters or provide data where and when information is most needed to improve situational awareness. In addition, it is potentially problematic if vulnerable populations are unaware of this resource or unable to contribute. Crowdsourced data are already used in formal scientific studies, yet further assessment of the availability and usefulness of the data are needed within disaster contexts. Crowdsourced data can provide beneficial content for decision-making when used alongside traditional datasets with an awareness of constraints given data collection and an evaluation of limitations.

Keywords: crowdsource, decision-making, disaster

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[E] Oral | U (Union)：Union

[U-17] Open Colloquium: What will we expect from Ryugu and Bennu samples?

convener:Satoshi Kasahara(The university of Tokyo), Aki Takigawa(Department of Earth and Planetary Science, The University of Tokyo)

JAXA's Hayabusa2 and NASA's OSIRIS-REx have been exploring near-Earth carbonaceous asteroids Ryugu and Bennu, and the surface samples will be delivered to the Earth in 2020 and 2023. The returned samples are expected to provide us with copious information on the origin and evolution of the Solar System. We will discuss what we have learned from the asteroids so far and what we expect to know from the samples.

[U17-01] What will we expect from Ryugu and Bennu samples?

*Shogo Tachibana[1,2], Harold C. Connolly Jr.[3] (1.UTokyo Organization for Planetary and Space Science, University of Tokyo , 2.Institute of Space and Astronautical Science, 3.Department of Geology, School of Earth and Environment, Rowan University)

[U17-02] Open discussion: What we expect from Ryugu and Bennu samples

*Satoshi Kasahara[1], Aki Takigawa[2], Shogo Tachibana[1,3], Harold C. Connolly Jr.[4] (1.The university of Tokyo, 2.Kyoto University, 3.Institute of Space and Astronautical Science, 4.Rowan University)

What will we expect from Ryugu and Bennu samples?

*Shogo Tachibana[1,2], Harold C. Connolly Jr.[3]

1. UTokyo Organization for Planetary and Space Science, University of Tokyo , 2. Institute of Space and Astronautical Science, 3. Department of Geology, School of Earth and Environment, Rowan University

JAXA's Hayabusa2 and NASA's OSIRIS-REx are the sample return missions from near-Earth carbonaceous asteroids Ryugu and Bennu, and the surface samples will be delivered to the Earth in 2020 and 2023. Both Ryugu and Bennu are expected to be pristine asteroids that records the origin and early evolution of the Solar System. Hayabusa2 explored near-Earth C-type asteroid Ryugu for 17 months (June 2018–November 2019) including two landing operations for sample collection and is now on the way back home. OSIRIS-Rex has been investigating near-Earth B-type asteroid Bennu since its arrival in December 2018. The spacecraft will make a touch-and-go landing operation for sample collection in August 2020.

Hayabusa2 and OSIRIS-Rex found that both Ryugu and Bennu are dark rubble pile bodies with spinning top shapes. The two asteroids have an almost identical bulk density of 1.19 g/cm3, and their macro porosities are ~50 % assuming they consist of carbonaceous chondrite-like materials. Both asteroids have hydrated silicates at the surfaces although Ryugu likely has less abundant hydrous phases than Bennu, a hypothesis that we will test through analysis of the returned samples.

In the open colloquium, we will review what the spacecrafts found at Ryugu and Bennu especially from the cosmochemical point of view, discuss the similarities and differences between two, and discuss with the audience our expectations of what will learn from Ryugu and Bennu samples after Earth return.

Keywords: Hayabusa2, OSIRIS-REx, Ryugu, Bennu

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Open discussion: What we expect from Ryugu and Bennu samples

*Satoshi Kasahara[1], Aki Takigawa[2], Shogo Tachibana[1,3], Harold C. Connolly Jr.[4]

1. The university of Tokyo, 2. Kyoto University, 3. Institute of Space and Astronautical Science, 4. Rowan University

We would like to discuss with the audience what Hayabusa2 and OSIRIS-REx found at Ryugu and Bennu, what we expect to learn from the returned samples, and the future of sample return missions and the Solar System science that includes the education and encouragement of young generations.

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[E] Oral | U (Union)：Union

[U-18] Open Colloquium: Recent advances in atmospheric and hydrospheric sciences

convener:Kazuaki Nishii(Graduate School of Bioresources, Mie University), Hong Liao(Nanjing University of Information Science and Technology), Masahiro Hori(University of Toyama School of Sustainable Design), Kazuhiro Misumi(Environmental Science Research Laboratory, Central Research Institute of Electric Power Industry), Chairperson:Kazuaki Nishii(Graduate School of Bioresources, Mie University)

Innovations in observational techniques and computer science have promoted atmospheric and hydrospheric sciences. This session is aimed at introducing recent advances in atmospheric and hydrospheric sciences to all kinds of participants in the JpGU-AGU Joint Meeting with the aid of the NASA's Hyperwall, a powerful tool to display high-resolution images and movies. This session will consist only of invited talks.

[U18-01] Seasonally dependent impact of cloud longwave scattering on the polar climate: why it is a necessity in polar climate modeling?

★Invited Papers

*Xianglei Huang[1], Yi-Hsuan Chen[1], Ping Yang[2], Chia-Pang Kuo[3], Xiuhong Chen[1] (1.Univ. Michigan Ann Arbor, 2.Texas A&M Univ., 3.Florida State Univ.)

[U18-04] **Overview of OMIX project “Ocean mixing processes: impact on biogeochemistry, climate and ecosystems”**

★Invited Papers

*Ichiro Yasuda[1] (1.Atmosphere and Ocean Research Institute, The University of Tokyo)

[U18-05] **Typhoon observations using an aircraft from the upper troposphere in the T-PARCII project**

★Invited Papers

*Taro Shinoda[1], Kazuhisa Tsuboki[1], Hiroyuki Yamada[2], Tadayasu Ohigashi[3], Kosuke Ito[2], Munehiko Yamaguchi[4], Tetsuo Nakazawa[4], Hisayuki Kubota[5], Yukihiro Takahashi[5], Norio Nagahama[6], Kensaku Shimizu[6], Nobuhiro Takahashi[1] (1.Institute for Space-Earth Environmental Research, Nagoya University, 2.Faculty of Science, University of the Ryukyus, 3.National Research Institute for Earth Science and Disaster Resilience, 4.Meteorological Research Institute, Japan Meteorological Agency, 5.School of Science, Hokkaido University, 6.Meisei Electric Co. Ltd.)

Discussion

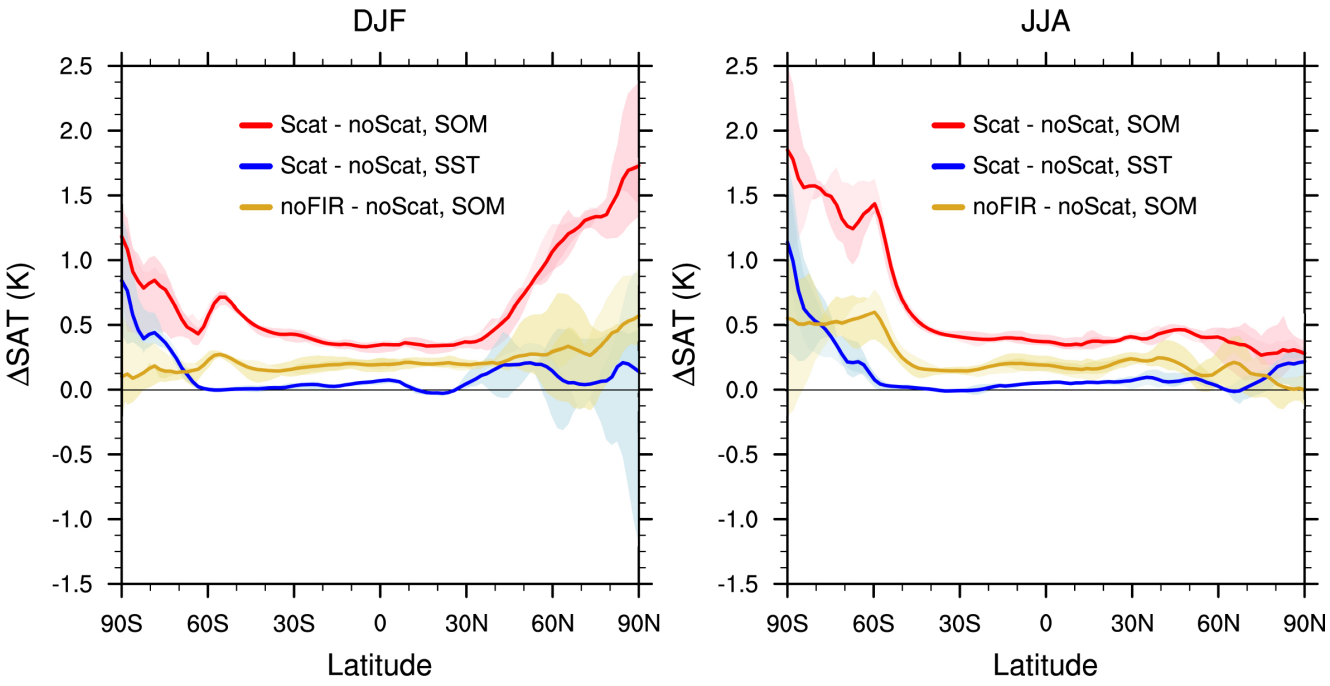
Seasonally dependent impact of cloud longwave scattering on the polar climate: why it is a necessity in polar climate modeling?

*Xianglei Huang[1], Yi-Hsuan Chen[1], Ping Yang[2], Chia-Pang Kuo[3], Xiuhong Chen[1]

1. Univ. Michigan Ann Arbor, 2. Texas A&M Univ., 3. Florida State Univ.

The importance of cloud-radiation interactions is well known. Most climate models assume non-scattering clouds in the longwave (LW) because LW scattering is considered negligible compared to strong LW absorption by clouds and greenhouse gases. Here we show that neglecting LW scattering is reasonable for simulations forced by observed sea surface temperature (SST) and sea ice (prescribed SST) and for the simulated extra-polar climate, but is invalid for simulated polar climate when the SST and sea ice are also simulated by the model. The traditional wisdom to ignore LW scattering can be well justified in the tropics and mid-latitudes, but it breaks down in the high-latitudes due to much less water vapor in the atmosphere. As a result, cloud LW scattering is non-negligible anymore. Furthermore, the cloud LW scattering increases downward LW radiation, warming the surface and then further warming and moistening the atmosphere. A prescribed SST run does not allow such ocean-atmosphere LW coupling, another issue that has been overlooked in traditional radiation scheme development. We incorporated a hybrid 4-stream and 2-stream scheme into the NCAR CESM model to handle the ice cloud longwave scattering. Using coupled simulations, we show that warming from LW scattering, especially in the far IR, is largest over the polar winter and can increase winter surface air temperature by 0.8-1.8K in the Arctic and 1.3-1.9K in the Antarctic. Climate models need to include cloud LW scattering to properly simulate polar climate. It is a necessity to have cloud LW scattering for faithfully representing the radiative coupling between atmosphere and surface in the polar regions.

Keywords: Polar climate, cloud longwave scattering, surface-atmosphere radiative coupling



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Overview of OMIX project “Ocean mixing processes: impact on biogeochemistry, climate and ecosystems”

*Ichiro Yasuda[1]

1. Atmosphere and Ocean Research Institute, The University of Tokyo

Overview is presented for the project ‘Ocean mixing processes: impact on biogeochemistry, climate and ecosystem (OMIX) from July 2015 to Mar. 2020’.A new turbulence observing system using fast response thermistors (attached to CTD etc.) was developed and contributed to widen microstructure measurements which showed basin-scale surface-bottom turbulence distribution in the western North Pacific. New data, theories and mixing data-assimilation system helped to revise the model turbulence fields of OGCM which reproduced radiocarbon distribution and deep circulation in the North Pacific. Large numbers of in-situ mixing and biogeochemical observations and modelling lead to findings such that enhanced tide-induced turbulence in the subarctic north Pacific especially in the Kuril and Aleutian passes lift up nutrients such as silicate and iron from deep to intermediate waters strengthens biological production with the iron input from the Okhotsk Sea. This silicate- and iron-rich North Pacific Intermediate Water (NPIW) is transported to subtropical waters and to the Kuroshio where several turbulence hot-spots were found in the Kuroshio which flows through the straits and islands (Tokara Str., Taiwan Str. and Izu-ridge) with also enhanced tide-induced turbulence. These turbulent nutrient supply from NPIW changes the Kuroshio view from oligotrophic to productive area where turbulent nutrient flux sustains various kinds of fish in spawning and nursery grounds. Life history of *chub mackerel*, one of the Kuroshio spawning fish, is elucidated by newly developed microscale otolith stable isotope analysis; better growing juvenile tend to migrate cool and food-abundant Oyashio water. The possibility of tide-induced 18.6-year period ocean and climate variability was examined by new mixing scheme and high-resolution models. Such newly spawning mixing science will be discussed.

Keywords: ocean, biogeochemistry, vertical mixing, ocean circulation, climate, ecosystem

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Typhoon observations using an aircraft from the upper troposphere in the T-PARCII project

*Taro Shinoda[1], Kazuhisa Tsuboki[1], Hiroyuki Yamada[2], Tadayasu Ohigashi[3], Kosuke Ito[2], Munehiko Yamaguchi[4], Tetsuo Nakazawa[4], Hisayuki Kubota[5], Yukihiro Takahashi[5], Norio Nagahama[6], Kensaku Shimizu[6], Nobuhiro Takahashi[1]

1. Institute for Space-Earth Environmental Research, Nagoya University, 2. Faculty of Science, University of the Ryukyus, 3. National Research Institute for Earth Science and Disaster Resilience, 4. Meteorological Research Institute, Japan Meteorological Agency, 5. School of Science, Hokkaido University, 6. Meisei Electric Co. Ltd.

A typhoon often brings about severe disaster by strong winds and heavy rainfall in East Asia, thus accurate prediction of typhoon track and intensity is a social requirement. By recent efforts of meteorological agencies, prediction of typhoon tracks has been improved steadily. However, that of typhoon intensity has not been improved for last few decades. Furthermore, the historical data of typhoon (best track data) have large uncertainty between the Joint Typhoon Warning Center (JTWC) and Japan Meteorological Agency (JMA) after the US aircraft reconnaissance of typhoons was terminated in 1987. To improve estimations and forecasts of typhoon intensity as well as its track, we conduct the Tropical cyclone-Pacific Asian Research Campaign for Improvement of Intensity estimations/forecasts (T-PARCII) project.
We utilized a commercial jet aircraft Gulfstream-II (G-II) of Diamond Air Service (DAS). In 2017, we penetrated 3 times into the inner core region (eye) of the intense typhoon Lan (T201721). In 2018, we penetrated 6 time into the eye of the intense typhoon Trami (T201824). Total 9 times penetration into the eye safely without severe turbulence and approximately 90 times dropsonde observations are conducted at the center of the eye and its surrounding region from a height of 13.8 km. Central pressure of typhoons is observed by dropsondes and compared with the estimated value by the JMA (Dovolak method). In the case of the Lan, the observed central pressure slightly increases from 926 hPa on October 21 to 928 hPa on 22. On the other hand, the JMA best-track data indicated that the central pressure decreases from 935 hPa on October 21 to 915 hPa on 22. The observations also shows a significant double warm core structure in the eye. In the case of the Trami, significant weakening of its intensity from September 25 to 26 with a large change of eye diameter from 60 km to 200 km. The thermodynamic structure in the eye of the Trami is quite different from that of the Lan.

Keywords: Aircraft observation, typhoon, dropsonde

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[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS01] Outer Solar System Exploration Today, and Tomorrow

convener:Jun Kimura(Osaka University), Kunio M. Sayanagi(Hampton University), Fuminori Tsuchiya(Planetary Plasma and Atmospheric Research Center, Graduate School of Science, Tohoku University), Steven Douglas Vance(NASA Jet Propulsion Laboratory, California Institute of Technology)

The giant planets provide many keys to understanding planetary processes. They play an important role in shaping our solar system, and the physical and chemical processes they harbor also provide a unique opportunity to study the phenomena relevant for studying Earth and other planets, including exoplanetary systems. In this session, we discuss a wide range of topics encompassing the giant planets and their moons, including their origins, interiors, atmospheres, compositions, surface features, and electromagnetic fields. To advocate for current and future outer planets exploration (Juno, New Horizons, JUICE, Europa Clipper, Dragonfly and beyond), we also call for discussions on future missions to explore giant planet systems, including how to develop better international cooperation. Discussion in this latter category will include progress in developing a solar sail mission concept for observing the Jupiter system and its trojan asteroids.

[PPS01-01] Dynamics in Jupiter's magnetosphere revealed by time variation of plasma densities and temperature in the Io plasma torus coincident with volcanic activations on Io

★Invited Papers

*Reina Hikida[1], Kazuo Yoshioka[1], Fuminori Tsuchiya[2], Masato Kagitani[2], Tomoki Kimura[2], Fran Bagenal[3], Nick Schneider[3], Go Murakami[4], Atsushi Yamazaki[4], Hajime Kita[4], Edward Nerney[3], Seiya Nishimura[1], Hidetaka Kuniyoshi[1], Ichiro Yoshikawa[1] (1.the University of Tokyo, 2.Tohoku University, 3.University of Colorado, 4.JAXA)

[PPS01-02] Identifying the particle responsible for energy supply during the IPT brightening event.

*Seiya Nishimura[1], Fumiharu Suzuki[1], Kazuo Yoshioka[1], Reina Hikida[1], Hidetaka Kuniyoshi[1], Fuminori Tsuchiya[3], Go Murakami[2], Ichiro Yoshikawa[1] (1.The university of tokyo, 2.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 3.Planetary Plasma and Atmospheric Research Center, Graduate School of Science, Tohoku University)

[PPS01-03] **Origin of delayed rotational periodicity in the inner magnetosphere of Jupiter**

*Fuminori Tsuchiya[1], Hiroaki Misawa[1], Masato Kagitani[1], Ryoichi Koga[1], Reina Hikida[2], Kazuo Yoshioka[2], Nick Schneider[5], Peter A Delamere[6], Fran Bagenal[5], Andrew Steffl[4], Tomoki Kimura[1], Yasumasa Kasaba[1], Go Murakami[3], Ichiro Yoshikawa[2], Atsushi Yamazaki[3] (1.Tohoku University, 2.The University of Tokyo, 3.ISAS/JAXA, 4.SwRI, 5.University of Colorado, 6.University of Alaska Fairbanks)

[PPS01-04] Observations of tenuous atmospheres and plumes at the icy Galilean moons: HST and future missions

★Invited Papers

*Lorenz Roth[1] (1.KTH Royal Institute of Technology, Stockholm, Sweden)

[PPS01-05] Performance, Operation and their Feasibilities for Jupiter and Icy Moons: High Frequency Receiver of Radio & Plasma Wave Investigation (RPWI) aboard JUICE

*Yasumasa Kasaba[1], Hiroaki Misawa[1], Fuminori Tsuchiya[1], Tomoki Kimura[1], Hajime Kita[3], Atsushi Kumamoto[1], Yuto Katoh[1], Yoshizumi Miyoshi[4], Yoshiya Kasahara[5], Satoshi Yagitani[4], Hirotsugu Kojima[8], Baptiste Cecconi[2], Lukas Wiśniewski[6], Walter Puccio[7], Jan Bergman[7], Jan-Erik Wahlund[7] (1.Tohoku University, 2.Observatoire de Paris, 3.Japan Aerospace Exploration Agency, 4.Nagoya University, 5.Kanazawa University, 6.Astronika, 7.IRF Uppsala, 8.Kyoto University)

Dynamics in Jupiter’s magnetosphere revealed by time variation of plasma densities and temperature in the Io plasma torus coincident with volcanic activations on Io

*Reina Hikida[1], Kazuo Yoshioka[1], Fuminori Tsuchiya[2], Masato Kagitani[2], Tomoki Kimura[2], Fran Bagenal[3], Nick Schneider[3], Go Murakami[4], Atsushi Yamazaki[4], Hajime Kita[4], Edward Nerney[3], Seiya Nishimura[1], Hidetaka Kuniyoshi[1], Ichiro Yoshikawa[1]

1. the University of Tokyo, 2. Tohoku University, 3. University of Colorado, 4. JAXA

The volcanic activity on the Io satellite and the associated outgassing into the Jupiter’s magnetosphere fluctuate dynamically. The fluctuations of plasma densities inside the Io plasma torus (IPT) associated with the volcanic activities on Io were indicated by the spectroscopic observation by the Hisaki satellite. If the supply of plasma from Io increases, the plasma mass-loading enhances, and the magnetospheric dynamics is expected to be affected. The time continuity of the Hisaki observation made it possible to explore the sequence of magnetospheric dynamics from the activation of volcanoes to the recovery for the first time. In this study, we apply the analysis method called plasma diagnosis to the spectroscopic data obtained by Hisaki with the widest slit (140 arc seconds slit). The time variation of plasma densities and temperature has been determined from December 2013 to April 2014, from November 2014 to May 2015, from January 2016 to March 2016, from May 2016 to August 2016, and from November 2016 to December 2016. During the above periods, four significant events of volcanic activation occurred. In each event, there was a common tendency that the density of hot electrons (several hundreds of eV) increased several tens of days after the core electron density increased. The hot electron density can be considered as a tracer for the radial inward transport of magnetic flux tubes. This is because the timescale for thermal relaxation of the hot electrons is at most several days and the outer region is more abundant in the hot electrons. This study revealed the following three facts about the time variation of the hot electron density. Firstly, the radial distribution of mass density showed that the interchange motion of flux tubes inside the IPT subsided before the hot electron density started to increase. This indicates that the cause of the increase in the hot electron density exists in the outside region of the IPT. Secondly, it was found that the timescale from the start of the activation of the volcano to the rise of the hot electron density was 20-30 days at any event. Finally, the hot electron density on the dusk side was higher than that on the dawn side at least with two events of volcanic activation. This suggests that the radial inward transport of flux tubes might reach the dusk side more easily than the dawn side. In this presentation, the dynamics in Jupiter’s magnetosphere will be discussed by using the above findings.

Keywords: Jupiter, Io plasma torus, Magnetospheric dynamics

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Identifying the particle responsible for energy supply during the IPT brightening event.

*Seiya Nishimura[1], Fumiharu Suzuki[1], Kazuo Yoshioka[1], Reina Hikida[1], Hidetaka Kuniyoshi[1], Fuminori Tsuchiya[3], Go Murakami[2], Ichiro Yoshikawa[1]

1. The university of tokyo, 2. Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 3. Planetary Plasma and Atmospheric Research Center, Graduate School of Science, Tohoku University

HISAKI spacecraft witnessed sudden brightenings of the Io plasma torus (IPT) in EUV spectral range not only for volcanic active period of Io but also for quiet times. Yoshikawa et al., 2016 has reported that the IPT brightens about 10 hours after the auroral brightening event which indicates radially inward energy transport. We have measured the relaxation time of the brightenings appearing between 2013 and 2016. We have also calculated the characteristic time for Coulomb collision with test particles (*e-,H+,S+)* in background plasma of IPT condition. By comparing the relaxation time of the brightenings to the characteristic time scale for Coulomb collision, we have determined that electrons supply energy during the brightening events. We also found that ions, which should be transporting to the IPT with electrons, should supply energy but with its low energy supply rate, it could not be observed as brightening.

Keywords: IPT, HISAKI spacecraft, brightening event

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Origin of delayed rotational periodicity in the inner magnetosphere of Jupiter

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Periodic signature of electromagnetic waves from planets has been used to determine planetary rotation period. In the case of Jupiter, four periodicities have been known so far: System I, II, III, and IV periods. System I and II are related with zonal circulations of the atmosphere and System III shows the intrinsic planet rotation period and determined from periodicity of Jovian auroral radio emission. Only the origin of System IV is unknown but it has been found in periodic variation in plasmas in the inner magnetosphere and is a few % delayed from System III, suggesting that the System IV frame is subcorotating around Jupiter. Here, we resolved the origin of the subcorotation by using spatially resolved extreme ultraviolet (EUV) spectrograph onboard the Hisaki satellite. Hisaki observed emission lines from sulfur and oxygen ions which are products of volcanic gases from the satellite Io and provides plasma parameters such as ion composition and electron temperature from the spectral analysis. We found that the plasma parameters showed periodic variation whose periodicity was delayed from System III and the delay depended on the radial distance from Jupiter. The delay was most significant around the radial distance of Io, which is consistent with mass-loading of plasma from neutral cloud distributed along Io’ s orbit. Hisaki also found change in the delay profile after eruptions of Io’ s volcanos. The delay became small around the Io’ s orbit where enhanced mass-loading was expected during the eruption. The change is not consistent with a previous theoretical prediction and updates of the magnetosphere-ionosphere coupling model may be required to resolve this new issue.

Keywords: Jupiter, Io, magnetosphere

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Observations of tenuous atmospheres and plumes at the icy Galilean moons: HST and future missions

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In this presentation, we review the UV observations by the Hubble Space Telescope (HST) of the tenuous atmospheres of Jupiter's large icy moons. The detections of the O_2 atmospheres at Europa and Ganymede through auroral emissions and at Callisto through photo-electron emissions are discussed and compared. In addition to the O_2 atmospheres, HST discovered atomic hydrogen coronae at all three moons and measured localized H and O atomic emissions at Europa, interpreted as first evidence for the existence of plumes. At the end, we give an overview on future measurements of the icy moon atmospheres by ESAs JUpiter Icy Moon Explorer (JUICE) and NASAs Europa Clipper mission, with focus on the UVS instruments.

Keywords: Jupiter, Icy moons, Hubble Space Telescope, JUICE, Europa Clipper

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Performance, Operation and their Feasibilities for Jupiter and Icy Moons: High Frequency Receiver of Radio & Plasma Wave Investigation (RPWI) aboard JUICE

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We are now at the final stage of the development of PFM/FM of Radio & Plasma Wave Investigation (RPWI) aboard the ESA JUICE mission, toward the luanch in 2022. RPWI provides an elaborate suite for electromagnetic fields and plasma environment around Jupiter and icy moons, with 4 Langmuir probes (LP-PWI; 3-axis E-field -1.6 MHz, and cold plasmas), a search coil magnetometer (SCM; 3-axis B-field -20 kHz), and a tri-dipole antenna system (RWI; 3-axis E-field 0.08-45 MHz, 2.5-m tip-to-tip length).

RWI with High Frequency (HF) Receiver have enough sensitivity reaching the galactic background for the highly-resolved Jovian radio emissions from magnetosphere (aurora etc.), atmosphere (lightning), and icy moons. Its direction and polarization capabilities enable us to identify the source locations and characteristics. Their developments are under the collaboration of Japan, France, Poland and Sweden, based on the H/W and S/W designs of Kaguya-LRS, BepiColombo-PWI, Arase-PWE, and Cassini-RPWS. In this paper, we provide the performance and operation concepts with their feasibilities. These are now realistic and enable us to achieve the best performances and quiet environment with enough tolerance for wide temperature range around Venus-Jupiter and harsh plasma environment (charging & intense radiation).

The most difficult parts of the RPWI HF are the sensing of the ionospheres, surface, and subsurface of icy moons duirng the flyby operations and on the orbit around Ganymede. The ionospheres are remotely sensed by the occultation of Jovian radio signals, which has a capability to detect the highest ionopheric density in usual status and expected plume ejection events. The surface and subsurfaces are challenging topics. It is based on the passive subsurface radar (PSSR) concept which sounds the icy crusts of Galilean satellites by the reflections of Jovian radio emissions (HOM/DAM). For continuous and coherent waves, reflector information is determined by spectrum patterns caused by the interference among the direct wave, reflected one from surface, and scattered one by subsurface. For burst waves, the reflection component is determined by cross-correlation of the waveforms for msecs length. It is not easy to reach the top of subsurface ocean directly, because of the strong attenuation in the ice close to its melting temperature just close to the ocean region. However, we arelooking forward to see real data and support the subsurface studies executed by RIME (active radar sounder) and many other payload teams.

Keywords: Jupiter, JUICE, RPWI, Magnetosphere, Icy moons, Subsurface ocean

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[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS01] Outer Solar System Exploration Today, and Tomorrow

convener:Jun Kimura(Osaka University), Kunio M. Sayanagi(Hampton University), Fuminori Tsuchiya(Planetary Plasma and Atmospheric Research Center, Graduate School of Science, Tohoku University), Steven Douglas Vance(NASA Jet Propulsion Laboratory, California Institute of Technology)

The giant planets provide many keys to understanding planetary processes. They play an important role in shaping our solar system, and the physical and chemical processes they harbor also provide a unique opportunity to study the phenomena relevant for studying Earth and other planets, including exoplanetary systems. In this session, we discuss a wide range of topics encompassing the giant planets and their moons, including their origins, interiors, atmospheres, compositions, surface features, and electromagnetic fields. To advocate for current and future outer planets exploration (Juno, New Horizons, JUICE, Europa Clipper, Dragonfly and beyond), we also call for discussions on future missions to explore giant planet systems, including how to develop better international cooperation. Discussion in this latter category will include progress in developing a solar sail mission concept for observing the Jupiter system and its trojan asteroids.

[PPS01-07] Uranus and Neptune are key to understand planets with hydrogen atmospheres

*Tristan Guillot[1,2] (1.Observatoire de la Cote d Azur, 2.JSPS/University of Tokyo)

[PPS01-08] A Possible Formation Scenario of Saturn-Titan System

*Yuri Fujii[1], Masahiro Ogihara[2] (1.Institute for Advanced Research, Nagoya University, 2.Division of Science, National Astronomical Observatory of Japan)

[PPS01-09] Variation in Titan’s polar sea distribution due to orbital forcing simulated by a sea balance model

*Tetsuya Tokano[1] (1.University of Cologne)

[PPS01-12] Forced libration of Ganymede: including visco-elastic tidal deformations

*Shinichiro Kojima[1], Jun Kimura[1], Shunichi Kamata[2] (1.Department of Earth and Space Science, Graduate School of Science, Osaka University, 2.Department of Earth and Planetary Science, Faculty of Science, Hokkaido University)

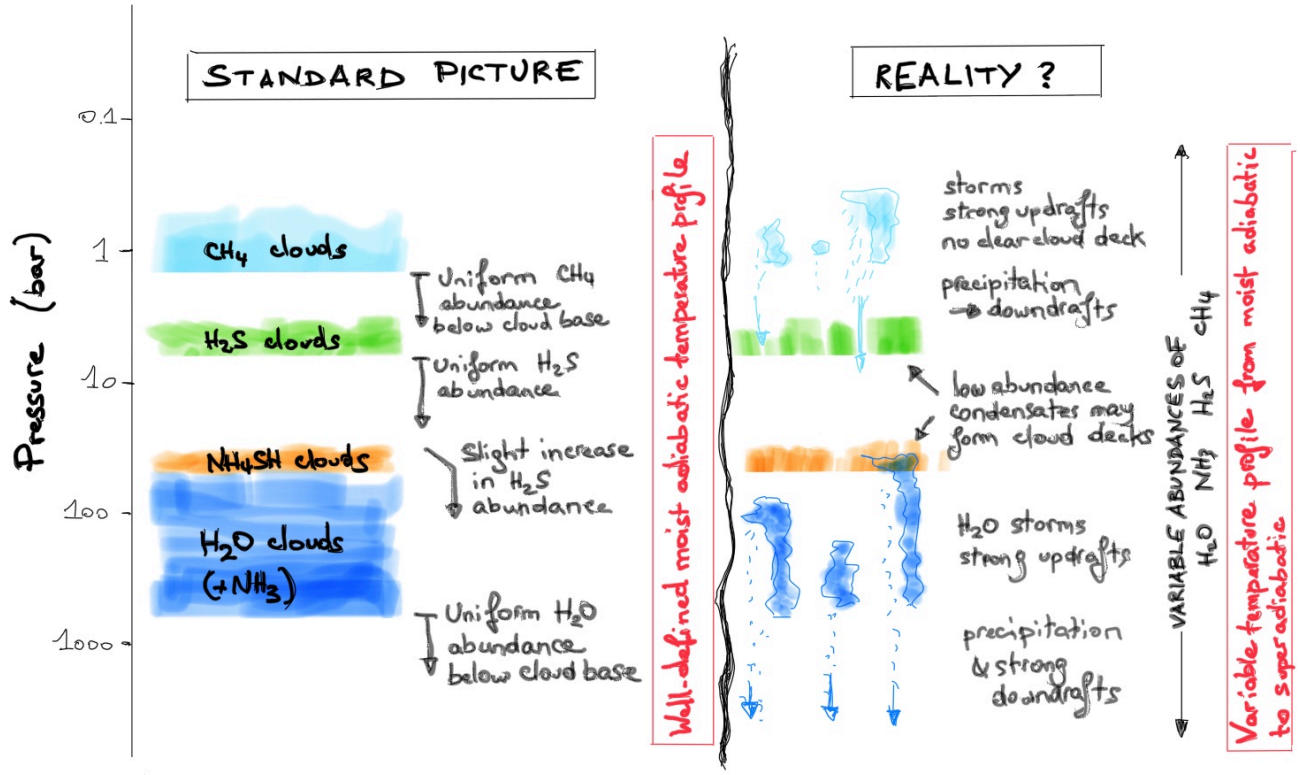
Uranus and Neptune are key to understand planets with hydrogen atmospheres

*Tristan Guillot[1,2]

1. Observatoire de la Cote d Azur, 2. JSPS/University of Tokyo

Uranus and Neptune are the last unexplored planets of the Solar System. I show that they hold crucial keys to understand the atmospheric dynamics and structure of planets with hydrogen atmospheres. Their atmospheres are active and storms are believed to be fueled by methane condensation which is both extremely abundant and occurs at low optical depth. This means that mapping temperature and methane abundance as a function of position and depth will inform us on how convection organizes in an atmosphere with no surface and condensates that are heavier than the surrounding air, a general feature of gas giants. Using this information will be essential to constrain the interior structure of Uranus and Neptune themselves, but also of Jupiter, Saturn and numerous exoplanets with hydrogen atmospheres. Owing to the spatial and temporal variability of these atmospheres, an orbiter is required. A probe would provide a reference profile to lift ambiguities inherent to remote observations. It would also measure abundances of noble gases which can be used to reconstruct the history of planet formation in the Solar System. Finally, mapping the planets' gravity and magnetic fields will be essential to constrain their global composition, structure and evolution. [see Guillot 2019, arXiv:1908.02092]

Keywords: Giant Planets, Atmospheres, Space Exploration, Solar System formation, Meteorology, Uranus, Neptune



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A Possible Formation Scenario of Saturn-Titan System

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Satellite systems around gas giants that have only one large moon, such as Titan around Saturn, are known to be difficult to explain their formation processes. Relatively large moons are thought to form in gaseous circumplanetary disks. The orbits of moons are affected by the interaction between the disk gas, and thus, the final configuration of the system is determined when the disk has dissipated. According to previous N-body simulations, a system tend to have multiple moons or loses all the moons if a simple power-low disk is assumed.

We examine the orbital evolution of satellites in order to find a way to form a single-large-moon system. Because the direction and speed of the orbital migration depend on the properties of circumplanetary disks, we model dissipating circumplanetary disks with considering the effect of temperature structures. We calculate the orbital evolution of Titan-mass moons in the final evolution stage of various circumplanetary disks. We also perform *N*-body simulations of systems with initially multiple satellites to see whether single-moon systems form at the end.

We find that the radial slope of the temperature structure characterized by the dust opacity produces a patch of orbits where the Titan-mass satellites stop inward migration and even migrate outwards in a certain range of the viscosity. The patch assists satellites initially located in the outer orbits to remain in the disk, while others in the inner orbits are lost into the planet. We demonstrated for the first time that systems with only one large moon around giant planet can form. Our results suggest satellite formation was not very efficient in the outer radii of circumplanetary disks.

Keywords: satellite formation, single-moon system, Titan, gas giant, circumplanetary disk, orbital evolution

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Variation in Titan’s polar sea distribution due to orbital forcing simulated by a sea balance model

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1. University of Cologne

Titan’s polar sea distribution is highly asymmetric about the equator in that most seas and lakes are found near the north pole, while the south polar region has only few lakes, among which Ontario Lacus. This hemispheric dichotomy in the polar sea distribution raised the question as to whether it may be a manifestation of the Croll-Milankovitch-type orbital forcing of Titan’s methane hydrological cycle, which would periodically reverse the hemispheric asymmetry in the polar sea distribution. This study investigates how the lake distribution in Ontario Basin near the south pole may have evolved over the past 45 kyr as a consequence of orbital forcing. The temporal variation in lake distribution is simulated by a lake balance model with meteorological output of a global climate model and considering the topography map measured by Cassini. The long-term variation in lake size is mainly caused by the temporal variation in precipitation rate rather than that in evaporation rate. The lake size of Ontario Lacus changes by a factor of approximately 2. In no epoch do the predicted area and volume of Ontario Lacus become nearly as large as the inferred paleosea in Ontario Basin or the observed present seas near the north pole. This implies that orbital forcing alone is not capable of reversing the hemispheric asymmetry in Titan’s polar sea distribution and a climate with substantially larger precipitation would have been necessary to explain the southern paleoseas.

Keywords: Titan, Seas

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Forced libration of Ganymede: including visco-elastic tidal deformations

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1. Department of Earth and Space Science, Graduate School of Science, Osaka University, 2. Department of Earth and Planetary Science, Faculty of Science, Hokkaido University

Most of solid bodies which are beyond Jupiter are covered by ice and therefore called icy bodies. Based on previous observations and theoretical works, some of these bodies are presumed to possess a subsurface ocean where extraterrestrial organism might exist.
Jovian moon Ganymede is one of these body and is the main target of a future Jovian exploration mission. A past exploration revealed that Ganymede has a small moment of inertia and an intrinsic magnetic field. These observational facts indicate that Ganymede has a fully differentiated interior composed of a metallic core at the center, rocky mantle, and the outermost ice shell. Although a magnetic observation by the past exploration indicates that the salty subsurface ocean exists within the shell, the existence of the ocean is still ambiguous. Therefore, this study uses libration as an alternative method for presuming the interior of Ganymede.
In recent years, a libration study for Ganymede has included an elastic tidal deformation. Consequently, the deformation strongly reduces a librational amplitude in the case with the ocean. On the other hand, the librational amplitude is comparable even in the case without the ocean. Their study concluded the amplitude cannot provide the information of the existence of the ocean. Although other study for Europa included the effect of viscosity, the viscosity profile in the ice shell of its model is considerably simplified, thus a refined model is needed.
In our study, we apply the refined interior model to calculate librational amplitudes and phase-lag including the amplitude and phase-lag of visco-elastic tidal deformations.
As a result, the librational amplitude reaches 110 m for a case with the ocean.
In contrast, the amplitude is up to 10 m for a case without the ocean. These contrasts provide the information of the existence of the ocean.
Also the librational phase-lag is useful to estimate a melting point viscosity at the bottom of the ice shell. These results will be examined in the next exploration mission named JUICE (JUpiter ICy moons Explorer).

Keywords: Ganymede, Libration, JUICE

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[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS01] Outer Solar System Exploration Today, and Tomorrow

convener:Jun Kimura(Osaka University), Kunio M. Sayanagi(Hampton University), Fuminori Tsuchiya(Planetary Plasma and Atmospheric Research Center, Graduate School of Science, Tohoku University), Steven Douglas Vance(NASA Jet Propulsion Laboratory, California Institute of Technology)

The giant planets provide many keys to understanding planetary processes. They play an important role in shaping our solar system, and the physical and chemical processes they harbor also provide a unique opportunity to study the phenomena relevant for studying Earth and other planets, including exoplanetary systems. In this session, we discuss a wide range of topics encompassing the giant planets and their moons, including their origins, interiors, atmospheres, compositions, surface features, and electromagnetic fields. To advocate for current and future outer planets exploration (Juno, New Horizons, JUICE, Europa Clipper, Dragonfly and beyond), we also call for discussions on future missions to explore giant planet systems, including how to develop better international cooperation. Discussion in this latter category will include progress in developing a solar sail mission concept for observing the Jupiter system and its trojan asteroids.

[PPS01-13] CHARISMA: A space telescope for planetary science

*Cindy Young[1], Kunio M. Sayanagi[2], Michael Wong[3] (1.NASA Langley Research Center, 2.Hampton University, 3.University of California, Berkeley)

[PPS01-14] Future ultraviolet observation for monitoring Europa and outer planetary systems

*Go Murakami[1], Fuminori Tsuchiya[2], Ryoichi Koga[2], Kazuo Yoshioka[3], Masato Kagitani[2], Tomoki Kimura[4], Atsushi Yamazaki[1], Yudai Suzuki[3], Hajime Kita[1], Masaki Kuwabara[1], Reina Hikida[3], Chihiro Tao[5], Yasumasa Kasaba[2], Ichiro Yoshikawa[3] (1.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 2.Planetary Plasma and Atmospheric Research Center, Graduate School of Science, Tohoku University, 3.Graduate School of Frontier Sciences, The University of Tokyo, 4.Frontier Research Institute for Interdisciplinary Sciences, Tohoku University, 5.National Institute of Information and Communications Technology)

[PPS01-15] The Europa Clipper Mission: Investigating an Ocean World's Habitability

*Steven Douglas Vance[1], Robert T Pappalardo[1], David A Senske[1], Haje Korth[2], Kate Craft[2], Sam Howell[1], Rachel L Klima[2], Erin J Leonard[1], Cynthia B Phillips[1], Christina Richey[1] (1.NASA Jet Propulsion Laboratory, California Institute of Technology, 2.The Johns Hopkins University Applied Physics Laboratory)

[PPS01-16] Geophysical and astrobiological perspectives for future spacecraft missions to Jovian icy moons

*Yasuhito Sekine[1], Shunichi Kamata[3], Shuya Tan[1], Shintaro Azuma[1], Ikuo Katayama[6], Yoshifumi Saito[2], Kazushi Asamura[2], Keigo Enya[2], Junichi Haruyama[2], Yasumasa Kasaba[4], YASUKO KASAI[5], Ayako Matsuoka[2] (1.Tokyo Institute of Technology, 2.JAXA, 3.Hokkaido University, 4.Tohoku University, 5.NICT, 6.Hiroshima University)

[PPS01-18] The Io Volcano Observer (IVO): Investigating the Interior of a Tidally Heated World

★Invited Papers

*Christopher W. Hamilton[1], Alfred S. McEwen[1], Xianzhe Jia[2], and the IVO Science Team (1.University of Arizona, 2.University of Michigan)

CHARISMA: A space telescope for planetary science

*Cindy Young[1], Kunio M. Sayanagi[2], Michael Wong[3]

1. NASA Langley Research Center, 2. Hampton University, 3. University of California, Berkeley

The Caroline Herschel high-Angular Resolution In-Space assembled Multi-Aperture (*CHARISMA*) telescope is a future mission concept being advocated by the U.S. planetary science community. The telescope addresses the US National Academy Committee on Astrobiology and Planetary Science (CAPS)' s recommendation to study a large/medium-class dedicated space telescope for planetary science. The concept ensures that the high-resolution, high-sensitivity observations of the solar system in visible and UV wavelengths revolutionized by the Hubble Space Telescope will continue after its expected end in the near future. Scientific objectives critically dependent on UV capabilities include studies of exospheric and auroral emissions in planetary atmospheres and plumes. *CHARISMA* will have the greatest impacts on science objectives particularly sensitive to dynamically evolving phenomena with fine-scale structures in planetary rings, active plumes/volcanism, atmospheric energy/momentum transport, and aurora. *CHARISMA* will also revolutionize our understanding of time-dependent phenomena in our solar system currently not supported by programs (in operation or under implementation) intended to observe and visit new targets. The time-domain phenomena to be explored by *CHARISMA* include: interaction of planetary magnetospheres with the solar wind, Venus and giant planet atmospheric dynamics, icy satellite geologic activity and surface evolution, cometary evolution, and evolving ring phenomena. *CHARISMA* also enables a comprehensive survey of the spectral characterization of minor bodies across the solar system, which requires a large time allocation not supported by existing facilities.

CHARISMA' s 10-meter class aperture is enabled by advanced in-Space Assembly (iSA) technologies developed at NASA Langley Research Center (LaRC) and the in-space servicing technologies developed at NASA Goddard Space Flight Center (GSFC). The telescope will be robotically assembled in orbit and will adopt a sparse, distributed-aperture architecture, which is inherently modular in design and conducive to iSA. We will also examine the potential for future servicing and upgrades enabled by the iSA technologies. *CHARISMA* will take advantage of LaRC' s leading role in the Orbital Servicing, Assembly and Manufacturing (OSAM) efforts to perform a series of trade studies spanning a variety of variables. Our design will also utilize lessons from the on-going Astrophysics Decadal Mission Study of a future 20-meter in-Space Assembled Telescope (iSAT) that covers the same wavelength range as *CHARISMA* between FUV and NIR. *CHARISMA* will help mature the technologies identified by the iSAT final report to construct a 20-meter telescope. Thus, while serving as a fully functional, dedicated telescope for planetary science, *CHARISMA* also provides an early demonstration of key technologies needed for future astrophysics telescopes. The *CHARISMA* mission concept has excellent synergy with astrophysical facilities (e.g., JWST, ALMA and SKA). *CHARISMA* will be able to place planetary discoveries made by astrophysics assets in temporal context, and *CHARISMA* discoveries of time-dependent phenomena may trigger detailed observations using larger telescopes. *CHARISMA* will also support future missions to the Ice Giants, Ocean Worlds, and minor bodies across the solar system by placing the results of such targeted missions in the context of longer records of temporal activities and larger sample populations. The CHARISMA notional design, estimated cost, and science objectives will be presented.

Keywords: volcanism, ring systems, small bodies, ocean worlds, ice giants, magnetospheres

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Future ultraviolet observation for monitoring Europa and outer planetary systems

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Ultraviolet observation technique is one of the most powerful tools to investigate space environments of outer planets. Japan’s space telescope Hisaki performed long-term and continuous monitoring of Io plasma torus (IPT) in UV range. The temporal variation of IPT emissions observed by Hisaki showed Jupiter’s magnetospheric dynamics and Io’s volcanic activities. However, due to the low spatial resolution (17 arc-sec) and low sensitivity (effective area of 1-3 cm^2), many science topics are not covered. For example, Hisaki cannot observe Jupiter’s and Saturn’s moons themselves because they are too small. The UV spectroscope onboard Hubble Space Telescope (HST) detected signatures of Europa’s water plume. However, due to the difficulty of long-term and continuous monitoring of Europa by HST, the frequency, periodicity, and driving processes of the plume are still open questions. It is also difficult for NASA’s Europa Clipper mission and ESA’s JUICE mission which will explore Jovian system in late 2020s to perform continuous monitoring due to their capabilities with Europa flyby observations. In order to achieve such observations, we are studying a concept of future ultraviolet spectroscopy mission. The preliminary design shows a Cassegrain telescope with 0.6-1-m primary mirror which can achieve an effective area of 100-200 cm2 and spatial resolution of 0.1-0.2 arc-sec. The baseline instruments are a spectrometer for 115-230 nm range and a wide field-of-view (~9 arc-min) imager. Here we present the overview of our mission concept, science targets, preliminary design of the ultraviolet telescope and instruments, and future plans.

Keywords: Ultraviolet, Europa, Space telescope

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The Europa Clipper Mission: Investigating an Ocean World's Habitability

*Steven Douglas Vance[1], Robert T Pappalardo[1], David A Senske[1], Haje Korth[2], Kate Craft[2], Sam Howell[1], Rachel L Klima[2], Erin J Leonard[1], Cynthia B Phillips[1], Christina Richey[1]

1. NASA Jet Propulsion Laboratory, California Institute of Technology, 2. The Johns Hopkins University Applied Physics Laboratory

Europa is believed to have a liquid ocean beneath its icy shell, abundant physical energy, and drivers for chemical disequilibrium. The *Europa Clipper* mission will conduct multiple fly-bys of Europa while orbiting Jupiter, with the overarching goal to explore this moon to investigate its habitability. This goal encompasses three Mission Objectives: *I. Characterize the ice shell and any subsurface water, including their heterogeneity, ocean properties, and the nature of surface-ice-ocean exchange; II. Understand the habitability of Europa's ocean through composition and chemistry; and III. Understand the formation of surface features, including sites of recent or current activity, and characterize high science interest localities.* The Europa Clipper addresses these with a capable payload of scientific instruments, plus gravity/radio and radiation science investigations.

NASA selected a payload consisting of both remote-sensing and in-situ-observing instruments. The remote-sensing instruments observe the wavelength range from ultraviolet through radar, which are the *Europa Ultraviolet Spectrograph (Europa-UVS)*, the *Europa Imaging System (EIS),* the *Mapping Imaging Spectrometer for Europa (MISE),* the *Europa Thermal Imaging System (E-THEMIS),* and the *Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON).* The *in-situ*-measuring particle instruments comprise the *Plasma Instrument for Magnetic Sounding (PIMS),* the *MAss Spectrometer for Planetary Exploration (MASPEX)*, and the *SUrface Dust Analyzer (SUDA)*. These investigations are complemented by the *Europa Clipper Magnetometer (ECM)*, which is a facility instrument contributed by NASA to measure magnetic fields. An additional gravity/radio science investigation can be achieved using the spacecraft's telecommunication system, combined with radar altimetry. Moreover, valuable scientific data could come from the spacecraft’s radiation monitoring system. Working together, the science instruments provide a synergistic framework to address key issues in assessing Europa’s habitability.

Keywords: Europa, Ocean Worlds, Habitability

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Geophysical and astrobiological perspectives for future spacecraft missions to Jovian icy moons

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1. Tokyo Institute of Technology, 2. JAXA, 3. Hokkaido University, 4. Tohoku University, 5. NICT, 6. Hiroshima University

Jovian icy moons, Europa, Ganymede, and Callisto, are key objects to understand both of the evolution of early Solar System and habitability beyond Earth. Geologically-inactive Callisto may preserve chemical information (e.g., isotopic compositions of volatiles) of building materials of the Jovian system, which is essential to constrain the formation temperature of proto-Jupiter in the protoplanetary disk. The interior structure is determined by its formation time in the circum-Jovian disk and, thereby, is essential to constrain the accretion rate of solid materials onto proto-Jupiter. Ganymede and Europa are believed to possess subsurface oceans beneath the icy shells. Given the sustainability of liquid water, habitability of these subsurface oceans largely relies on the availability of both reductants and oxidants. Reductants can be found in plume materials erupting from Europa’ s surface, whereas oxidants can be observed on the surface. However, the existence of oxidants and reductants is unconstrained based on observational data.

In this talk, we discuss key observations in future spacecraft missions to constrain the formation of the Jovian system and habitability of Europa and Ganymede. The key observations include the moment of inertia of Callisto (and Ganymede) based on high resolution gravity measurements, lateral heterogeneity of crustal thickness, isotopic compositions of water, the abundance of reductants, H_2 and H_2S, in Europa’ s plume, and the chemical compositions of surface salts on Europa and Ganymede. We discuss how these observations can be used to resolve the key issues on the formation of the Jovian system and habitability in the subsurface oceans.

Keywords: icy satellite, Solar System exploration

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The Io Volcano Observer (IVO): Investigating the Interior of a Tidally Heated World

*Christopher W. Hamilton[1], Alfred S. McEwen[1], Xianzhe Jia[2], and the IVO Science Team

1. University of Arizona, 2. University of Michigan

NASA's Discovery program recently selected the Io Volcano Observer (IVO) as one of four missions to advance to a Phase A study. Io's proximity to the Jupiter and its Laplace orbital resonances with Europa and Ganymede mean the interior of the moon is flexed by gravitational processes leading to heating and volcanic activity at its surface. This makes Io the quintessential location for investigating processes of tidal heating within the Solar System. The mission will provide fundamental new constraints on Io's interior by assessing whether or not it has an extant magma ocean (i.e., a layer, on the surface or in the interior of a body, that has such a high melt fraction that it behaves like a fluid). One of IVO's prime objectives is therefore to "follow the heat" and determine the degree and distribution of melt within Io's mantle and test whether or not tidal heating maintains a magma ocean inside present day Io.

Magnetometer measurements made by the Galileo spacecraft have provided an important constraint on this problem. Galileo observed an induced magnetic field within Io, which can be accounted for if the moon's upper mantle contains at least 20% melt. However, plasma interactions with an inhomogeneous atmosphere could generate similar magnetic signatures. IVO will address this issue by better constraining Io's plasma environment and conducting multiple flybys that are optimized to the best times and places for measuring variations in Io's magnetic field. Independent measurements will also be used to assess the rigidity of Io's lithosphere and its coupling to the deeper mantle. Specifically, if Io has a detached lithosphere over a globally continuous partial melt layer, then two independent measurements would provide definitive evidence of a magma ocean. One of these measurements is the ratio of imposed gravitational potential from Jupiter (which is well known) and the induced gravitational potential from the deformation of Io (to be measured by IVO), which is known as k_2. The second measurement is libration amplitude of Io.

Combining these lines of evidence, a weak induced magnetic field, low k_2, and low libration amplitude would imply that Io does not include a magma ocean. A strong magnetic induction signal, high k_2, and high libration amplitude would support the existence of a subsurface magma ocean. The accompanying figure summarizes these two end-member scenarios as well as important variations. For instance, dissipation within the solid interior of Io could occur preferentially in the asthenosphere or in deep mantle. Alternatively, melt within Io's interior could either form a magma ocean or a globally connected "magmatic sponge" layer with a lower, but still interconnected melt fraction. Global maps of heat flow, as well as volcanic and tectonic features, would also enable new measurements of lava temperatures and compositions that would provide additional means to discriminate between these interior models, and better understand mechanisms of "heat pipe" magma transport.

IVO will orbit Jupiter at an inclination of ~45°, designed so that the radiation dose per flyby is ~20 krad. IVO's total radiation dose over ten orbits of its nominal mission phase will therefore be less than one tenth that of the Europa Clipper spacecraft. Science instruments will include a narrow-angle camera nearly identical to that of the Europa Imaging System, the Plasma Instrument for Magnetic Sounding, dual fluxgate magnetometers with multi-mission heritage, a thermal mapper with heritage from the BepiColombo spacecraft, and a neutral mass spectrometer in development for JUpiter ICy moons Explorer

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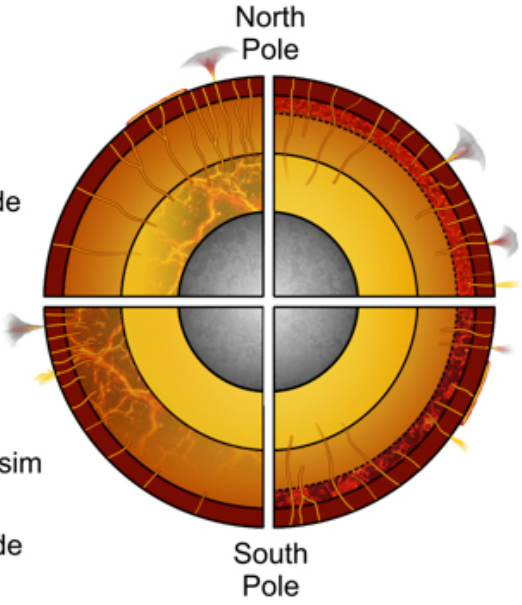
(JUICE) spacecraft. In Phase A, we will propose an additional wide-angle stereo camera as a student collaboration instrument. The geometry and timing of each Io encounter are carefully designed to accomplish our science objectives, and will enable IVO to revolutionize our understanding of Io and tidally heated worlds in the Solar System and beyond.

Keywords: Io, Juipter, Tidal, Heating, NASA, Discovery

Solid Body Dissipation in Deep Mantle:
- Weak magnetic induction
- Polar focused volcansim
- High temperature magma
- Low k_2 and libration amplitude

Solid Body Dissipation in Asthenosphere:
- Weak magnetic induction
- Low-latitude focused volcansim
- Lower temperature magma
- Low k_2 and libration amplitude



Fluid Body Dissipation in "Magma Ocean":
- Strong magnetic induction
- Volcanism may be focused at low-latitudes with a longitude shift
- High temperature magma
- High k_2 and libration amplitude

Fluid Dissipation in "Magmatic Sponge":
- Strong magnetic induction
- Volcanism may be focused at low-latitudes
- Low to high temperature magma
- Low k_2 and libration amplitude

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[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS02] Lunar Science and Exploration

convener:Masaki N Nishino(Japan Aerospace Exploration Agency, Institute of Space and Astronautical Science), Masahiro KAYAMA(Department of General Systems Studies, Graduate School of Arts and Sciences, The University of Tokyo), Hiroshi Nagaoka(Japan Aerospace Exploration Agency), Yusuke Nakauchi(Japan Aerospace Exploration Agency)

Scientific data sets acquired by Japanese lunar mission SELENE (Kaguya) have become the standard of the lunar sciences. Other missions such as Chandrayaan-1, LRO, GRAIL, LCROSS, LADEE, Artemis, and Chang'e series as well as ground observations are also providing new knowledges of the Moon. Apollo/Luna samples and lunar meteorite analyses are also being advanced. In concurrence with these studies, some countries including Japan are planning near-future lunar missions. In this session, we will discuss scientific results based on newly acquired lunar data, strategies for future missions, lunar sample analyses, and theoretical and experimental studies of lunar sciences.

[PPS02-01] Energetic Neutral Atom Imaging for Lunar science: Interactions between space plasma, exosphere, and surface

★Invited Papers

*Yoshifumi Futaana[1] (1.Swedish Institute of Space Physics)

[PPS02-02] Development of a detection system for new craters using feature-based image registration

*Emi Morikawa[1], Keisuke Onodera[2,3], Kei Shirai[4], Mitsuo Yamamoto[5], Satoshi Tanaka[5] (1.The University of Tokyo, 2.University of Paris / Institut de Physique du Globe de Paris, 3.The Graduate University for Advanced Studies (SOKENDAI), 4.Kobe University, 5.Institute of Space and Astronautical Science (ISAS) / Japan Aerospace Exploration Agency)

[PPS02-03] Are old continental crusts of the Earth Theia-origin?: Implications for the origin of the Moon

*Masaki Ogawa[1] (1.Division of General Systems Studies, Graduate School of Arts and Sciences, University of Tokyo)

[PPS02-04] High-pressure and -temperature experiments simulating the lunar KREEP layer and constraint on its water content

Miki Muranushi[1], *Masahiro KAYAMA[2], Tsuyoshi MIYAMOTO[3], Seiji Kamada[5], Hiroshi Nagaoka[4], Akio Suzuki[1] (1.Department of Earth Science, Graduate School of Science, Tohoku University, 2.Department of General Systems Studies, Graduate School of Arts and Sciences, The University of Tokyo, 3.Center for Northeast Asian Studies, Tohoku University, 4.Japan Aerospace Exploration Agency, 5.Frontier Research Institute for Interdisciplinary Sciences, Tohoku University)

[PPS02-06] SLIM (Smart Lander for Investigating Moon) project for pin-point landing demonstration

★Invited Papers

*Shin-ichiro Sakai[1], Kenichi Kushiki[1], Syujiro Sawai[1], Seisuke Fukuda[1], Tetsuhito Arakawa[1], Hiroo Saito[1], Haruhiko Shimoji[2], Project Team SLIM[1] (1.Japan Aerospace Exploration Agency, 2.Mitsubishi Electric Corporation)

Energetic Neutral Atom Imaging for Lunar science: Interactions between space plasma, exosphere, and surface

*Yoshifumi Futaana[1]

1. Swedish Institute of Space Physics

More than 99% of all known matters in the Universe is in the plasma state. The behavior of the plasma is therefore a key for understanding how the Universe works. On top of the traditional in-situ measurements of charged particles, energetic neutral atom (ENA) imaging has opened a new channel for space plasma investigations in this two decades. ENA is produced when an ion receives an electron from neighboring matters. Due to its neutrality the ENA do not feel any electromagnetic forces, and therefore, the ENA imaging is possible. We can extract the plasma characteristics from obtained ENA images.

ENA imaging has been utilized first to plasma physics missions, but were applied to lunar and planetary missions. Low energy (~1 keV) ENA instruments deployed at a Moon orbit (by Chandrayaan-1) provided basic physics on the solar wind - Moon surface interaction. For example, a global map of the solar wind proton flux was produced from the orbiter data. The flux is highly dependent on the existence of the magnetic anomaly, distributed globally over the lunar surface. The solar wind proton flux pattern at the surface exhibits a high similarity to the global map of the hydroxyl distribution, independently characterized by the infrared spectroscopy. This coincidence indicates that the solar wind proton is a major source of the surface hydration.

In this talk, we review science outcomes achieved by ENA imaging at the Moon. We further describe a future lunar mission to investigate the origin of the lunar water and its transport, equipped with the ENA imaging technique.

Keywords: Moon, Lunar exploration, Plasma, Lunar water

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Development of a detection system for new craters using feature-based image registration

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Finding new craters leads to a better understanding of the lunar surface environment by estimating the contemporary crater-production rate. Moreover, the precise information about the locations of lunar impact flashes would help us investigate the internal structure (e.g. [1]). In particular, little was known about small changes on the lunar surface due to the limitations of image resolution. However Lunar Reconnaissance Orbiter (LRO) Narrow Angle Camera (NAC) images make it possible to find small changes on the lunar surface, because the resolution of the images is 0.5 m per pixel at an altitude of 50 km. Thus, we developed a detection system for new craters using LROC NAC images in order to detect small changes.

Speyerer *et al.,* (2016) proposed a method using pair images (called temporal pair) taken before and after at the same spatial area under similar lightning conditions [2]. Instead of template matching algorithms used in a previous research [2], We used another approach for image registration of temporal pair, feature detection and matching algorithm. In general, feature-based image registration makes it faster and more robust for image scaling, rotation and lightning condition than template matching. In this study, we used SIFT (Scale Invariant Feature Transform; [3]) for feature detection algorithm and FLANN (Fast Library for Approximate Nearest Neighbors; [4]) for feature match algorithm.

A few locations are tying with lunar impact flash events. As a test operation, we applied our detection system to one of the locations, at 17.2˚S, 339.6˚W. Firstly, Temporal pairs were made under similar conditions to the previous study, such as an incident angle of less than 50˚. These data were obtained from NAC ancillary information. Then 7 temporal pairs were made. Regarding this location, our detection system detected 55 spots as surface reflectance changes and the true positive rate was 61.8%. In our detection system, it was possible to compare temporal pairs whose incident angles were over 50˚, which were not applied in the previous research to avoid the influence of shadows [2]. Therefore, more temporal pairs could be created than the previous studies, although more differences between the temporal pairs are detected. As a next step, we try to precisely locate 16 lunar impact flashes observed in period from 2017 to 2019, by collaboration of ISAS/JAXA, The University of Electro-Communications and Nihon University.

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[3] Lowe, D. (2004), Int. Journal of Computer Vision, 60(2), pp.91-110.
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Keywords: moon, automatic detection, LROC, crater

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Are old continental crusts of the Earth Theia-origin?: Implications for the origin of the Moon

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Crustal materials in the Archean continents (4-2.5 Gyr ago) often had elevated isotopic ratios of tungsten, i.e. the deviation of $^{182}W/^{184}W$ from its value for today's upper mantle $m^{182}W > 0$ holds, as is the case for the Moon. The elevated $m^{182}W$ together with the rather low content of highly siderophile elements (HSEs) in these materials are suggested to imply that the proto-Earth had high $m^{182}W$ and low HSE-content, that the materials ejected from the proto-Earth by a giant impact (GI) formed the Moon, and that $m^{182}W$ was reduced and HSE-content increased later in the Earth by the chondritic materials that accreted to the Earth as a late veneer [e.g., *Touboul et al.,* 2015]. However, convective current in the Earth's mantle has probably not been vigorous enough to make the upper mantle isotopically homogeneous on the spatial scale of hand specimen today by mechanically mixing the late veneer with the original mantle materials from the proto-Earth. Indeed, convective stirring of the mantle can dissolve its compositional and isotopic heterogeneity only at the spatial scale of 10^3 km or longer, and smaller scale heterogeneities often survive throughout the history of the Earth in my numerical models of mantle evolution caused by a coupled magmatism-mantle convection system [*Ogawa*, 2014]. Here, I propose an alternative model for the isotopic evolution in the Earth: (1) $m^{182}W$ was positive in Theia but was 0 in the proto-Earth before GI. (2) A part of the Theia-materials formed into the Moon, while the rest covered the surface of the proto-Earth at the time of GI. (3) As the continental crusts grow in the early Earth, the materials from Theia contaminated them. (4) The Theia-origin materials on the Earth's surface then recycled into the deep mantle. (5) Continental crusts have further grown after the recycling without contamination from Theia. The different $m^{182}W$ between the proto-Earth and Theia suggested here can be compatible with the classical GI model [e.g., *Canup*, 2014] and the multiple-impact model [*Rufu et al.,* 2017; *Citron et al.*, 2018] for the origin of the Moon, but is at odds with some other models, like synestia [*Lock* et al, 2018].

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Lock, S.J., et al. (2018) *J. Geophys. Res.,* **123**, 910-951

Ogawa, M. (2014) *J. Geophys. Res.,* **119**, doi:10.1002/2013JB010315.

Rufu, R., et al. (2017) *Nature Geosci.,* **10**, 89-94.

Touboul, M. et al. (2015) *Nature*, **520**, 530-533.

Keywords: tungsten isotopic ratio in old continental crusts, late veneer, stirring of the mantle by convection, the origin of the Moon

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High-pressure and -temperature experiments simulating the lunar KREEP layer and constraint on its water content

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KREEP, being the acronyms for **K** (potassium), **R**are **E**arth **E**lements, and **P** (phosphorous), layer is the lunar structure formed between the mantle and crust during the late-stage lunar magma ocean (LMO) differentiation and consequently is thought to be enriched in the incompatibles (Warren and Wasson, 1979). Volatile elements such as H, F, and, Cl are also incompatible in the LMO, and thus they should have been highly concentrated in the latest residuum of the LMO, urKREEP (Greenwood et al., 2017). According to Hui et al. (2013), the urKREEP might contain 1.4 wt% H_2O, based on water content of plagioclase in the Highland anorthosite and the LMO differentiation model. Greenwood et al. (2017) concluded that the urKREEP might reach ~1.3–2.4 wt% H_2O, considering degassing and diffusion of hydrogen through the lunar volcanism and volatile contents obtained from glasses and apatite in KREEPy basalts. However, the estimated water contents of the KREEP layer are model-dependent, because original KREEP rocks have not been returned yet. Here we performed high-pressure and -temperature experiment of the analogue material for KREEP to constrain water content of the KREEP layer.

Terrestrial alkali basalt (Changbaishan) were selected for the starting material, and the powder samples were enclosed in inner graphite and outer Pt capsules with ~ 1.0–6.2 wt% H_2O. The capsules were compressed at 1.0 GPa and heated at ~1050–1300 ˚C for 24 h duration using piston-cylinder apparatus and then were immediately after quenched by cutting power. The recovered samples were measured by SEM and FT-IR analyses for observation of the textures and determination of the chemical compositions and water contents retained in each experiment.

As a result of the SEM analysis, mineral assemblages of the recovered samples were olivine, clinopyroxene, plagioclase, ilmenite, amphibole, apatite, and glass. The minerals occur as an euhedral crystal and have no zoning structure of the chemical compositions within the grains. Furthermore, $K_D^{Cpx-liq}$ [Mg–Fe] values of clinopyroxene against glass quenched from the liquid (=[$FeO^{Cpx}MgO^{liq}$]/[$FeO^{liq}MgO^{Cpx}$]) become 0.24–0.32. These facts demonstrates that almost all of the mineral crystals produced by the present high-pressure and -temperature experiments grew under equilibrium state. In addition, glasses quenched from the liquid show a homogeneous chemical composition in each recovered sample, implying no occurrence of melt immiscibility. Water contents of the glasses and modal abundance of the amphibole crystals obtained from FTIR and SEM analyses revealed that most of water remains in the capsules even after high-pressure and -temperature experiments. Amphibole is absent in the recovered samples below ~3.2 wt% H_2O. Since no hydrous mineral such as amphibole has been discovered in the Apollo/Luna samples and lunar meteorites as well as by remote sensing observation, amphibole is unlikely to form as a major mineral differentiated from the LMO. Therefore, the maximum water content of the KREEP layer can be constrained to ~3.2 wt% because of absence of amphibole in the recovered samples below this value, from the viewpoint of the present experimental conditions and starting materials. Focusing on the Procellarum KREEP terrane volcanism (PKT), existence of 3.2 wt% water leads to 120 ˚C

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decrease in liquidus of the KREEP layer, suggesting that water might be one of the significant trigger for PKT volcanism.

Keywords: lunar water, KREEP, high-pressure and -temperature experiment, the Procellarum KREEP terrane

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SLIM (Smart Lander for Investigating Moon) project for pin-point landing demonstration

*Shin-ichiro Sakai[1], Kenichi Kushiki[1], Syujiro Sawai[1], Seisuke Fukuda[1], Tetsuhito Arakawa[1], Hiroo Saito[1], Haruhiko Shimoji[2], Project Team SLIM[1]

1. Japan Aerospace Exploration Agency, 2. Mitsubishi Electric Corporation

“SLIM” is a project in ISAS/JAXA to demonstrate “pin-point” landing on the lunar surface with small spacecraft. Recently, capability to "land anywhere you want” is expected from several viewpoints, such as science or resource exploration. "Pin-point" landing is a key technology for this capability, however, conventional ground-based navigation is not accurate enough. SLIM lander is designed to achieve precise landing whose error ellipse has a radius of 100m, although past lunar landers' error ellipse radius was more than a few km. Image-based onboard navigation system, and autonomous guidance, navigation and control are the breakthrough technology for this next-generation landing accuracy.

Another unique aspect of SLIM lander is its light weight: 200kg in dry mass and 700kg in wet mass. Several new technologies are developed to realize such a light-weight spacecraft,

and they will be useful for future frequent interplanetary missions.

Although the SLIM’s main mission is technological demonstration described above, additional small scientific payloads, Multi-Band Camera, is also employed. Multi-Band Camera is designed to investigate an olivine bearing lithology for understanding their origin and investigating the composition of the lunar unsampled mantle or deep crustal material. SHIOLI crater (13.3degS, 25.2degE) was selected as a target landing point to derive this detailed mineralogy of the olivine-rich exposure. “Two step landing scheme” is another unique landing technology of SLIM to achieve safe landing on a slope, and this target landing point bit close to a crater is a typical example requiring such ability. Image based obstacle avoidance onboard will also take an important role at the final landing stage.

SLIM is scheduled to be launched in Japanese fiscal year 2021, and at this moment, the development is at the end of so-called Phase-C. In the coming joint meeting, development status will be also introduced, including several engineering models test.

Keywords: SLIM project, pin-point landing, lunar lander, precise landing technology, terrain reference navigation(TRN)

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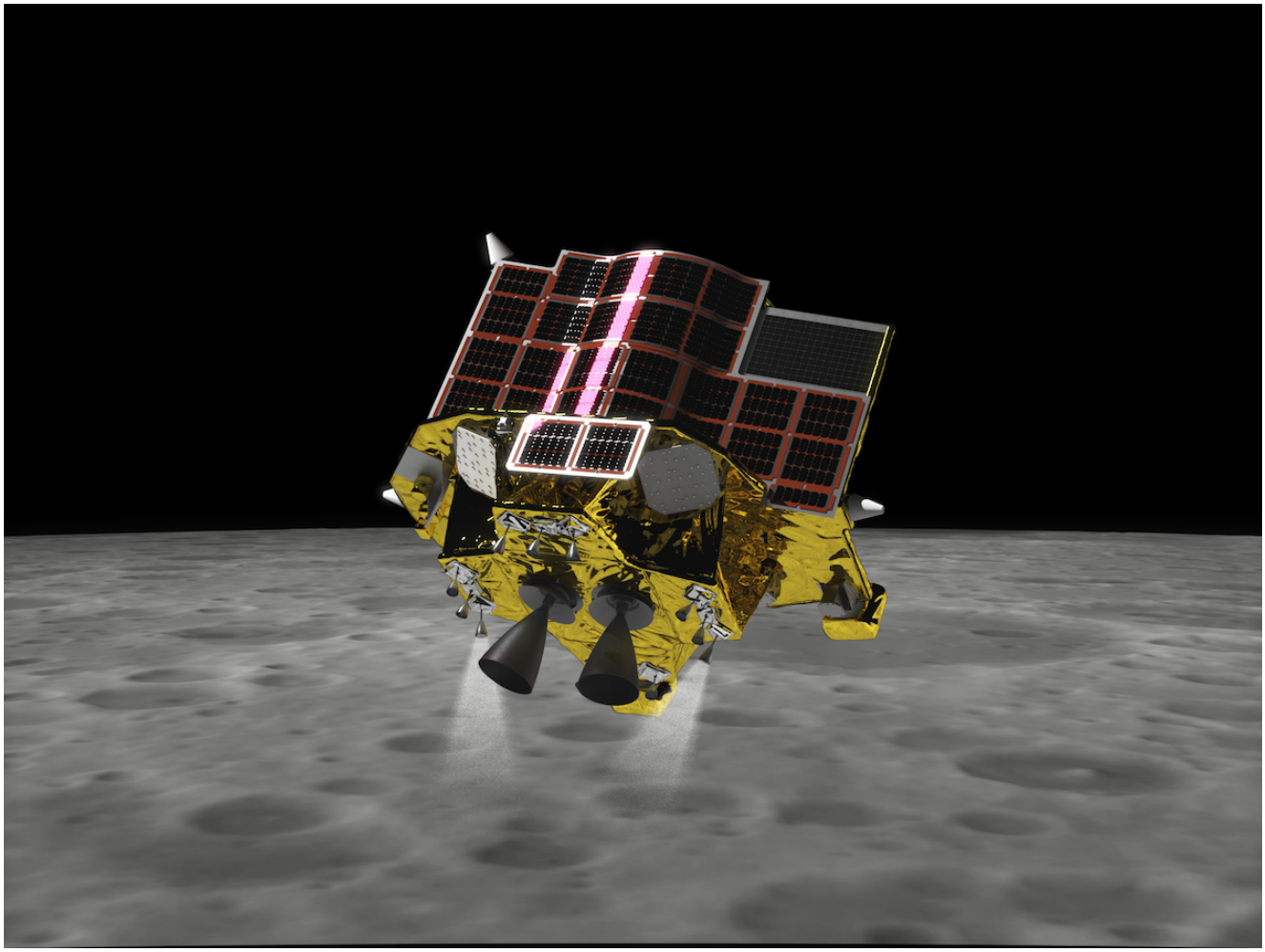

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[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS02] Lunar Science and Exploration

convener:Masaki N Nishino(Japan Aerospace Exploration Agency, Institute of Space and Astronautical Science), Masahiro KAYAMA(Department of General Systems Studies, Graduate School of Arts and Sciences, The University of Tokyo), Hiroshi Nagaoka(Japan Aerospace Exploration Agency), Yusuke Nakauchi(Japan Aerospace Exploration Agency)

Scientific data sets acquired by Japanese lunar mission SELENE (Kaguya) have become the standard of the lunar sciences. Other missions such as Chandrayaan-1, LRO, GRAIL, LCROSS, LADEE, Artemis, and Chang'e series as well as ground observations are also providing new knowledges of the Moon. Apollo/Luna samples and lunar meteorite analyses are also being advanced. In concurrence with these studies, some countries including Japan are planning near-future lunar missions. In this session, we will discuss scientific results based on newly acquired lunar data, strategies for future missions, lunar sample analyses, and theoretical and experimental studies of lunar sciences.

[PPS02-09] Global emissions of carbon ions from the total lunar surface

*Shoichiro Yokota[1], Kentaro Terada[1], Yoshifumi Saito[2], Kazushi Asamura[2], Masaki N Nishino[2], Hisayoshi Shimizu[3], Futoshi Takahashi[4], Hidetoshi Shibuya[5], Masaki Matsushima[6], Hideo Tsunakawa[2] (1.Osaka University, 2.ISAS/JAXA, 3.Earthquake Research Institute, The University of Tokyo, 4.Kyushu University, 5.Kumamoto University, 6.Tokyo Institute of Technology)

[PPS02-10] Status on Japanese Lunar Polar Exploration Mission

★Invited Papers

*Dai ASOH[1], Takeshi HOSHINO[1], Makiko OHTAKE[1], Yuzuru KAROUJI[1] (1.Japan Aerospace Exploration Agency)

[PPS02-11] Examination of water observation procedure in lunar polar exploration

*Yuzuru Karouji[1], Makiko Ohtake[1], Hiroaki Shiraishi[1], Hiroshi Kanamori[1], Inoue Hiroka[1], Takeshi Hoshino[1], Dai Asoh[1], Lunar Polar Exploration Pre-Project Team[1] (1.Japan Aerospace Exploration Agency)

[PPS02-12] The research review on the plasma and dust environment of the moon toward the participation in NASA's Artemis program

*Hideyuki Usui[1], Masaki N Nishino[2], Noriyuki Namiki[3], Yuko Inatomi[2], Makiko Ohtake[2], Tomokatsu Morota[4], Tomohiro Usui[2] (1.Graduate school of system informatics Kobe University, 2.JAXA/ISAS, 3.NAOJ, 4.School of Science The university of Tokyo)

Global emissions of carbon ions from the total lunar surface

*Shoichiro Yokota[1], Kentaro Terada[1], Yoshifumi Saito[2], Kazushi Asamura[2], Masaki N Nishino[2], Hisayoshi Shimizu[3], Futoshi Takahashi[4], Hidetoshi Shibuya[5], Masaki Matsushima[6], Hideo Tsunakawa[2]

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It had been believed that carbon and other volatile elements are depleted in the Moon for the decades, because of early analyses of the Apollo samples. The notion of a volatile-depleted Moon is one of the greatest premises behind the hypothesis that a giant impact occurred between the nascent Earth and a Mars-sized body, which generated high-temperature events. Recently, advanced analyses have determined volatile elements, such as water and carbon, in volcanic lunar glasses. Analyses of meteorites and returned samples are the most precise methods currently available for determining the chemical composition of the parent bodies and investigating their geologic origins and histories, even though it is acknowledged that a small number of samples are potentially biased. The existence of indigenous water in lunar materials has been supported not only by analyses of Apollo samples but also by conducting wide-area observations using neutron spectrometers and neutral mass spectrometers on lunar orbiters. In the case of carbon, however, no such observations have been conducted around the Moon to date because both the neutron interactive properties and brightness in the ultraviolet range are insufficient for spaceborne instruments.
Here, we present observations by the lunar orbiter KAGUYA of carbon ions emitted from the Moon. These emissions were distributed over almost the total lunar surface, but amounts differed with respect to lunar geographical areas. The estimated emission fluxes to space were ~5.0×10^{4} cm^{-2} s^{-1}, which is greater than possible ongoing supplies from the solar wind and micrometeoroids. Our estimates demonstrate that indigenous carbon exists over the entire Moon, supporting the hypothesis of a carbon-containing Moon, where the carbon was embedded at its formation and/or was transported billions of years ago.

Keywords: Moon, Volatile elements, KAGUYA, Mass analyses, Carbon

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Status on Japanese Lunar Polar Exploration Mission

*Dai ASOH[1], Takeshi HOSHINO[1], Makiko OHTAKE[1], Yuzuru KAROUJI[1]

1. Japan Aerospace Exploration Agency

Introduction:

JAXA aims to conduct sustainable lunar exploration activities in the next 50 years, such as operation of lunar base with international partners and private sectors. To realize this goal, we will conduct technology demonstration step-by-step. JAXA envisions our space exploration as the extension from the Low Earth Orbit (LEO) to the Moon and Mars, with our international partners, in order to advance our contribution to intellectual assets.
In October last year, the Japanese government announced its decision to officially join the international space exploration, and to proceed on coordination in the several areas including sharing of data acquired from our lunar exploration missions and technologies for lunar landing site selection.

Japanese lunar exploration missions:

Regarding lunar surface robotic missions, JAXA is developing Smart Lander for Investigating the Moon (SLIM), which aims to demonstrate the high-precision landing technology. The targeted launch year is 2021. Following this SLIM mission, a lunar polar exploration mission is aimed at investigating the water ice resources in the lunar polar region. This is a collaborative mission with Indian Space Research Organisation (ISRO).

Objectives of the lunar polar exploration:

In addition to the scientific interest about the origin and concentration mechanism of the water ice, there is strong interest in using water ice (if present) as an in-situ resources. Specifically, using water ice as a propellant will significantly affect future exploration scenarios and activities because the propellant generated from the water can be used for ascent from the lunar surface.
Because of the existing limited remote-sensed data, we need to find out, by direct measurement on the lunar surface, the presence of water ice, it’ s quantity, quality (pure water or contain other phases such as CO_2 or CH_4), and usability (how deep do we need to drill or how much energy is required to get water) in order to assess if we can use it as resources. Obtaining data to understand the principle of the water distribution and concentration is necessary to estimate the quantity and quality of water across the Moon.

Status on the mission:

ISRO/JAXA are jointly conducting the conceptual design (i.e. Phase-A study) under the Implementation Arrangement (IA) for the lunar polar exploration mission, in which JAXA provides a launch vehicle and a rover while ISRO provides a lander. System Requirement Review (SRR) is scheduled for this year. JAXA selected function and specification of several instruments, which will be loaded on the rover or the lander.

Spacecraft configuration:

The spacecraft system is based on direct communication with the Earth. The target mass of the spacecraft (incl. payload and propellant) is about 6ton and the payload mass is about 350kg. After the spacecraft reaches the Moon, it is inserted into a circular orbit having a 100km altitude via a few orbital changes. During powered-descent phase, the position of the lander is estimated by landmark navigation using shadows created by the terrain. After landing, the rover is deployed on the lunar surface using ramps. The rover then prospects water ice with its observation instruments.

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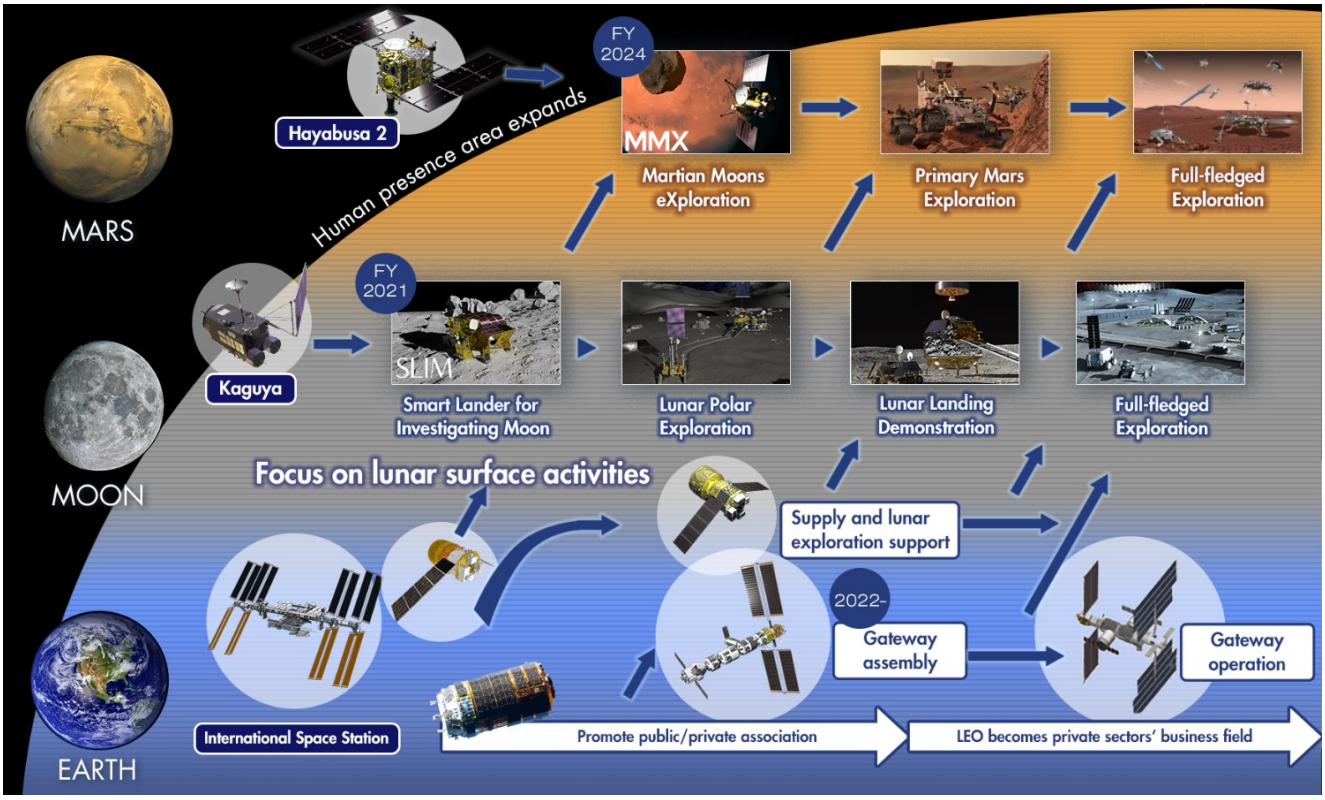
Landing site selection:
We are down-selecting the candidates of landing site of the lunar polar region using the following parameters as constraints:
- Continuous daytime: equal or more than 60days.
- Continuous nighttime: equal or less than 14days.
- Comm. capability: equal or more than 25%.
- Land inclination: equal or less than 10deg.

As a trial of the landing site selection, sunshine is simulated using digital elevation models to obtain the sunlight days per year and the number of continuous sunshine periods at each site. The maps of simulated communication visibility from the Earth and the slope are created.

Conclusion:
In this presentation, we will introduce current status on Japanese lunar exploration missions, focusing on a lunar polar exploration.

Keywords: lunar polar exploration, lunar water, volatile, resource availability



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Examination of water observation procedure in lunar polar exploration

*Yuzuru Karouji[1], Makiko Ohtake[1], Hiroaki Shiraishi[1], Hiroshi Kanamori[1], Inoue Hiroka[1], Takeshi Hoshino[1], Dai Asoh[1], Lunar Polar Exploration Pre-Project Team[1]

1. Japan Aerospace Exploration Agency

In recent years, the lunar polar region has been attracting attention as a lunar exploration target. Multiple remote sensing datasets from lunar exploration missions [e.g., 1, 2] suggested that water ice might be widely present in the lunar polar regions. For this reason, several space agencies are investigating the availability of water ice resources that might exist in the lunar polar region. The availability of water ice as propellant is expected to have a significant impact on future lunar exploration scenarios and activities. Also, it is known that some hills and crater rims of the lunar polar region have areas of continuous sunshine for more than half a year and more than 80% sunshine ratio [3], therefore the lunar polar region is considered to a useful base for sustainable activities.
In this situation, Japan Aerospace Exploration Agency (JAXA) is planning a lunar polar exploration mission that aims mainly to confirm the abundance of water ice resources and to establish the technology of planetary surface exploration in collaboration with the Indian Space Research Organisation (ISRO)[e.g., 4]. This presentation describes the examination status of the water ice observation method for this mission.
To achieve the objectives of the mission, the following parameters are listed as constraints for selecting a landing site, taking into account the unique conditions of the lunar polar region; presence of water, surface topography, communication capability, and duration of sunshine. By superimposing these analysis results, the candidate for landing sites is selected [5]. Currently, around 30 sites of the north and the south pole of the Moon have been identified as landing site candidates.
In this mission, the "course observation" will investigate the horizontal distribution of the surface and subsurface of the water ice existing area while traveling with the rover. And the "fine observation" will investigate the vertical distribution of underground of the water ice existing area by excavating with a drill. In the course observation, neutron spectrometer, ground-penetrating radar and imaging spectroscopy camera are being considered as model payload instruments. In the fine observation, regolith is excavated by earth auger and sampling of excavated regolith is carried out by the rover working system. And the concentration of gas generated by sample heating and the molecular species contained in the gas is measured using thermogravimetric analyzer, mass spectrometer and cavity ring-down spectroscopy analyzer, which are assumed to be model payload instruments. By performing these observations in multiple exploration areas (waypoints), ground truth data on water abundance and resource availability around the landing site will be obtained.

Reference: [1] Li S. et al. (2018) PNAS September 4, 115 (36), 8907-8912. [2] Sanin A.B. et al. (2017) Icarus 283, 20-30. [3] Rosa D.D. et al. (2012) Planetary and Space Science 74, 1, 224-246. [4] Asoh D. et al. (2020) JPGU2020, this volume. [5] Inoue et al. (2019) LPSC abstract #2155.

Keywords: lunar polar exploration, lunar water, volatile

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The research review on the plasma and dust environment of the moon toward the participation in NASA’s Artemis program

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Following the decision by the Japanese government on the participation in the NASA’s Artemis program, the task force members asked by the JAXA’s technical committee on the international space exploration intensively reviewed the research topics and their significance on the lunar environment exploration from the perspectives of science as well as engineering.

The moon which has no atmosphere is directly exposed to the solar wind plasma. The surface is consequently charged due to the deposition of the solar wind as well as the secondary emission of ions and photoelectrons from the surface. The dust particles which are micro grains covering the moon surface are also charged and their dynamics and distribution are to be investigated. Meanwhile, KAGUYA found many crustal magnetic field regions called lunar magnetic anomalies (LMA) scattered on the surface. Due to the solar wind interaction, a small scale magnetosphere is formed over LMA. KAGUYA observed ion reflection and deflection as well as various types of plasma waves when it passed over LMA. The exosphere is also found which is composed of neutral particles originated from the moon surface. In this paper, we will report the current understanding of the lunar plasma environment affected by the solar wind interaction.

In the lunar surface exploration, one of the most important objectives is the quest for evidence of water resources in the surface environment. In terms of solar wind interaction, we are curious to know how the continuous injection of the solar wind proton to the lunar surface can be associated with the generation of water resources. In this paper, we will also touch on this topic.

The altitude of the KAGUYA orbits is limited to approximately between 100km and 20km. To observe the plasma phenomena in detail occurring at low altitudes below 20km, multiple CubeSat released from the GATEWAY station will play an important role.

In this paper, we will report the review on the plasma and dust of the lunar environment summarized by the task force members asked by the JAXA’s technical committee on the international space exploration. We will also discuss the significance of the interactions between the solar wind plasma and the lunar environment from a viewpoint of solar-terrestrial physics.

Keywords: Artemis program, Lunar plasma environment, Lunar dust, Lunar magnetic anomaly, solar wind, water

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[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS04] Regolith Science

convener:Koji Wada(Planetary Exploration Research Center, Chiba Institute of Technology), Akiko Nakamura(Graduate School of Science, Kobe University), Patrick Michel(Universite Cote D Azur Observatoire De La Cote D Azur CNRS Laboratoire Lagrange), Kevin John Walsh(Southwest Research Institute Boulder)

Recent planetary explorations have revealed that almost all solid bodies in the solar system are covered with small particles, called regolith. The surface geology, especially regolith behavior on the surfaces of solid bodies, becomes increasingly more important as represented by Hayabusa mission and other on-going and planned sample-return missions such as Hayabusa2, OSIRIS-REx, and MMX.
For fully understanding the regolith science, it is required to know and compare the regolith conditions on various celestial bodies, from asteroids to planets, with various methods.
Therefore, this session welcomes broad topics related to regolith on various celestial bodies, such as asteroids, comets, the Moon, the martian moons, Mars, etc. Papers on the formation, evolution, and alteration processes of regolith particles and regolith systems on the surface of planetary bodies, remote and in-situ observational results and techniques, analyses and results of returned samples, and laboratory, numerical, and theoretical studies on the fundamental physical and chemical processes are all welcome.
Note that what we call regolith is not just fine grains: all kinds of materials (more or less loose) that lie on the surface, from cobbles to finer grains, are our targets.

[PPS04-01] Crater scaling laws in low speed impacts

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[PPS04-02] Impact experiments for crater scaling laws and impact-induced seismic shaking on rubble-pile asteroids

*Yuya Yamamoto[1], Masahiko Arakawa[1], Minami Yasui[1], Sunao Hasegawa[2], Ryo Sugimura[1], Yusaku Yokota[1], Hatsune Okawa[1] (1.Graduate School of Science, Kobe University, 2.Japan Aerospace Exploration Agency)

[PPS04-03] The size of ejecta particles of the artificial impact crater formed by Hayabusa2 Small Carry-on Impactor

*Koji Wada[1], Ko Ishibashi[1], Hiroshi Kimura[1], Masahiko Arakawa[2], Hirotaka Sawada[3], Kazunori Ogawa[3,2], Kei Shirai[2], Rie Honda[4], Yuichi Iijima[3], Toshihiko Kadono[5], Naoya Sakatani[3], Yuya Mimasu[3], Tomoaki Toda[3], Yuri Shimaki[3], Satoru Nakazawa[3], Hajime Hayakawa[3], Takanao Saiki[3], Yasuhiko Takagi[6], Hiroshi Imamura[3], Chisato Okamoto[2], Masahiko Hayakawa[3], Naru Hirata[7], Hajime Yano[3] (1.Planetary Exploration Research Center, Chiba Institute of Technology, 2.Kobe University, 3.JAXA, 4.Kochi University, 5.University of Occupational and Environmental Health, 6.Aichi Toho University, 7.The University of Aizu)

[PPS04-04] Space impact experiment on Ryugu: Pattern of ejecta curtain and the properties of particles in surface and subsurface layers

★Invited Papers

*Toshihiko Kadono[1], Masahiko Arakawa[2], Rie Honda[3], Ko Ishibashi[4], Kazunori Ogawa[5], Naoya Sakatani[5], Yuri Shimaki[5], Seiji Sugita[6], Koji Wada[4] (1.University of Occupational and Environmental Health, 2.Graduate School of Science, Kobe University, 3.Departiment of Scinece and Technology, System of Natural Science, Kochi University, 4.Planetary Exploration Research Center, Chiba Institute of Technology, 5.Institute of Space and Astronautical Science, 6.Graduate School of Science, The University of Tokyo)

[PPS04-05] Thermophysical property of the artificial impact crater on asteroid Ryugu

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Takita[7], Tetsuya Fukuhara[8], Makoto Taguchi[8], Thomas G. Müller[9], Axel Hagermann[10], Jens Biele[11], Matthias Grott[11], Maximilian Hamm[12,11], Marco Delbo[13], Mizuki Ito[1,19], Naoyuki Hirata[14], Masahiko Arakawa[14], Kazunori Ogawa[15,14], Koji Wada[4], Toshihiko Kadono[16], Rie Honda[17], Kei Shirai[14], Takanao Saiki[1], Hiroshi Imamura[1], Yasuhiko Takagi[18], Hajime Yano[1], Masahiko Hayakawa[1], Chisato Okamoto[14], Hirotaka Sawada[1], Satoru Nakazawa[1], Yu-ichi Iijima[1], Seiji Sugita[19], Tomokatsu Morota[19], Manabu Yamada[4], Shingo Kameda[8], Eri Tatsumi[20], Yasuhiro Yokota[1], Hidehiko Suzuki[21], Chikatoshi Honda[3], Kazuo Yoshioka[19], Moe Matsuoka[1], Yuichiro Cho[19] (1.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 2.National Institute of Advanced Industrial Science and Technology, 3.University of Aizu, 4.Chiba Institute of Technology, 5.Ashikaga University, 6.Hokkaido University of Education, 7.Hokkaido Kitami Hokuto High School, 8.Rikkyo University, 9.Max-Planck Institute for Extraterrestrial Physics, 10.University of Stirling, 11.German Aerospace Center, 12.University of Potsdam, 13.Observatoire de la Côte d'Azur, CNRS, 14.Kobe University, 15.JAXA Space Exploration Center, Japan Aerospace Exploration Agency, 16.University of Occupational and Environmental Health, 17.Kochi University, 18.Aichi Toho University, 19.University of Tokyo, 20.Instituto de Astrofisica de Canarias, 21.Meiji University)

[PPS04-06] Experimental study on the relaxation of slope terrain due to small-scale impact

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Crater scaling laws in low speed impacts

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Regolith-covered small bodies have numerous craters in varying sizes across their surfaces. The long-established scaling laws have been successful in large craters arising from astronomical impacts, which occur in orbital speeds of several km/s (Housen et al., 1983). Moreover, it has also recently been observed during OSIRIS-REx mission that material ejection from the active asteroids may be originated through micrometeoroid impacts that occur at similar velocities, but should produce much smaller craters (Lauretta et al., 2019). In that case, the ejecta velocity field of a crater would contain materials with velocities less than the escape speed of small-body, i.e. typically below m/s. Such material would eventually fall back to surface after orbital motion, creating new craters at lower-speed impacts. In a similar case, small lander spacecraft, e.g. the MASCOT and MINERVA rovers onboard Hayabusa2, impact small-body surfaces at cm/s-level speeds and bounce across the surface, essentially making new craters (where regolith is available) at low speeds, before settling on the surface (Thuillet et al., 2018). These two seemingly different phenomena highlight the relevance of understanding low-speed cratering process that primarily occurs in low gravity environments through the interaction of natural and artificial objects with regolith-covered small body surfaces. However, it is currently not known whether the scaling laws developed for high-speed astronomical impacts would hold for impacts of orders of magnitude lower speed.

To test this question, a literature survey was performed on impact experiments in high- and low-speed and under different gravity levels to demonstrate that the scaling law holds for impact speeds from km/s to m/s (Fig. 1). A full study of the applicability of the crater scaling laws to lower-speed impacts is currently a gap in the experimental literature. This is because performing impacts at below-m/s speeds is difficult on Earth in terms of data resolution due to high gravitational acceleration. On the other hand, currently available low-speed impact data under low-gravity only provides phenomenological explanations due to these challenges in measurements (Brisset et al., 2018). To overcome these limitations and bridge the aforementioned gap in literature, this study instead makes use of discrete-element method (DEM) granular mechanics simulations in order to test the crater scaling laws quantitatively. The DEM simulations avoid limited low-gravity time and test conditions, as well as vibration-caused noisy data in drop towers and parabolic flights while allowing to perform “experiments” in virtually any small-body environment. The DEM code employed in the study is called pkdgrav, a state-of-the-art parallelized granular mechanics code, which treats particle collisions through a soft-sphere discrete element method (SSDEM). Through SSDEM implementation, pkdgrav handles multi-contact and frictional forces using dissipative and frictional parameters that allow mimicking the behavior of angular and rough particles. The code has been tested extensively and calibrated for a variety of materials to represent the actual granular behaviour realistically throughout different studies.

Impact simulations of a spherical impactor in the study are performed in local vertical at speeds between 1 cm/s and 1 m/s in a regolith bed under asteroid level gravity that is created in the simulation environment. As each particle’s state is recorded during the simulations, the collected data are post-processed to compute not only crater size but also velocity field and ejected mass during the process. This would then yield a complete test of the theory under given conditions which is typically not

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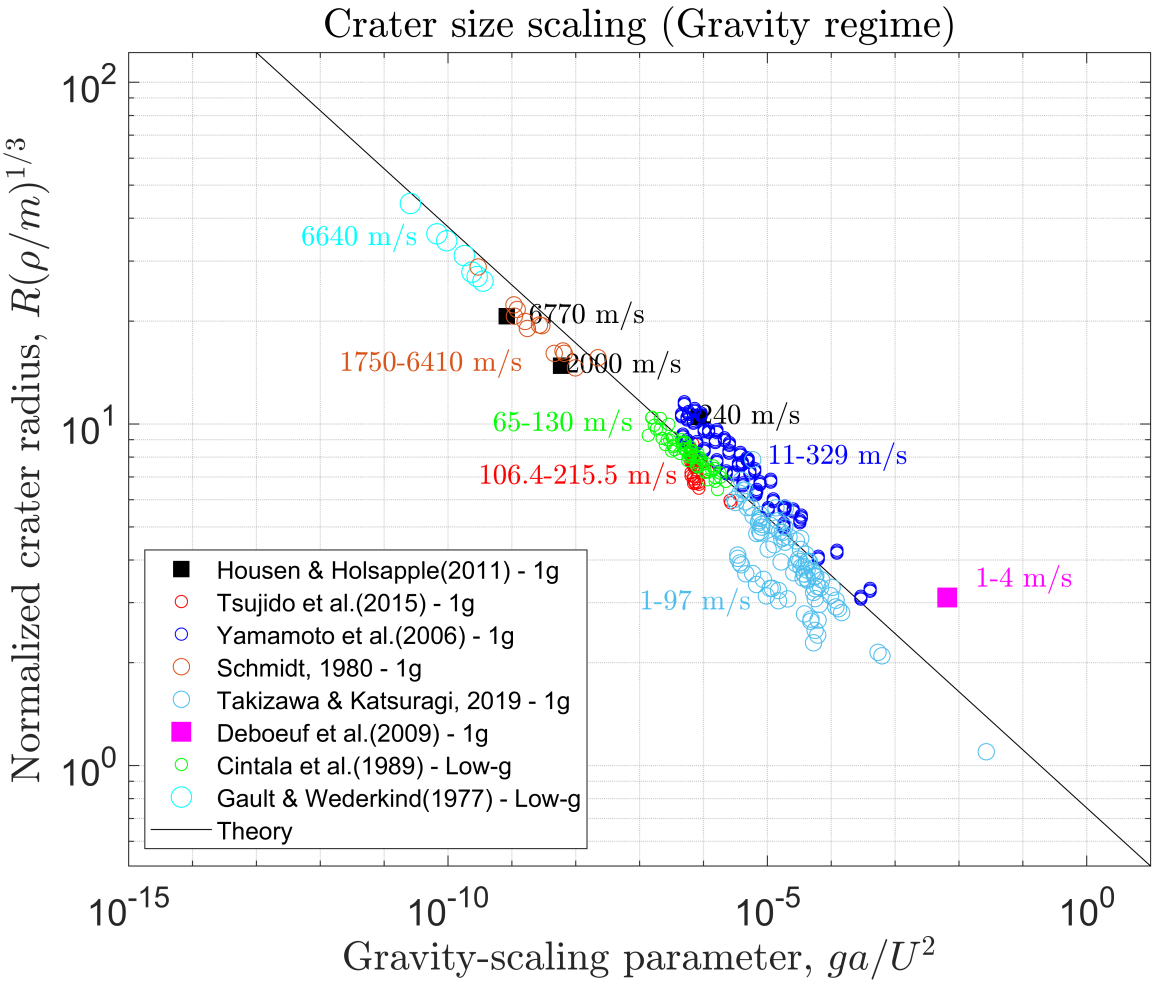
available in experimental studies. The tested theory can then be applied to a variety of problems that relevant to current small-body exploration framework, e.g. estimating coefficient of restitution on regolith-covered portions of asteroids, which would subsequently be used in designing landers, sampling spacecraft as well as explaining the reimpact behaviour of ejected materials.

Keywords: Small body, Low speed impact, Cratering, Scaling laws, Regolith science, Discrete element method



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Impact experiments for crater scaling laws and impact-induced seismic shaking on rubble-pile asteroids

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Impact cratering is one of the most important physical processes, then we study crater impact scaling laws in order to elucidate the impact processes on asteroids. It is suggested that the size ratio of the impactor to the surface boulders and the fracture strength of the boulders could affect the crater formation process. In addition, it is suggested that the impact-induced seismic shaking could propagate through an asteroid interior and change the surface topography. Therefore, it is important to understand the impact-induced seismic shaking and to construct crater scaling laws considering the surface boulder strength. Then, in this study, we performed impact cratering experiments by using the target composed of low-strength coarse particles, and studied the effect of the size ratio of the projectile to the target grains, and the fracture strength on the crater scale law, and also investigated the impact-induced seismic shaking.

Cratering experiments were conducted by using a gas gun set at Kobe University and ISAS. Granular targets were prepared by using weathered tuff granules with the size of 1 to 4mm (small particle) and the size of 1 to 4cm (large particle). The crush strength of these tuff particles was measured to be about 60 kPa and 30 kPa. A spherical projectile with the size of 3mm (SUS, zirconia, alumina, glass, and nylon) was lunched at the impact velocity from 40 to 200m/s, and a spherical projectile with the size of 2mm (WC, copper, SUS, zirconia, titan, Al, and nylon) was lunched at the impact velocity from 1.2 to 4.5 km/s, and these two types of the projectile were impacted on the target surface at the normal direction. Impact cratering process was observed by a high-speed camera at 10^3-10^5fps. After the shot, the crater morphology was observed and the diameter and the depth were measured. Impact-induced seismic waves were measured by using 3 accelerometers (specific frequency is 30kHz) set at different positions from the impact point, and a data logger was used to record the seismic data through charge amplifiers (data acquisition rate is 100kHz) connecting to the accelerometer.

The crater size was found to increase with the projectile kinetic energy (E_k) at lower than 0.14J and at higher than 0.63J, so that the crater size was almost constant among them, and more the crater size obtained at very high $E_k$was almost on the extrapolated line from the relationship given by the low $E_k$data. In addition, the crater formation efficiency of the large grain was lower than that of the small grain. The pi-scaling law was used to construct the relationship between normalized radius and the normalized gravity, and all the data was found to be separated into two regions with a large offset according to the impact velocity and the projectile material. This offset might be caused by the disruption energy of several tuff grains. From the above results, it was recognized that the crater formation process of the low-strength coarse grain was different from that of the sand grain target, that is, the crater formation efficiency of the target composed of low-strength grains was lower than that of sand targets composed of high-strength quartz grains.

The propagation velocity of the impact-induced seismic wave was obtained from the accelerometer data. The propagation velocity was 47.0 ±7.6 m/s for the small grain regardless of the impact velocity, and was 42.7 ±4.7 m/s for the large grain regardless of the impact velocity and projectile material. Compared to

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previous studies, it was found that the propagation velocity was similar to that of quartz sand. Furthermore, we obtained the relationship between the maximum acceleration and the distance from the impact point. Then, we scaled this relationship with the distance normalized by the crater radius and obtained the following empirical formulas for the attenuation. For small grain target, $g_{max=}10^{1.81}(x/R)^{-1.98}$. For large grain target, $g_{max}=10^{1.77}(x/R)^{-2.21}$.

Keywords: regolith, crater scaling law, impact-induced seismic shaking, impact experiment, rubble-pile asteroid

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The size of ejecta particles of the artificial impact crater formed by Hayabusa2 Small Carry-on Impactor

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A projectile accelerated by Hayabusa2 Small Carry-on Impactor succeeded in producing an artificial impact crater with a diameter of >10 m on the surface of the asteroid Ryugu on April 5, 2019. At the time of cratering, Deployable Camera 3 (DCAM3) took clear images of ejecta curtain emerged from the crater. Comparing the ejecta curtain images to a theoretical model of ejecta curtain, we infer the size of the particles composing the ejecta curtain. Since almost of the ejecta particles come from the underground, we can discuss about the particle size distribution of the subsurface layer of Ryugu and the evolution process of Ryugu’ s surface layer. As a result, the typical size range of the ejecta particles is estimated to be ~cm to several 10 cm, although it depends on the assumed size distribution. This typical size is relatviely small compared to the boulder size on the uppermost surface, suggesting some kind of surface process occured in the past.

Keywords: Hayabusa2, Small Carry-on Impactor, Deployable Camera 3, Ryugu, Impact crater, ejecta

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Space impact experiment on Ryugu: Pattern of ejecta curtain and the properties of particles in surface and subsurface layers

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Space-impact experiment was performed on the surface of the C-type asteroid 162173Ryugu using an instrument called the Small Carry-on Impactor (SCI), carried by JAXA spacecraft Hayabusa2. One advantage of the Hayabusa2 for space-impact experiments was the use of a small satellite separated from the spacecraft, the Deployable CAMera-3 (DCAM3), using which we observed the evolution of the ejecta curtain by the SCI impact in situ. In this presentation, based on the patterns of the ejecta curtain, we evaluated the properties of boulders and particles in the surface and subsurface of Ryugu. We found that the boulders on the surface layer had a strength of ~ a few hundred kPa. Furthermore, the particles in the curtain had a characteristic size of a few cm with the maximum size of several decimeters, mainly originated from the subsurface layer. We propose some processes to realize these features.

Keywords: Hayabusa2, Space Impact Experiment, ejecta curtain

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Thermophysical property of the artificial impact crater on asteroid Ryugu

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The Hayabusa2 spacecraft has completed the rendezvous phase around Cb-type asteroid Ryugu in 2019. From thermal infrared imaging by TIR, global temperature distribution of Ryugu is consistent with the thermal calculation with thermal inertia of 300±100 J m^{-2} K^{-1} $s^{-0.5}$ [1], and thermal inertia values of the floors of craters are in general roughly comparable with the global average [2]. On the other hand, few small craters show anomalously low thermal inertia about 50 J m^{-2} K^{-1} $s^{-0.5}$, which might be contributed from the thermal insulating nature of the fine-grained and unconsolidated materials [3]. However, it is unknown how relaxation process of the crater relates to the thermophysical property and physical condition of the surface materials. On April 2019, Hayabusa2 have carried out an artificial impact (Small Carry-on Impactor or SCI) experiment [4], whereby a ~2 kg mass was fired at 2 km/s against the asteroid surface. As a result of the successful operation, an artificial crater (SCI crater) with diameter larger than 10 m was created on the asteroid. In this study, we investigated thermal property of the SCI crater as the freshest crater on Ryugu.

We had acquired TIR images of the SCI crater in some descending sequences (PPTD-TM1A&B operations on May and June, 2019). All of these images showed higher temperature in the SCI crater than surroundings by ~10 K, especially on the western side of the crater. This high temperature would indicate low thermal inertia materials in the crater, or the high solar incident angle on the crater inner wall would make the temperature higher.

Since the number of images and observation duration were limited for each operation, we could not examine diurnal temperature profile of the crater. In order to estimate the thermal inertia of the SCI crater from single thermal image, we conducted surface temperature simulation using a local digital elevation model (DEM) around the SCI crater. With varying thermal inertia, the simulated images were produced, and thermal inertia was estimated by comparison with the simulation results and observed temperature

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images.

As a result, the simulated temperature distribution inside the SCI crater agrees well with the observed image. In this preliminary analysis, we expect that the thermal inertia in the SCI crater is uniformly about 300 J m^{-2} K^{-1} $s^{-0.5}$, consistent with large boulders (Iijima boulder and Okamoto boulder) in the crater, surrounding materials, and the global average. Therefore, the chief determinant of the high temperature in the SCI crater would not be the change of the thermal inertia.

Diurnal thermal skin depth of Ryugu is a few centimeters, assuming the thermal inertia of 300 J m^{-2} K^{-1} $s^{-0.5}$. Although the inside of the SCI crater seems to be filled with finer grains than the surroundings [4], less change in thermal inertia of the SCI crater compared with the surroundings or top-surface large boulders indicates that the typical grain size of the subsurface layer (meter-scale in depth) is larger than a few centimeters. Furthermore, since the centimeter-sized grains have thermal property consistent with the larger boulders and the small grains are considered to be crushed from the large boulders, the thermophysical property of the boulders is expected to be homogeneous in centimeter-scale or larger.

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Experimental study on the relaxation of slope terrain due to small-scale impact

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Observation of planetary surfaces shows some evidence of the relaxation of sloped terrains such as impact craters. The mechanism of the relaxation might be the resurfacing due to impacts and/or the fluidization due to seismicity. Here we focus on relaxation due to small-scale impacts, which occurs on relatively large bodies, e.g., the Moon. Soderblom (1970) modeled the effect of a small-scale impact on the relaxation of the slope terrain by considering asymmetric ejecta deposit. However, the model did not consider the effect of the collapse of cavity and the impact angle. In this study, we study the effect of slope angle and impact conditions on the relaxation efficiency of slope terrain using the result of low-velocity impact experiments on the inclined granular surface obtained by Takizawa & Katsuragi (2020).

We used Toyoura sand in the diameter of 0.1-0.3 mm as a target material. The angle of repose of the sand was 34˚. The spherical impactors in diameter of 6 mm and masses of 0.12, 0.25, and 0.4 g were used. The impact velocity was ranged from 7 to 97 m/s. Experiments were conducted under atmospheric pressure. We analyzed the data with the slope angle of the target θ of $0^\circ \leqq \theta \leqq 34^\circ$ and the impact angle measured from the upper surface ϕ of $50^\circ \leqq \phi \leqq 130^\circ$. The 3D profile before and after the crater formation was measured with a laser profiler.

We measured the displacement of the center of mass caused by the asymmetric ejecta deposit and the collapse of the crater cavity, as an index of relaxation efficiency. We conducted the analysis using the crater profile as follows. First, we made the reference shape using the crater profile obtained by experiment with $\theta=0^\circ$ and $\phi=90^\circ$. The profile was scaled based on the scaling law of the crater minor axis D_{cy} (Takizawa & Katsuragi, 2020) to equalize the D_{cy} of the reference shape and the analyzed profile, and the cavity part was extracted as the reference shape. Next, we subtracted the reference shape from the crater profile. We assumed the part higher/lower than the reference shape has plus/minus mass and calculated the center of mass of the differential part. Finally, we calculated the distance Δx from the impact point to the center of mass of the differential part with defining downward as a positive sense.

When $\theta=0^\circ$, the normalized migration distance of the center of mass $\Delta x/D_{cy}$ was almost 0 owing to the symmetric ejecta deposit around the impact point. However, $\Delta x/D_{cy}$ increased with an increase of slope angle θ because of the collapse of the crater cavity and the asymmetric deposition of the ejecta.

We approximated the dependence of $\Delta x/D_{cy}$ on $\tan\theta$ for data with similar ϕ based on the theoretical model of sediment flux of hillslope (Roering et al., 1999) as follows:

$\Delta x/D_{cy}=a[\tan\theta/\{1-(\tan\theta/b)^2\}]+c$ (1),

where a, b, and c are constants. We will discuss the physical interpretation of each constant on the presentation.

Keywords: Regolith, Planetary terrain, Modification process of craters

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[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS04] Regolith Science

convener:Koji Wada(Planetary Exploration Research Center, Chiba Institute of Technology), Akiko Nakamura(Graduate School of Science, Kobe University), Patrick Michel(Universite Cote D Azur Observatoire De La Cote D Azur CNRS Laboratoire Lagrange), Kevin John Walsh(Southwest Research Institute Boulder)

Recent planetary explorations have revealed that almost all solid bodies in the solar system are covered with small particles, called regolith. The surface geology, especially regolith behavior on the surfaces of solid bodies, becomes increasingly more important as represented by Hayabusa mission and other on-going and planned sample-return missions such as Hayabusa2, OSIRIS-REx, and MMX.
For fully understanding the regolith science, it is required to know and compare the regolith conditions on various celestial bodies, from asteroids to planets, with various methods.
Therefore, this session welcomes broad topics related to regolith on various celestial bodies, such as asteroids, comets, the Moon, the martian moons, Mars, etc. Papers on the formation, evolution, and alteration processes of regolith particles and regolith systems on the surface of planetary bodies, remote and in-situ observational results and techniques, analyses and results of returned samples, and laboratory, numerical, and theoretical studies on the fundamental physical and chemical processes are all welcome.
Note that what we call regolith is not just fine grains: all kinds of materials (more or less loose) that lie on the surface, from cobbles to finer grains, are our targets.

[PPS04-07] Investigation into the characteristics of granular materials in low gravitational environment (Introduction of Hourglass mission)

★Invited Papers

*Masatsugu Otsuki[1], Shingo Ozaki[2], Genya Ishigami[3], Takao Maeda[4], Masataku Sutoh[1], Taizo Kobayashi[5], Hideaki Miyamoto[6], Koji Wada[7], Chihiro Kurosawa[1], Yuta Kawai[1], Haruo Kasahara[1], Tetsuya Sakashita[1], Shinobu Doi[1], Hideaki Uchikawa[1], Terumitsu Mano[1] (1.Japan Aerospace Exploration Agency, 2.Yokohama National University, 3.Keio University, 4.Chuo University, 5.Ritsumeikan University, 6.The University of Tokyo, 7.Chiba Institute of Technology)

[PPS04-08] Surface Flow Analysis Based on Spectral Distributions around Larger Boulders on Ryugu

*Naofumi Takaki[1], ERI TATSUMI[1,2], Tomokatsu Morota[1], Yuichiro Cho[1], Kazuo Yoshioka[1], Hirotaka Sawada[3], yokota yasuhiro[3,4], Naoya Sakatani[3], Masahiko Hayakawa[3], Rie Honda[4], Shingo Kameda[5], Moe Matsuoka[3], Manabu Yamada[6], Chikatoshi Honda[7], Toru Kouyama[8], Hidehiko Suzuki[9], Kazunori Ogawa[3,10], Hideaki Miyamoto[1], Naru Hirata[7], Naoyuki Hirata[10], Seiji Sugita[1] (1.The University of Tokyo, 2.Instituto de Astrofísica de Canarias, 3.Japan Aerospace Exploration Agency, 4.Kochi University, 5.Rikkyo University, 6.Planetary Exploration Research Center Chiba Institute of Technology, 7.The University of Aizu, 8.National Institute of Advanced Industrial Science and Technology, 9.Meiji University, 10.Kobe University)

[PPS04-09] Global Geology of Bennu from NASA's OSIRIS-REx Space Mission

*Kevin John Walsh[1], Erica R Jawin[2], Timothy McCoy[2], Harold Connolly[3], Dante S Lauretta[4], Ronald-Louis Ballouz[4], Olivier S Barnouin[5], Chloe Beddingfield[6], Carina Bennet[4], Edward Bierhaus[7], Keara Burke[4], Benton Clark[8], Michael Daly[9], Marco Delbo[10], Daniella DellaGiustina[4], Jason Dworkin[11], Christine Hartzell[12], John Marshall[6], Patrick Michel[10], Jamie Molaro[13], Michael Nolan[4], Maurizio Pajola[14], Michael Perry[5], Bashar Rizk[4], Scott Sandford[15], Daniel Scheeres[16], Steven Schwartz[4], David Trang[17] (1.Southwest Research Institute Boulder, 2.Smithsonian National Institute, 3.Dept. of Geology, Rowan University, 4.Lunar and Planetary Laboratory, University of Arizona, 5.Johns Hopkins University Applied Physics Laboratory, 6.SETI Institute, 7.Lockheed Martin Space, 8.Space Science Institute, 9.York University, 10.Laboratoire Lagrange, Université Côte d'Azur, 11.NASA Goddard Space Flight Center, 12.Department of Aerospace Engineering, University of Maryland, 13.Planetary Science Institute, 14.INAF - Astronomical Observatory of Padova, 15.NASA Ames Research Center, 16.Smead Dept. of Aerospace Engineering Sciences, University of Colorado, 17.HIGP/University of Hawaii at Manoa)

[PPS04-10] Equatorial features on asteroid (101955) Bennu support mass loss by fission

*Alan R Hildebrand[1], Lincoln TJ Hanton[1], Fabio Ciceri[1], Olivier S Barnouin[2], Michael G Daly[3], Jeff A Seabrook[3], Benjamin Rozitis[4], Joshua P Emery[5], Daniella N DellaGiustina[6], Bashar Rizk[6], Michael C Nolan[6], Dante S Lauretta[6], Catherine Johnson[10], Daniel J Scheeres[7], Edward B Bierhaus[8], Paul Sanchez[9] (1.Department of Geoscience, University of Calgary, Calgary, AB, Canada, 2.The Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA, 3.The Centre for Research in Earth and Space Science, York University, Toronto, ON, Canada, 4.The Open University, Milton Keynes, UK, 5.Northern Arizona University, Flagstaff, AZ, USA, 6.Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA, 7.Smead Department of Aerospace Engineering, University of Colorado, Boulder, CO, USA, 8.Lockheed Martin Space, Littleton, CO, USA, 9.Colorado Center for Astrodynamics Research, University of Colorado, Boulder, CO, USA, 10.Department of Earth, Ocean and Atmospheric Sciences, University of British Columbia, Vancouver, BC, Canada)

[PPS04-12] The Morphological, Elastic, and Electric Properties of Dust Aggregates in Comets: A Close Look at COSIMA/Rosetta's Data on Dust in Comet 67P/Churyumov-Gerasimenko

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Investigation into the characteristics of granular materials in low gravitational environment (Introduction of Hourglass mission)

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For sample returns from celestial bodies, there is a demand for more advanced technology for safe long stay from the instantaneous touch-and-go method represented by the Hayabusa series spacecrafts. In the future, landing exploration on the moon and Martian moons is also planned in Japan and understanding the interaction with regolith in the low gravitational environment on the surface of the target celestial body is the key to design spacecraft equipments. Thus, it is considered that the experimental data set for obtaining the parameters to identify behavior of the granular materials under low gravity for long time is still highly valuable. To observe the behavior of granular material such as regolith under low gravity, aircraft experiments and drop test have been conducted in the ground test. However, the range for design verification of spacecraft is not only limited due to the time constraints for maintaining the gravitational environment, but the transition from high gravity to low gravity above 1G affects the initial state of the granular material. It has also been recognized that it is a key issue to accurately understand the interaction between particles and mechanical systems in ground tests. Consequently, the "Hourglass" mission has been performed to investigate the gravitational dependence of basic parameters for reproduction of behavior of granular materials such as regolith and ground sand, and to obtain information that contributes to future spacecraft design. This presents the outline of Hourglass mission and its initial results.

In the Hourglass mission, the behaviors of regolith and ground sand in an arbitrary gravity environment are observed with an artificial gravity generator included in the Cell Biology Experiment Facility (CBEF) in the Kibo module of the International Space Station (ISS). The purpose of this mission is to investigate the effect of low gravity on the properties of granular materials. An hourglass-type container and a measuring-cylinder-type container containing particles such as simulated regolith of planets and ground sand are packed into a sealed metal box mounted on the artificial gravity generator. The behavior of particles is observed with an optical camera while they are periodically reversed under arbitrary low gravity. Eight kinds of specimens are employed for the target samples, and dynamic behavior and sedimentation state (bulk density, angle of repose, etc.) of these granular materials are evaluated. Hourglass mission would have the contribution of understanding of the celestial growth process, provision of basic data for the construction of terramechanics on celestial bodies, optimization of design for future landers, exploration rovers, automatic construction machines on the lunar surface and manned pressurized rover for lunar exploration, and the appeal of the value and ability of “Kibo” artificial gravity environment. The initial experimental results revealed the relation between the artificial gravity and the hourglass hour, and the composition of the forces acting on the granular material during experiments using artificial gravity generators.

Keywords: Hourglass mission, granular materials, low gravitational environment

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Surface Flow Analysis Based on Spectral Distributions around Larger Boulders on Ryugu

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Global observations of Ryugu by Hayabusa2 found various geomorphological features, such as high abundance of boulders, depletion in small craters [1], and the presence of a circular circum-equatorial ridge [2]. Furthermore, evidence for mass movement have been found on both sides of the equatorial ridge [1]. Ryugu has a globally uniform spectral distribution, but spectral slope distribution shows regional differences. The equatorial ridge and poles have blue spectra while mid-latitude regions have red spectra [1]. This global spectral variation may be due to surface flows from the equator to mid-latitude regions [1,3]. Ryugu might have the stratigraphic architecture of redder surface materials covering bluer subsurface materials. The spectral variation has been proposed to be caused by surface flow, which removed a reddish top layer and exposed subsurface bluer materials [3]. However, the degree of such surface flows is poorly understood yet. In this study, we search the Ryugu surface for possible surface flow features using spectral slope. Then, we quantitatively investigate both degrees and direction of surface flows.

Wake-like features have been found around large boulders on the equatorial ridge slopes. Although downstream regions of boulders do not have clear and geomorphological flow features, the downstream regions have bluer spectra than their surrounding surface. If a boulder is sitting in the surface flow from the equator, surface redder materials in the downstream region of the boulder would flow away to mid-latitude regions, and the boulder prevents redder materials in the upstream region from flowing into there. Consequently, subsurface bluer materials in downstream regions would be exposed. We measured the length (longitudinal length) and width (latitudinal length) of the flow features. We also measured the lengths of flow features on the equatorial ridge. The color analysis has been conducted based on the calibration obtained with inflight observations of Hayabusa2 [4].

As a result of the survey, we found 20 boulders with wake-like features (i.e., bluer downstream regions associated with boulders). The average width and length of the flow features associated with boulders are 22 ±12 m and 16 ±10 m, respectively. The width and length of the flow features show a good correlation with boulder width. Most of the boulder-associated flows are generally shorter than the flows around the equator. The longitudinal length of the blue band surrounding the equator, suggestive of continuous flows from the equator toward higher latitudes, is 51 ±18 m over different longitudes. However, we found that the length of the boulder-associated flow does not have a correlation with topographical slope or surface potential.

The correlation between the width of boulders and the width and length of flows suggests that the

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boulders prevented the surface materials from flowing into higher latitudes, because otherwise the widths of bluer regions are independent of the boulder width. The lack of strongcorrelation between the flow length and topological slope or surface potential suggests that these parameters where a boulder occurs are irrelevant to the flow lengths. On the other hand, the correlation between the width of boulders and the length of flows suggests that the flow lengths associated with boulders may be controlled by boulder size.

The thickness of red surface layer may be from 10 cm to ~1 m if change in spectral slope is resulted in by solar heating [3]. The thickness of fluidized layer is needed to be thicker than that of red surface layer at least. On the other hand, the maximum thickness of fluidized layer may not reach to 10 m because the flow feature areas do not have large depressions.

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[3] T. Morota et al. (2019) JpGU 2019, Abstract PPS03-08.

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Keywords: Hayabusa2, Surface flow

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Global Geology of Bennu from NASA's OSIRIS-REx Space Mission

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NASA’s OSIRIS-REx sample return mission has been studying near-Earth Asteroid (101955) Bennu since December 2018 to understand the nature of this body and to support site selection and sample acquisition. This effort has produced a wealth of data with which to constrain its geologic history. Here we report on the global geology of Bennu based on analyses of images combined with shape, mass, and slope measurements. Bennu is a 500-m-diameter object with an oblate spheroidal shape and an equatorial bulge that is similar to other near-Earth asteroids, including Ryugu, as observed by the Hayabusa2 sample return space mission. Candidate impact craters have been observed at a range of diameters, reaching up to 150 m, across the surface of Bennu. An apparent concentration of large craters at low latitudes suggest that the equatorial ridge is stratigraphically old.

The population of boulders is diverse, with many of the largest boulders being darker than the average surface albedo and exhibiting a hummocky texture. A smoother and brighter class of boulders occurs at smaller sizes, and the populations are mixed throughout the surface. Notably there is a distinct lack of very large boulders in the equatorial region (+/− 25 deg.). Only 2 of the 16 boulders larger than 30 m are located in this band. Patterns of apparent mass movement across the surface suggest movement from the mid-latitudes towards the equator. There is evidence of imbrication in the local downslope direction, as well as evidence of mass movement at smaller particle sizes in the form of partial burial of boulders and pileup of boulders at locations downslope of scarps. Many of these signatures are found specifically in regions with high surface slope and in regions where the surface slope would have increased substantially as the asteroid experienced its observed increase in spin rate. The spatial distributions of craters, boulders, observed particle ejection events and signatures of mass movement suggest a dynamic recent history in some regions of Bennu’s surface, and we use these data to divine information about the most mobile elements of its surface and their? relation to the history of Bennu’s equatorial ridge.

Keywords: Rubble Pile Asteroids, Asteroids, Craters

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Equatorial features on asteroid (101955) Bennu support mass loss by fission

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Introduction: Asteroid (101955) Bennu's bicone shape is widely ascribed to deformation during periods of critical spin rate [e.g., 1]. Finding geological evidence that can constrain material flow mechanisms and deformation regions is a goal of the OSIRIS-REx mission [e.g., 2]. Two topographic features found near Bennu's equator on high parts of its equatorial ridge - a cone-shaped hill and a deep crater-like cavity - are consistent with formation by fission at critical spin rates. The cavity floor contains evidence of internal flow as thin vertical sheets of rubble.

Bennu Equatorial Features: At ~8° E, centred on the equator, is a unique Bennu landform, a remarkably symmetric ~12 m-tall, ~40 m-diameter cone composed of fine-grained rubble (relative to its immediate surroundings) with some large boulders on its east side. Bennu's equatorial cross section is slightly square in shape [3] with four high points; this cone is located at one of these high points. Although the cone is slightly spectrally distinct from the remainder of the equatorial ridge, and thus may be younger, it has at least 8 small craters 2 to 4 m diameter preserved in its non-boulder-covered area.

At ~4° S, 126° E is a relatively fresh impact crater-like cavity ~10 m-deep and ~45 m-wide formed on the southeast side of a high equatorial hill. Its floor and walls are composed of relatively fine-grained rubble and no large boulders occur within it. Larger crater-like cavities occur both east and west of this feature; the adjacent hills constitute another of the four high spots on Bennu's equatorial ridge. Parts of the floor and walls show a unique banded albedo pattern (of variable distinctness) with rubble bands ~3 to 7 m width. The bands show no obvious topographic expression and a near-vertical dip is indicated by consistent orientation across slope changes. The rubble bands are almost parallel to Bennu's equator (~5° WNW-ESE). A distinct spectral signature suggests that the cavity is relatively young, but the interior has 10 small craters of ~2 to 4 m diameter; this post-formation crater population is comparable to that found on the cone described above.

Possible fission and interior flow scenarios: Equatorial mass loss through fission has been modelled for other NEA's [e.g., 4] to explain equatorial cavities; Bennu's cone and cavity could both be remnants of fission. The described cavity could not have formed by impact or the banded floor structure would not be preserved; the cavity also lacks an ejecta blanket as is found around other young Bennu impact craters. The crater and cone both occur on the highest Bennu equatorial topography, so are logical fission candidates resulting from Bennu's last YORP spin up. The cone may represent an interrupted fission event. For example, Bennu may have been oscillating slightly, allowing the fission flow to start before declining oscillation magnitude lowered the high point always below the loss radius. Modelling of the similarly sized NEA 2008 EV5 equatorial fission required rubble cohesion of <2 Pa [4]. Modelling of Bennu

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interior deformation by [1] produces equatorial upwelling with cohesion of 1.25 - 2.5 Pa; given the uncertainties of 2008 EV5 modelling, a common rubble cohesion value may result in both phenomena. The banding would then represent the tops of thin sheets of rising rubble from Bennu’s interior in response to interior deformation and equatorial mass loss.

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Keywords: Bennu, regolith cohesion, fission, regolith, rubble pile, asteroid

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The Morphological, Elastic, and Electric Properties of Dust Aggregates in Comets: A Close Look at COSIMA/Rosetta's Data on Dust in Comet 67P/Churyumov-Gerasimenko

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The Cometary Secondary Ion Mass Analyzer (COSIMA) onboard ESA's Rosetta orbiter has revealed that dust particles in the coma of Comet 67P/Churyumov-Gerasimenko are aggregates of small grains. We study the morphological, elastic, and electric properties of dust aggregates in the coma of Comet 67P/Churyumov-Gerasimenko using optical microscopic images taken by the COSIMA instrument. Dust aggregates in COSIMA images are well represented as fractals in harmony with morphological data from MIDAS (Micro-Imaging Dust Analysis System) and GIADA (Grain Impact Analyzer and Dust Accumulator) onboard Rosetta. COSIMA's images, together with the data from the other Rosetta's instruments such as MIDAS and GIADA do not contradict the so-called rainout growth of 10 μm-sized particles in the solar nebula. The elastic and electric properties of dust aggregates measured by COSIMA suggest that the surface chemistry of cometary dust is well represented as carbonaceous matter rather than silicates or ices, consistent with the mass spectra, and that organic matter is to some extent carbonized by solar radiation, as inferred from optical and infrared observations of various comets. Electrostatic lofting of cometary dust by intense electric fields at the terminator of its parent comet is unlikely, unless the surface chemistry of the dust changes from a dielectric to a conductor. Our findings are not in conflict with our current understanding of comet formation and evolution, which begin with the accumulation of condensates in the solar nebula and follow with the formation of a dust mantle in the inner solar system.

Keywords: comets: general, comets: individual (67P/Churyumov-Gerasimenko), meteorites, meteors, meteoroids, protoplanetary disks

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[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS05] Planetary Seismic Exploration-From InSight and Apollo to Future Missions-

convener:Taichi Kawamura(Institut de Physique du Globe de Paris), Takeshi Tsuji(Department of Earth Resources Engineering, Kyushu University), Ralph Lorenz(Johns Hopkins University Applied Physics Laboratory), William Bruce Banerdt(Jet Propulsion Laboratory)

[PPS05-01] SEIS-InSight on Mars: results and first constrains on Mars's seismic noise, seismicity and crust/subsurface structure after one year of operation

★Invited Papers

*Philippe Henri Lognonné[1], Domenico Giardini[2], W. Bruce Banerdt[3], W. Tom Pike[4], Maren Böse[5,2], Savas Ceylan[2], Ullrich Christensen[6], John Clinton[2], Martin van Driel[2], Raphael F. Garcia[7], Taichi Kawamura[1], Sharon Kedar[3], Amir Khan[2,8], Brigitte Knapmeyer-Endrun[9], Ludovic Margerin[10], Francis Nimmo[11], Mark Panning[3], Clément Perrin[1], Sue Smrekar[3], Simon Stähler[2], Benoit Tauzin[12], John-Robert Schloz[6], InSight SEIS science team (1.Université de Paris, Institut de physique du globe de Paris, CNRS, 2.Institute of Geophysics, ETH Zurich, Sonneggstr. 5, 8092 Zurich, Switzerland, 3.Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA, 4.Department of Electrical and Electronic Engineering, Imperial College London, South Kensington Campus, London SW7 2AZ, UK, 5.Swiss Seismological Service (SED), ETH Zurich Zurich Switzerland, 6.Max Planck Institute for Solar System Research, Justus-von-Liebig-Weg 3, 37077 Göttingen, Germany, 7.Institut Supérieur de l'Aéronautique et de l'Espace SUPAERO, 10 Avenue Edouard Belin, 31400 Toulouse, France, 8.Institute of Theoretical Physics, University of Zurich Zurich Switzerland, 9.Bensberg Observatory, University of Cologne, Vinzenz-Pallotti-Str. 26, 51429 Bergisch Gladbach, Germany, 10.Institut de Recherche en Astrophysique et Planétologie, Université Toulouse III Paul Sabatier, CNRS, CNES, 14 Av. E. Belin, 31400, Toulouse, France, 11.Dept. of Earth and Planetary Sciences, University of California Santa Cruz, Santa Cruz, CA 95064, USA, 12.Université de Lyon, Université Claude Bernard Lyon 1, ENS, CNRS, Laboratoire de Géologie de Lyon : Terre, Planètes, Environnement, 69622 Villeurbanne, France)

[PPS05-03] "Time-reversal" inversion of InSight seismogram for quake estimation

*Nobuaki Fuji[1], Alice Jacob[1], Clément Perrin[1], Éléonore Stutzmann[1], Philippe Lognonné[1], Mark Panning[3], Bruce Banerdt[3], Simon Stähler[2], Martin van Driel[2], Savas Ceylan[2], Mélanie Drilleau[1], Taichi Kawamura[1] (1.Université de Paris, Institut de physique du globe de Paris, 2.ETH Zürich, 3.NASA Jet Propulsion Laboratory)

SEIS-InSight on Mars: results and first constrains on Mars' s seismic noise, seismicity and crust/subsurface structure after one year of operation

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SEIS, InSight' s seismometer, is monitoring Mars' seismic activity and noise since January 2019 and its installation with a Wind Shield protection has been completed in early February, 2019. We present here results and findings after the first year of monitoring

During the first part of the night, Mars is extremely quiet. Seismic noise is ~500 times lower than Earth' s micro-seismic noise between 4-30 seconds, with ground velocity below 10^{-10} m/s/$Hz^{1/2}$ at 2.5 seconds. The recorded seismic noise increases during the second part of the night and then during the day due to ground deformations induced by convective vortices and ground transferred wind-generated lander noise. During these noisy times, pressure data shows significant coherency with the recorded seismic signals and can therefore be used to perform noise decorrelations.

The subsurface below the landing site has been constrained with seismic signals from dust-devil-like vortices, long period atmospheric signals and from the hammering of the Heat Flow and Physical Properties (HP^3). These analysis reveals a 2-3 meters of very low rigidity materials, possibly associated to eaolian deposition in a eroded crater above more rigid layers. The subsurface is also constrained by shallow site effects, generating ground resonances.

We recorded 389 events until December 31, 2019, with mostly two distinct populations of seismic: mostly small-magnitude events with High or Very high frequencies, and more than 30 Low frequency or Broadband events with signals at and/or below 1 Hz. These have the signature of Marsquakes of magnitude 3-4 located near the crust-mantle interface and with waves propagating at different depths in the mantle. The two larger events are near the Cerberus Fossae system, and preliminary focal inversions have been found to be coherent with the local tectonics, as constrained from remote sensing data.

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The three largest quakes detected until September 2019, on sols 128, 173 and 235 have been used for crustal analysis. Receiver function analysis suggested a 8 to 11 km thick superficial layer of highly altered and/or fractured crustal material and multi-scattering analysis constrained the crustal diffusivity and intrinsic attenuation using and find a crustal seismic attenuation ~3 times larger than on the Moon suggesting a crust with small amounts of volatiles.
All data and Activity catalogue of SEIS are available to the community through request on the SEIS data portail (http://seis-insight.eu), IRIS-DMC or NASA PDS.

Keywords: Mars, seismology, InSight

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“Time-reversal” inversion of InSight seismogram for quake estimation

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We re-define time-reversal inversion (back projection) operator that can infer the source location. When we have a good coverage of seismic stations and a robust knowledge on the structure, a classical time-reversal, which cross-correlates observed data and synthetic Green’s functions should work. Due to a poor configuration of one-station seismology in InSight project, however, we need to explicitly include the inverse of the full Hessian matrix in order to detect quakes. We have proven this with synthetic tests using 1D Mars models with/without regolith layers on the top of the planet with an explosion source exerted on the surface. We then applied this method to the real data, especially that of “A” quality, with a set of vertical Green’s functions with an explosion source on the surface in order to roughly estimate the distance, which matches the catalog given by the Marsquake Service. We then extend this method for refining the solution using Green’s functions for all the components.

Keywords: InSight, waveform inversion , Regolith

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[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS05] Planetary Seismic Exploration-From InSight and Apollo to Future Missions-

convener:Taichi Kawamura(Institut de Physique du Globe de Paris), Takeshi Tsuji(Department of Earth Resources Engineering, Kyushu University), Ralph Lorenz(Johns Hopkins University Applied Physics Laboratory), William Bruce Banerdt(Jet Propulsion Laboratory)

Given that seismic exploration is one of the most successful approach to study the internal structure of planetary bodies, it has been proposed to various planetary missions. Starting from Passive Seismic Experiment on Apollo missions, various seismic experiments were proposed over the next 50 years. Recently, several such proposals have been approved and thus we are entering a new active era of planetary seismology. In early 2019, the NASA InSight Lander successfully deployed the first seismometer on the surface of Mars and detected the first Marsquakes. In addition, recent global interest in lunar exploration has rekindled interest in a new seismic network on the Moon. In-situ resource utilization is being intensively discussed and seismic exploration has been investigated as an approach to search for subsurface water/ice. Finally, the Dragonfly mission was selected as NASA's next New Frontiers mission and a set of short period seismometers is being considered for its payload. With such a diversity of on-going and future missions, the next decade should see significant advances planetary seismology. The aim of this session will be to discuss the latest planetary seismology discoveries and possible future exploration and developments in this field. In terms of recent discoveries, the focus will be on analyses of InSight seismic data from Mars as well as results from other missions. The session will also include discussion on future missions, both selected and proposed. These include the active seismic experiment on the Japanese Lunar Resource Prospector mission and the seismic experiment on NASA's Dragonfly. Though planetary seismology has a long history dating back to the Apollo era, the associated research community is relatively immature due to the nearly 50-years gap in new data. We propose this session to provide opportunity to bring together scientist working on related topics and encourage discussion and collaboration for future development of this theme.

[PPS05-06] Seismic investigation of the Moon: Past, Present, and Future

★Invited Papers

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[PPS05-07] VBB on the Moon: Expected performances and science return

*Tanguy Nebut[1,2,3], Philippe Lognonne[1,3], Sébastien de Raucourt[1,3], Taichi Kawamura[1,3], Gabriel Pont[4], Taoufik Gabsi[1,2,3], Sylvain Tillier[1,2,3], Olivier Robert[1,2,3], Michel Parise[1,2,3] (1.Institut de Physique du Globe de Paris, 2.CNRS, 3.Université de Paris, 4.CNES)

[PPS05-09] Seismic wave propagation on asteroid Ryugu induced by the impact experiment of the Hayabusa2 mission

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Seismic investigation of the Moon: Past, Present, and Future

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Beginning in 1969, NASA’s Apollo program successfully deployed a long-lived network of seismometers on the Moon. The resulting seismic data revolutionized our understanding of the Moon's interior. In the intervening years, re-examination of Apollo geophysical data and sample analyses combined with a wealth of new data from orbital missions have led to an understanding of a crust, mantle, and core that are likely spatially and compositionally heterogeneous at scales ranging from microscopic to hemispherical, reflecting the Moon’s unique formation history and subsequent evolution.

The structure of the Moon’s interior is elucidated primarily via seismology, with gravity, heat flow, laser ranging, and electromagnetic sounding providing supporting indirect constraints. A passive seismic experiment was deployed on the lunar near side at the Apollo 12, 14, 15, and 16 sites, and operated continuously from 1969 to 1977. Due to the highly scattering nature of the lunar regolith and the overall quality of the instrumentation compared to modern seismometers, lunar seismograms are of limited quality compared to their terrestrial counterparts. Crustal thickness estimates have decreased over the years as newer and more computationally expensive techniques have been applied. Early models based on arrival time inversion alone were supplanted by newer models using maximum likelihood estimates, joint seismic and gravity inversion, and free oscillations. These newer models mostly agree that the only major discernable discontinuity in the lunar interior is the crust-mantle boundary located around 30km deep.

Uncertainties in deep structure estimates afforded from other geophysical measurements are reflected in the seismic structure models. Although many types of naturally occurring seismicity were recorded, no seismic energy originating from the far side penetrated the core, thus it was suggested that the core is likely attenuating. The deepest moonquake sources lie between ~1200-1400km depth, so the core is likely no more than 300-500km in radius.

Previous studies of the Apollo seismic data focused on structure constrained by direct arrivals, meaning they were only able to resolve structure to the depth of the deepest ray connecting a source to a receiver. The geographical extent of the Apollo array, all located around the equator on the nearside, precluded the constraint of any core structure based on direct ray geometry. Two groups have re-analyzed the seismic data looking instead for core reflections, and separately discovered convincing evidence for the presence of a liquid lunar core. One of these also constrained a solid inner core on the basis of the lack of observed SH reflections (horizontally polarized shear waves), and a partially molten layer at the base of the mantle on the basis of observed P reflections (vertically polarized compressional waves). The presence of a fluid-like transition layer between the lunar core and mantle suggests the Moon may still be undergoing cooling. Numerous studies have since emerged offering differing perspectives on the origins of the partial melt layer and whether it is required to satisfy available constraints.

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Despite recent advances in lunar seismology, many questions remain regarding the detailed global structure of the Moon’ s deep interior, which has bearing on its thermal, petrological, and rotational history. To build upon the legacy of Apollo, the U.S. National Academies recommends a Lunar Geophysical Network as a prioritized mission in the current planetary decadal survey. A network of four nodes (each with a seismometer, heat flow probe, retroreflector, and magnetometer), operating continuously for up to10 years, would enable progress towards a consistent model of the Moon’ s interior from crust to core.

Keywords: Moon, seismology, geophysics

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VBB on the Moon: Expected performances and science return

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The SEIS VBB, InSight's Very Broad band seismometer, is monitoring Mars' seismic activity and noise since January 2019 and its installation with a Wind Shield protection has been completed in early February, 2019. During the first part of the night ground velocity below 10^{-10} m/s/Hz$^{1/2}$ at 2.5 seconds have been shown, about one order of magnitude below the self-noise of the companion SP instrument, showing the importance of low self-noise and well installed instruments in planetary seismology.

By using the VBB technology, we shows that different configuration of instrument can be proposed. The more simple will be a vertical VBB, which can be used from the spare units of the InSight SEIS experiment, and can be available for very early opportunities prior 2025. Much better will be oblique, 3 axis VBB, designed for the lunar gravity. We detail here the expected performances of these Lunar version of the VBB (3 10^{-11} m/s^2/Hz$^{1/2}$ between 0.02Hz and 1Hz), which can be considered for near future Lunar investigations, either deployed by robotic missions or by human deployed Autonomous surface package.

These performances are about 10 times better than Apollo and will allow addressing several seismic investigations never performed on the Moon. We focus on the detection capabilities of Deep Moon Quakes, Impacts and Shallow Moonquakes, including for surface waves and address what could be observed, including core phases, lunar seismic noise and impacts signals.

We finally conclude by discussing expectations at very long periods, for the detection of free oscillations excited by the largest events and discuss possible improvements made with optical sensing.

Keywords: Moon seismology, Apollo, InSight, Deep Moonquakes, Lunar seismic noise, Optical sensor

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Seismic wave propagation on asteroid Ryugu induced by the impact experiment of the Hayabusa2 mission

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Recently, multiple space exploration missions have revealed that asteroids are affected by active surface renewal. Such mass movement has also been observed on 162173 Ryugu, which was explored by the Japanese spacecraft Hayabusa2 from June 2018 to November 2019. While there are several processes that can account for both lateral and vertical mass transport of asteroid regolith, the most plausible hypothesis has been global vibration, that is, impact-induced seismic shaking. The Hayabusa2 was expected to observe such impact-induced seismic shaking through the Small Carry-on Impactor (SCI) operation based on previous numerical simulations and laboratory experiments which suggest that the energy of this impact experiment is high enough to generate boulder movement around a newly formed crater. In April 2019, the SCI operation was successfully conducted and provided surprising images of crater ejecta taken by a Deployable CAMera 3 (DCAM3). Later, the Hayabusa2 Optical Navigation Camera (ONC) took an image of the periphery of the SCI crater in order to compare it with the image taken prior to the SCI impact. The images show that the impactor made a crater of about 13 m in diameter, but boulders located around the edge of the crater appear unmoved by the seismic waves supposedly produced by the SCI impact. Aiming to explain this unexpected observation, we conduct seismic wave propagation modelling with a wide range of elastic parameters of Ryugu.

Using a fast modelling code for 3D seismic wave propagation, AxiSEM3D, we numerically simulate seismic shaking on asteroids, changing rigidities, quality factors and seismic efficiencies (the conversion ratio of impactor’s kinetic energy to seismic wave energy). Following previous studies, an isotropic seismic moment tensor of explosion form is assumed. Through the comparison between simulations and observations, we find that quality factor smaller than 0.5 or seismic efficiency smaller than 10^{-7} are required. However, such an extremely low quality factor seems unrealistic because anelastic heat generation and scattering in anhydrous asteroid regolith are expected to be too small to reduce wave energies rapidly. Thus, we consider very low seismic efficiency more plausible. The reason for such a low seismic efficiency can be resulted from the powdery behavior of regolith. Seismic waves propagate through powdery materials only if the elastic stress is lower than its yield strength. Assuming that the yield strength of regolith is 1 kPa as laboratory experiments, calculated boulder’s lateral movement would be always smaller than 1 m. This hypothesis may account for the absence of regolith lateral movement observed in the SCI operation during the Hayabusa2 mission and indicate that the low yield strength of regolith possibly limits the seismic wave propagation on asteroids, making the apparent seismic efficiency small.

Keywords: Hayabusa2, asteroid, seismology, surface evolution, Ryugu

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[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS06] Science of Venus: Venus Express, Akatsuki, and beyond

convener:Takehiko Satoh(Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency), Kevin McGouldrick(University of Colorado Boulder), Hideo Sagawa(Kyoto Sangyo University), Thomas Widemann(Observatoire De Paris)

In this century, our knowledge about the earth's twin sister, Venus, has greatly been advanced through two latest missions, ESA's Venus Express and JAXA's Akatsuki. The latter, in Venus orbit since December 2015, is providing high-quality data that allow studies of atmospheric dynamics in particular. Successful missions are the trigger of ideas of new missions (Russian Venera-D and Indian Shukrayaan-1 under development, European EnVision, and some US proposals). This session invites papers of the new results from data (spacecraft and ground-based), latest results of theoretical and numerical works, and descriptions of new missions as well.

[PPS06-01] Next generation Japan's Venus Exploration in 2020s

★Invited Papers

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[PPS06-02] EnVision M5 Venus Orbiter Proposal

*Thomas Widemann[1], Colin Wilson[2], Richard Ghail[3], Dmitri Titov[4] (1.Observatoire de Paris, F, 2.Oxford University, UK, 3.Royal Holloway London, UK, 4.ESTEC, NL)

[PPS06-03] Improving Venus gravity field with the Envision candidate mission

★Invited Papers

*Pascal Rosenblatt[1], Caroline Dumoulin[1], Jean-Charles Marty[2], Antonio Genova[3] (1.Laboratory of Planetology and Geodynamics, 2.CNES/GRGS, 3.Sapienza Rome University)

[PPS06-04] Crustal recycling and the history of magmatism in Venus

*Masaki Ogawa[1] (1.Division of General Systems Studies, Graduate School of Arts and Sciences, University of Tokyo)

[PPS06-05] Constraining the Formation of Venus with N-body simulations of Terrestrial Planet Formation

*Patryk Sofia Lykawka[1], Takashi Ito[2] (1.School of Interdisciplinary Social and Human Sciences, Kindai University, 2.National Astronomical Observatory of Japan)

[PPS06-06] VERITAS: Discovering the Secrets of a Lost Habitable World

★Invited Papers

*Suzanne E Smrekar[1] (1.Jet Propulsion Laboratory)

Next generation Japan's Venus Exploration in 2020s

*Masato Nakamura[1], Atsushi Yamazaki[1], Ryoma Yamashiro[2], Nobuaki Ishii[1], Tomoaki Toda[1], Yoshifumi Futaana[4], Sanjay S. Limaye[3], Naoki Terada[5], Hiroki Ando[6], Toru Kouyama[7], Takehiko Satoh[1], Takeshi Imamura[8], Makoto Taguchi[9], Yoshi-Yuki Hayashi[10], Takeshi Horinouchi[11], Yeon Joo Lee[12], Masahiro Takagi[6], Masataka Imai[7], Tetsuya Fukuhara[9], Norihiko Sugimoto[13], Hiroki Kashimura[10], Shigeto Watanabe[14], Takao M. Sato[14], George L. Hashimoto[15], Shin-ya Murakami[1], Kevin McGouldrick[16], Takumi Abe[1], Chikako Hirose[2], Manabu Yamada[17], Kazunori Ogohara[18], Ko-ichiro Sugiyama[19], Shoko Ohtsuki[20], Javier Peralta[1], Seiko Takagi[11], Naomoto Iwagami, Munetaka Ueno[2], Takeshi Sakanoi[5], Shingo Kameda[9], Yasumasa Kasaba[5], Yukihiro Takahashi[11], Mitsuteru Sato[11], Yoshihisa Matsuda[21], Masaru Yamamoto[22]

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Akatsuki is the first Japanese Venus orbiter, which was launched in 2010. After the Venus orbit insertion (VOI) in 2015, a lot of images have been taken by the cameras onboard Akatsuki. Lower and middle clouds in the nightside are imaged by 2-μm infrared camera (IR2). Cloud top in the dayside is imaged by the ultra violet imager (UVI). Temperature at the cloud top level is measured by a longwave infrared camera (LIR). UVI and LIR have been working for 4 years after the VOI, but IR2 has ceased its observation about one year after the VOI due to its malfunction of the electronics. Total numbers of the UVI, LIR and IR2 images are different among them; 17,306, 31,444 and 3,201, respectively. Akatsuki observes the Venus atmosphere at different altitudes, local times, and latitudes, then we come close to understanding the Venusian atmospheric dynamics. However, we have to say that the knowledges in the cloud layer are not enough. We need to plan a follow up Venus mission to get more information from the Venusian atmosphere. Now Russia is planning Venera-D mission, and the European scientists are proposing EnVision mission to ESA. Japan should also follow up Akatsuki with a new mission which has the same designed cameras onboard Akatsuki. This leads to the creation of an international Venus observation network.

We are considering that two small probes put at the Lagrange 1 and 2 points of Venus, which is located almost 10^6 km from its dayside and nightside. This idea is inspired by Limaye and Kovalenko [2019][1]. From Lagrange 1(2) point, the dayside (nightside) hemisphere can be always observed. The radius of the Lissajous orbits depends on the delta-V which is required in the insertion. We assumed that the observation phase angle is 25 degrees and estimated total delta-V (for the orbit maneuver to Venus and L1(2) Lissajous orbit insertion) as 720 m s^{-1}.

One idea is to use JAXA’s Epsilon launcher. Epsilon launch vehicle of JAXA is expected to launch 200-250 kg mass to Venus. Then the weight of each probe is about 100 kg, and the required fuel (monopropellant) for the delta-V is estimated to be 36 kg. Assuming 10 kg for the science payload, remaining mass of 54 kg can be used for the bus system including the propulsion, telecommunication, etc. Other possibilities inserting two probes to Lagrange points of Venus, e.g. using H3 launch vehicle or others, should be investigated.

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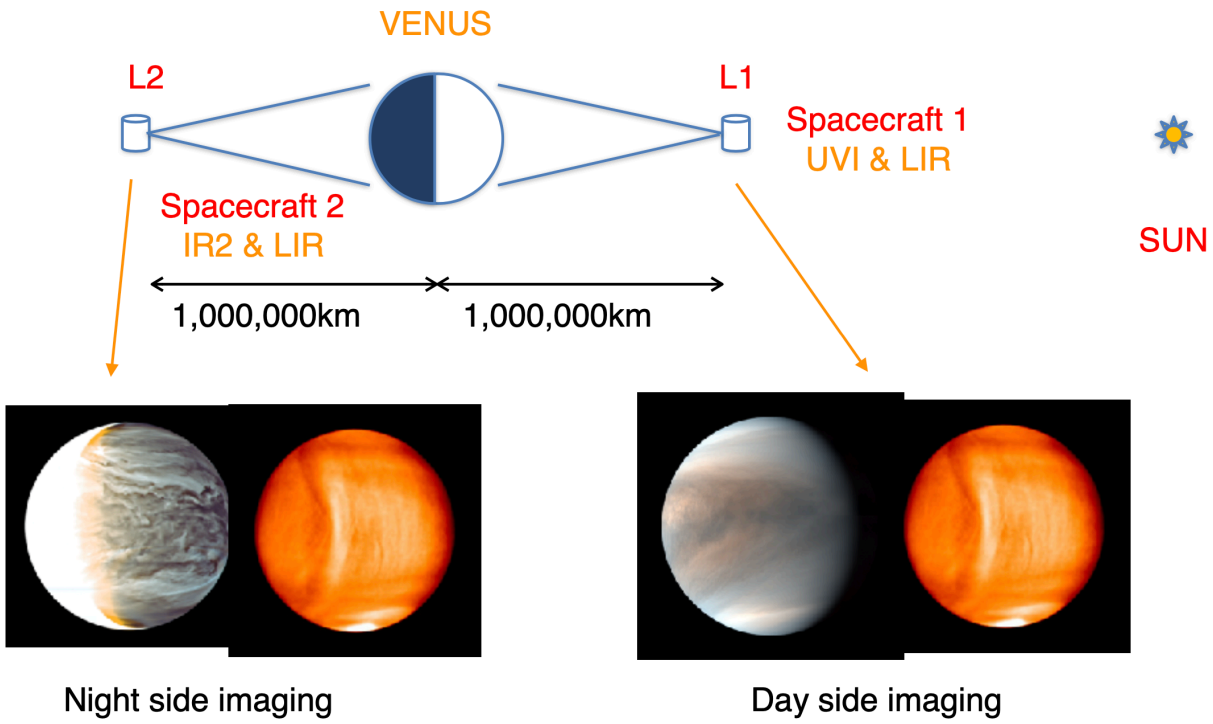
We will discuss follow up Venus science as well as more detail of our future mission plan (launcher, orbit insertion, probe system, etc.) to Venus in the presentation.

Reference

1. Monitoring Venus and communications relay from Lagrange Points, Limaye and Kovalenko, Planetary and Space Science 2019, https://doi.org/10.1016/j.pss.2019.104710

Keywords: Venus, Exploration, Lagrange points



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EnVision M5 Venus Orbiter Proposal

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EnVision [1,2] is a Venus orbiter mission that will determine the nature and current state of geological activity on Venus, and its relationship with the atmosphere, to understand how and why Venus and Earth evolved so differently. It is a candidate for ESA' s M5 Space Science mission, with strong NASA participation. It is currently in Phase A study; Wnal mission selection is expected in June 2021. If selected, EnVision will launch by 2032 on an Ariane 6.2 into a six month cruise to Venus, followed by aerobraking, to achieve a near-circular polar orbit for a nominal science phase lasting at least 4 Venus days (2.7 Earth years).

The **Synthetic Aperture Radar, VenSAR,** will:

- Obtain images at a range of spatial resolutions from regional coverage to images of targeted localities
- Measure topography from stereo and InSAR observation;
- Characterize volcanic and tectonic activity, estimate rates of weathering and surface alteration; and
- Characterize surface mechanical properties and weathering through multi-polarisation radar, and emissivity mapping.

The **Subsurface Sounder, SRS,** will:

- Characterize the vertical structure and stratigraphy of geological units including volcanic bows; and
- Determine the depths of weathering and aeolian deposits.

The **Venus Spectrometer suite, VenSpec**, will:

- Obtain global maps of surface emissivity in Wve wavelength bands in the near-infrared, to constrain surface composition and inform evolution scenarios; and
- Measure variations of SO2, SO and linked gases in the mesosphere, in order to link these variations to tropospheric variations and volcanism.

The **Radio Science & Geodesy** investigation will:

- Constrain crustal & lithospheric structure at Wner spatial scale than Magellan; and
- Measure spin rate and spin axis variations to constrain interior structure.

EnVision will produce a huge dataset of geophysical data of a quality similar to that available for Earth and Mars, so will permit investigation across a large range of disciplines. Lab-based and modelling work will also be required to interpret results from the mission. We therefore invite scientists from across planetary, exoplanetary and earth science disciplines to participate in the mission preparation and analysis of the data.

[1] Ghail R. C. et al., (2016) EnVision M5 proposal,https://arxiv.org/abs/1703.09010

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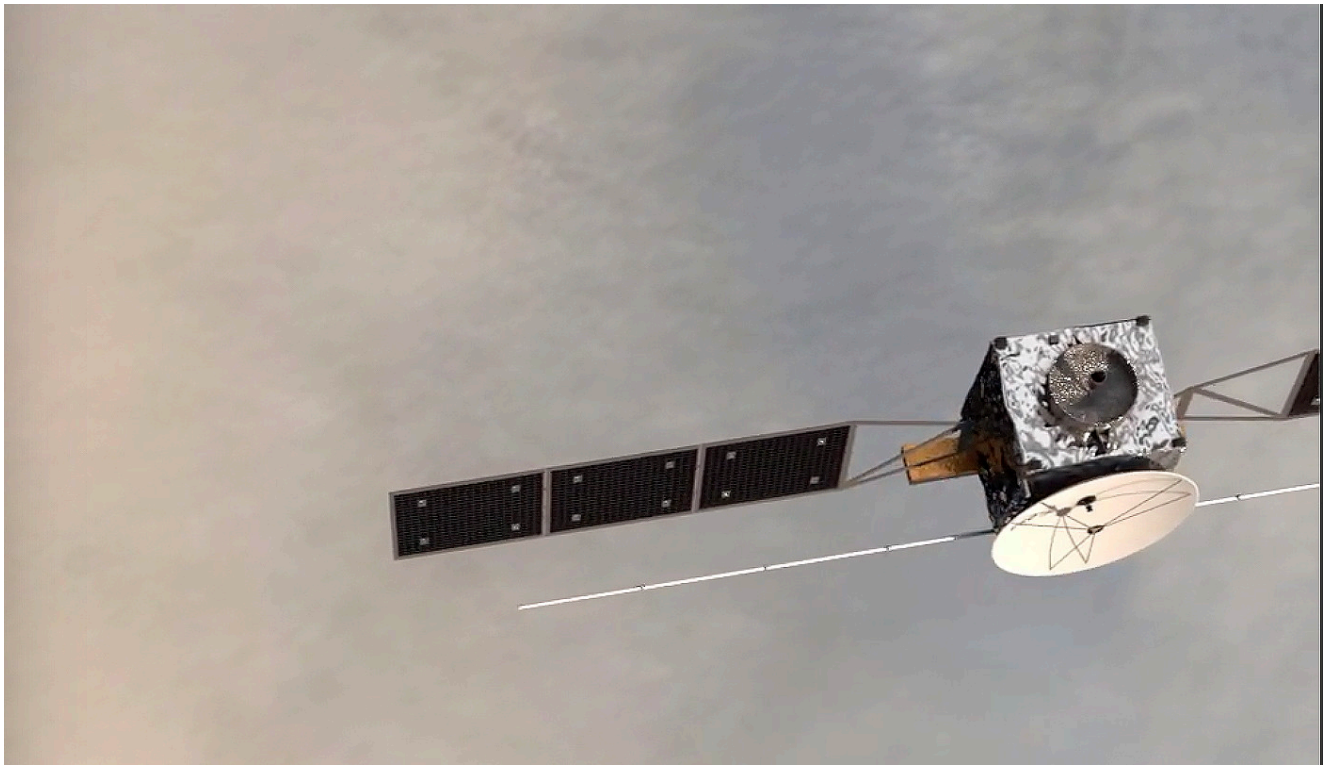
[2] www.envisionvenus.eu

Keywords: Venus, Surface activity and history, Interior, Atmosphere



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Improving Venus gravity field with the Envision candidate mission

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The gravity field of Venus is merely known from tracking data of two spacecraft: Magellan and Pioneer Venus Orbiter. It shows highly variable resolution preventing the detection of possible lateral variations of the lithospheric and crust thicknesses and the precise knowledge of the size and state of the core. The EnVision mission, which is ongoing selection at ESA, offers the opportunity to improve the current solution of the gravity field of the planet. Precise Doppler tracking data of the spacecraft are indeed foreseen to be performed during telemetry slots of the payload instrument data, providing at least 7 hours of effective tracking per day. This tracking will use the Ka-band carrier frequency, which allows less noisy Doppler data than in X-band (Magellan data). In this study, simulations are performed to assess the expected improvement of the gravity field solution, taking into account a realistic Doppler noise budget and the misleading of the knowledge of the full dynamics of the spacecraft motion. Preliminary results show that a spatial resolution better than 200 km can be reached over the southern hemisphere when the spacecraft altitude is lower than 300-350 km, thus allowing to fill the major gaps in the resolution of the current solution. The precision on the potential tidal Love number k2 allows to better constrain the size and state of the core. The improvement would also allow to investigate more tiny gravity variations due to the mass transfer in the atmosphere related to the thermal tides in the atmosphere.

Keywords: Planet, Venus, Gravity field

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Crustal recycling and the history of magmatism in Venus

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Magmatism cannot continue long in a planet where the lithosphere behaves as a stagnant lid and mantle convection occurs only beneath it, because magmatism extracts the heat producing elements (HPEs) that cause the magmatism itself from the mantle to form the crust. In a planet like the Earth and Venus where magmatism is active even today, therefore, there must be some agents that have recycled the crust. On the Earth, the crust recycles by subduction of tectonic plates. In Venus, however, evidence for crustal recycling has not been identified. The two-stage mantle evolution model that I developed for Venus based on a numerical simulation of coupled magmatism-mantle convection system suggests that the crust recycled on the earlier stage owing to mantle bursts: the solid-solid phase boundaries at the top of the lower mantle make the upward convective flow of hot lower mantle materials into the upper mantle episodic, and each episode of convective flow, or mantle burst, causes a vigorous magmatism that forms the tessera terrain and induces crustal recycling. On the later stage, however, mantle bursts cease due to decay of HPEs. Instead, melting in the uppermost mantle continuously generates magma that overlays tessera terrain to form the volcanic plain; there will be no crustal recycling on the later stage. Search for vestiges of past crustal recycling in tessera terrain is important for understanding the history of Venus.

Keywords: Venus, two-stage evolution, crustal recycling

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Constraining the Formation of Venus with N-body simulations of Terrestrial Planet Formation

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One of the most difficult challenges in planet formation theory is to reproduce the orbits and masses of the terrestrial planets Mercury, Venus, Earth, and Mars. Here, we investigated terrestrial planet formation by performing extensive N-body simulations of primordial protoplanetary disks representative of typical models in the literature. Those disks consisted of embryos and planetesimals placed up to ~1-4 au (depending on the disk model).

We used our classification algorithm to identify the systems that formed planet analogs of Venus and Earth (in terms of orbit and mass) plus Mercury or/and Mars in the same system. From the analysis of the terrestrial planets formed in such 3- or 4-planet system analogs, we acquired detailed information about the formation and evolution of our identified Venus analogs. In particular, we obtained a-e-i-mass distributions, feeding zones, delivery of water/volatiles, number of giant impacts, accretion histories, and other properties about Venus analogs.

In this presentation, we also discuss the dependence of the results on the initial conditions, which allowed us to discuss the conditions that a protoplanetary disk must satisfy in order to form simultaneously the four terrestrial planets.

Keywords: Solar System, Terrestrial Planets, Planet Formation, Venus

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VERITAS: Discovering the Secrets of a Lost Habitable World

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Magellan almost 30 years ago along with the Venus Express and Akatsuki missions to Venus have done much to elucidate to geologic and atmospheric processes operating at Venus. Yet, basic questions remain informed by these prior investigations about the most Earth-like planet in terms of size, bulk composition, and stellar energy. Answers to these questions for Venus have profound implications beyond Venus to understanding how rocky planets evolve and what makes them habitable.

Geologic processes on Venus are a missing link for rocky planet evolution. Its present condition is a geodynamic analog for early Earth, when the lithosphere was hotter and thinner, plate tectonics began, and life emerged. In turn, plate tectonics led to continent formation. Earth no longer retains a clear record of how these processes began, but Venus may have active subduction—the necessary first step to initiate plate tectonics. Venus is the control case to Earth for determining what conditions give rise to these fundamental processes, thus enabling their prediction for exoplanets.

The proposed VERITAS (Venus Emissivity, Radio science, InSAR, Topography, And Spectroscopy) mission to the NASA Discovery 2019 is structured around 18 science questions designed to understand the processes that led to Venus' current geologic state and determine what processes are geologically active. VERITAS is equipped with an interferometric synthetic aperture radar to acquire high resolution imagery and topography as well as make repeat pass interferometric deformation measurements. It is also equipped with a near IR spectral imager with optimized spectral bands for observing the surface of Venus that supports the determination of igneous rock type and the search for active and recent volcanism. The low Venus orbit of the VERIATS spacecraft supports major improvements in the determination of the Venus gravity field as well as determination of the tidal Love number and phase lag leading to a refined understanding of the Venus interior and assessment of core size and state. This talk provides an overview of its science objectives, measurements and mission profile.

This research was partially conducted at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

Keywords: Venus, Mission, Habitability, Geophysics, Radar, spectroscopy

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[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS06] Science of Venus: Venus Express, Akatsuki, and beyond

convener:Takehiko Satoh(Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency), Kevin McGouldrick(University of Colorado Boulder), Hideo Sagawa(Kyoto Sangyo University), Thomas Widemann(Observatoire De Paris)

In this century, our knowledge about the earth's twin sister, Venus, has greatly been advanced through two latest missions, ESA's Venus Express and JAXA's Akatsuki. The latter, in Venus orbit since December 2015, is providing high-quality data that allow studies of atmospheric dynamics in particular. Successful missions are the trigger of ideas of new missions (Russian Venera-D and Indian Shukrayaan-1 under development, European EnVision, and some US proposals). This session invites papers of the new results from data (spacecraft and ground-based), latest results of theoretical and numerical works, and descriptions of new missions as well.

[PPS06-07] Wavelet analysis of gravity wave packets in Venus' atmosphere using radio occultation temperature profiles

Ryota Mori[1], *Takeshi Imamura[1], Hiroki Ando[2], Bernd Hausler[3], Martin Patzold[4], Silvia Tellmann[4] (1.Graduate School of Frontier Sciences, The University of Tokyo, 2.Faculty of Science, Kyoto Sangyo University, 3.Universitat der Bundeswehr Munchen, Germany, 4.Universitat zu Koln, Germany)

[PPS06-08] Cross-link Radio Occultation measurements of Venus Atmosphere by using multiple small satellites

*Hiroki Ando[1], Satoshi Ikari[2], Takeshi Imamura[3], Tomotaka Yamamoto[2], Yosuke Kawabata[2], Shoko Sano[2], Norihiko Sugimoto[4], Masahiro Takagi[1], Hideo Sagawa[1], Yukiko Fujisawa[4], Mutsuko Morimoto[4], Mirai Abe[5], Asako Hosono[6], Ryu Funase[2] (1.Faculty of Science, Kyoto Sangyo University, 2.Department of Aeronautics and Astronautics, The University of Tokyo, 3.Graduate School of Frontier Science, The University of Tokyo, 4.Department of Physics, Keio University, 5.Faculty of Law, Keio University, 6.Toshimagaoka Women High School)

[PPS06-09] Determination of the homopause altitude on Venus from SOIR/VEx observations

★Invited Papers

*Arnaud Mahieux[1,2], Hiromu Nakagawa[3], Nao Yoshida[3], Ann Carine Vandaele[1], Roger Yelle[4], Séverine Robert[1], Shohei Aoki[1,5], Arianna Piccialli[1], Loïc Trompet[1], Yasumasa Kasaba[3] (1.Royal Belgian Institute for Space Aeronomy, Brussels, Belgium, 2.The University of Texas at Austin, Austin, Texas, 3.Tohoku University, Sendai, Japan, 4.University of Arizona, Tucson, Arizona, 5.Université de Liège, Liège, Belgium)

[PPS06-10] Long term monitoring of planetary scale temperature variations at the cloud top level of Venus by Akatsuki/LIR observations

★Invited Papers

*Toru Kouyama[1], Masataka Imai[1], Takeshi Horinouchi[2], Takeshi Imamura[3], Makoto Taguchi[4], Tetsuya Fukuhara[4] (1.National Institute of Advanced Industrial Science and Technology, 2.Hokkaido University, 3.University of Tokyo, 4.Rikkyo University)

[PPS06-11] Dayside cloud top structure of Venus retrieved from Akatsuki IR2 observations

*Takao M. Sato[1], Takehiko Satoh[2], Hideo Sagawa[3], Naohiro Manago[4], Yeon Joo Lee[5], Shin-ya Murakami[2], Kazunori Ogohara[6], George HASHIMOTO[7], Yasumasa Kasaba[8], Atsushi Yamazaki[2], Manabu Yamada[9], Shigeto Watanabe[1], Takeshi Imamura[10], Masato Nakamura[2] (1.Hokkaido Information University, 2.ISAS/JAXA, 3.Kyoto Sangyo University, 4.Chiba University, 5.Technische Universität Berlin, 6.The University of Shiga Prefecture, 7.Okayama Unviersity, 8.Tohoku University, 9.Chiba Institute of Technology, 10.The University of Tokyo)

[PPS06-12] Variability of UV albedo and its relation to the wind field revealed by Akatsuki UVI

*Tatsuro Iwanaka[1], Takeshi Imamura[1], Yeon Joo Lee[2], Takeshi Horinouchi[3] (1.The Univesity of Tokyo, 2.Technical University of Berlin, 3.Hokkaido University)

Wavelet analysis of gravity wave packets in Venus' atmosphere using radio occultation temperature profiles

Ryota Mori[1], *Takeshi Imamura[1], Hiroki Ando[2], Bernd Hausler[3], Martin Patzold[4], Silvia Tellmann[4]

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Atmospheric gravity waves are thought to play crucial roles in transporting momentum and energy in planetary atmospheres. They are frequently observed as localized quasi-monochromatic wave packets in cloud images, while the vertical structures of the wave packets have not been investigated. The wavelengths and the periods of the wave packets should reflect their respective generation processes. Though wave packets are thought to propagate independently, they can be superposed on each other to induce an unstable field. The statistical characteristics of wave packets need to be known to understand the roles of the waves in the development of the atmospheric structure.

We study the characteristics of gravity wave packets in Venus' s atmosphere using high vertical resolution temperature profiles obtained by Venus Express and Akatsuki radio occultation experiments with radio holographic methods. Localized disturbances are extracted by applying wavelet transform to the vertical temperature distributions. The analysis showed that (1) wave packets having different wavelengths are overlapped with each other, (2) each wave packet typically includes 2-3 cycles, (3) waves with vertical wavelengths of ~1 km are dominant,(4) individual wave packets are hardly saturating in isolation, while saturation occurs as a result of superposition of wave packets, and (4) short-vertical wavelength waves are more frequently observed at lower altitudes.

Keywords: atmospheric gravity wave, Venus, wavelet analysis, radio occultation

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Cross-link Radio Occultation measurements of Venus Atmosphere by using multiple small satellites

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By imaging measurements using a spectrometer onboard Venus Express and a camera onboard Akatsuki and ground-based observations using a telescope, the knowledges about the Venusian atmospheric structure in the horizontal direction are steadily being accumulated by imaging measurements using a spectrometer onboard Venus Express, a camera onboard Akatsuki and ground-based observations using a telescope. However, they enable us to observe only the atmosphere at the specific altitude. On the other hand, the progress of modelling studies using GCM is also remarkable, but we cannot confirm the validity of modelling results sufficiently; the optical measurements can only observe the atmospheric structure at the cloud level, and then we cannot compare the modelling results with them globally. In particular, the knowledges about the vertical structure are insufficient.
Radio occultation measurements are usually conducted concurrently with optical measurements. Radio waves are transmitted from the spacecraft, refracted in the planetary atmosphere, and received at a ground station. From the measured atmospheric Doppler shift, we can obtain a vertical temperature profile with a high accuracy (measurement error ~ 0.1 K) and a high vertical resolution (~1 km). Therefore this method is useful for us to investigate the atmospheric structure in the vertical direction. However, the observational region and chance are limited because such a conventional radio occultation measurement highly depends on the configuration of the spatial positions of a spacecraft, a planet and the Earth. In the case of a conventional radio occultation measurement, however, the observational region and chance are limited by the orbit of a spacecraft and the spatial positions of a spacecraft, a planet and the Earth. One of the methods to overcome this weak point is a cross-link radio occultation technique among the multiple spacecraft.
We consider the cross-link radio occultation measurements of the Venus atmosphere by using multiple small satellites, one main satellite and two sub satellites, in terms of both engineering and science. It is assumed that they are conducted by one main satellite and two sub satellites. As a result of the trade-off between the fuel consumption for based on Venus orbit insertion and orbit transfers for the optimal satellite configuration and the number of observation points, it is expected that the number of measurements would be 179 in the rotation period of Venus super-rotation (4 Earth days) and the observation points could distribute globally. This enables us to obtain four-dimensional data of temperature and pressure. If the submillimeter, ultra-violet and infrared imaging measurements were also conducted, we would investigate the cloud physics and the photochemistry as well as the atmospheric structure and dynamics. In addition, we might be able to create a more precise Venusian meteorological model by using a data assimilation technique. In this presentation, we are going to talk about the current status and the future prospect of this conceptual study.

Keywords: Venus, Cross-link radio occultation measurements, Small satellites

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Determination of the homopause altitude on Venus from SOIR/VEx observations

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1. Royal Belgian Institute for Space Aeronomy, Brussels, Belgium, 2. The University of Texas at Austin, Austin, Texas, 3. Tohoku University, Sendai, Japan, 4. University of Arizona, Tucson, Arizona, 5. Université de Liège, Liège, Belgium

SOIR was an infrared echelle spectrometer on board the ESA Venus Express mission (2006-2014) (Nevejans et al., 2006). It performed solar occultations of the Venus mesosphere and thermosphere in the 2.2 to 4.4 μm range (Mahieux et al., 2008). It studied both sides of the terminator and the database covers all latitudes. Its very high spectral resolution (~0.2 cm^{-1}) and spectral sampling (~0.04 cm^{-1}) resolved the ro-vibrational lines of the atmospheric gases. Vertical profiles were retrieved from the spectra. SOIR was sensitive to the main species absorbing in the upper atmosphere (Vandaele et al., 2016): CO_2 (Mahieux et al., 2012), CO (Vandaele et al., 2015), H_2O (Chamberlain et al., 2020), HCl, HF (Mahieux et al., 2015c), SO_2 (Mahieux et al., 2015b), and the aerosols (Wilquet et al., 2012). Considering the CO_2 vertical profiles calculated from the SOIR measured spectra and the hydrostatic equilibrium, we could calculate the kinetic temperature profiles (Mahieux et al., 2015a).

The homopause is an altitude region separating the homosphere and the heterosphere. In the homosphere, eddy diffusion exceeds molecular diffusion, such that all the gases are all well mixed. Their vertical distribution all have the same scale height. In the heterosphere, the opposite occurs, and gases are not well mixed anymore. Consequently, each species follows its own scale height, function of the species' molecular weight.

In this work, we present computations of the mean homopause altitude at the terminator based on the CO and CO_2 simultaneously measured number density profiles, and the corresponding temperature profiles. We found out that it is located at a pressure level of 10^{-4} mbar (~120 km). The results are compared to a 1D vertical diffusion code, which accounts for eddy and molecular diffusions.

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Keywords: Venus, Mesosphere, Homopause

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Long term monitoring of planetary scale temperature variations at the cloud top level of Venus by Akatsuki/LIR observations

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1. National Institute of Advanced Industrial Science and Technology, 2. Hokkaido University, 3. University of Tokyo, 4. Rikkyo University

Since Mariner 10 observation in 1970s, planetary-scale (wavenumber 1) transient waves have been frequently observed at the cloud top level of Venus in both UV albedo and wind speed variations. The typical periods of the wave propagation around Venus are 4-days, which is faster than the super-rotation of Venus at the cloud top, and 5-days, which is slower. Due to the characteristics of their faster or slower propagation speed than the super-rotation, these waves have been considered as Kelvin and Rossby waves. It has been known that the appearances of the Kelvin and Rossby waves are not permanent, and recently it was confirmed that one cycle of increasing and decreasing of a wave amplitude was ~100 days derived from the ultraviolet imager (UVI) onboard Akatsuki (Imai et al., 2019). From these observational evidences, the wave activities are different at different periods, and such variation of wave activity potentially affects the temporal variation of the super-rotation at the cloud level, because these waves can transport atmospheric momentum vertically through their propagation. Therefore, it is worth to confirm typical time scales of the wave life-cycles from observations for assessing temporal variation of atmospheric momentum transportation in Venusian atmosphere.

In this study, we used images obtained by the longwave infrared camera (LIR) onboard Akatsuki from September 2016 to December 2019. The LIR can observe both dayside and night side regions of Venus equally, because the LIR captures thermal emission from the cloud top level of Venus (~70 km). LIR dataset has less observation gaps that is suite for monitoring temporal variations of waves. To extract wave signatures, we performed a periodical analysis with Lomb-Scargle periodgram and used a sliding window method proposed in Imai et al. (2019) in which we set a 40-day window for each analysis. From the result, both 4-day and 5-day wave signatures were confirmed, and their life-times were basically 100 - 200 days. In addition, by averaging the temperature field from the LIR data with a consideration of the 4-day propagation, a horizontal structure of Kelvin-wave like temperature perturbation was also confirmed.

Keywords: Venus, Akatsuki, LIR, Planetary scale waves

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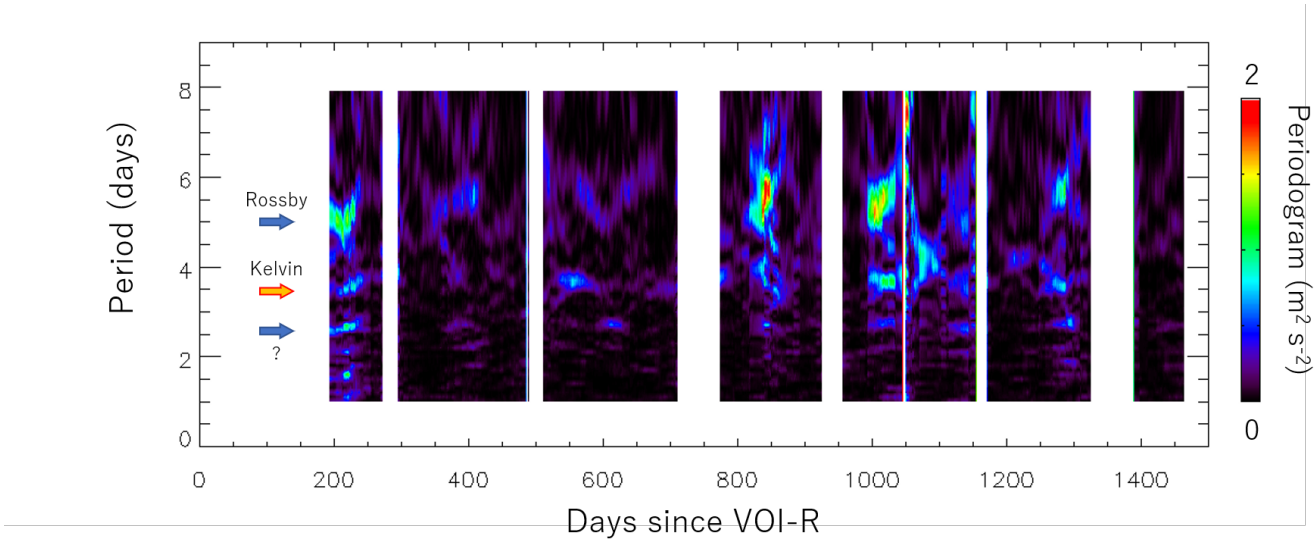

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Dayside cloud top structure of Venus retrieved from Akatsuki IR2 observations

*Takao M. Sato[1], Takehiko Satoh[2], Hideo Sagawa[3], Naohiro Manago[4], Yeon Joo Lee[5], Shin-ya Murakami[2], Kazunori Ogohara[6], George HASHIMOTO[7], Yasumasa Kasaba[8], Atsushi Yamazaki[2], Manabu Yamada[9], Shigeto Watanabe[1], Takeshi Imamura[10], Masato Nakamura[2]

1. Hokkaido Information University, 2. ISAS/JAXA, 3. Kyoto Sangyo University, 4. Chiba University, 5. Technische Universität Berlin, 6. The University of Shiga Prefecture, 7. Okayama Unviersity, 8. Tohoku University, 9. Chiba Institute of Technology, 10. The University of Tokyo

We describe the dayside cloud top structure of Venus as retrieved from 93 images acquired at a wide variety of solar phase angles (0–120 deg) using the 2.02-μm channel of the 2-μm camera (IR2) onboard the Venus orbiter, Akatsuki, from April 4 to May 25, 2016. Since the 2.02-μm channel is located in a CO_2 absorption band, the sunlight reflected from Venus allowed us to determine the cloud top altitude corresponding to a unit aerosol optical depth at 2.02 μm. First, the observed solar phase angle dependence and the center-to-limb variation of the reflected sunlight in the region equatorward of 30 deg were used to construct a spatially averaged cloud top structure characterized by cloud top altitude , Mode 2 modal radius , and cloud scale height , which were 70.4 km, 1.06 μm, and 5.3 km, respectively. Second, cloud top altitudes at individual locations were retrieved on a pixel-by-pixel basis with an assumption that and were uniform for the entire planet. The latitudinal structure of the cloud top altitude was symmetric with respect to the equator. The average cloud top altitude was 70.5 km in the equatorial region and showed a gradual decrease of ~2 km by the 45 deg latitude. It rapidly dropped at latitudes of 50–60 deg and reached 61 km in latitudes of 70–75 deg. The average cloud top altitude in the region equatorward of 30 deg showed negligible local time dependence, with changes up to 1 km at most. Local variations in cloud top altitude, including stationary gravity wave features, occurred within several hundreds of meters. Although long zonal or tilted streaky features poleward of ~45 deg were clearly identifiable, features in the low and middle latitudes were usually subtle. These did not necessarily appear as local variations at the cloud top level, where mottled and patchy UV patterns were observed, suggestive of convection and turbulence at the cloud top level.

Keywords: Venus, atmosphere, cloud structure, infrared observations, radiative transfer, Akatsuki

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Variability of UV albedo and its relation to the wind field revealed by Akatsuki UVI

*Tatsuro Iwanaka[1], Takeshi Imamura[1], Yeon Joo Lee[2], Takeshi Horinouchi[3]

1. The Univesity of Tokyo, 2. Technical University of Berlin, 3. Hokkaido University

Venus is entirely covered by optically thick clouds that play essential roles in the Venus' climate system. The cloud consists of H_2SO_4 aerosols, and H_2SO_4 is produced from SO_2 photochemically. SO_2 is abundant in the lower part of the cloud layer and in the subcloud region (Bertaux, 1996), and is thought to be transported to the cloud top in the sulfur cycle (Mills et al., 2007), although the dynamical processes responsible for the transport are not well understood. The purpose of our study is to confirm that SO_2 is supplied from the lower atmosphere to the cloud top where it is lost via photochemical reactions and to analyze how the stationary planetary-scale circulation and time-varying disturbances contribute to the SO_2 transport. The horizontal divergence calculated from the cloud-tracked wind (Ikegawa & Horinouchi, 2016, Horinouchi et al., 2017 and Horinouchi et al., 2018) is considered as an index of vertical flow. The 283-nm radiance, which is subject to SO_2 absorption, measured by Akatsuki UVI (Yamazaki et al., 2018) was converted to UV albedo following the method of Lee et al. (2015) and Lee et al. (2017), and the albedo is considered to be anti-correlated with the amount of SO_2. By comparing the Lagrangian derivative of UV albedo with the horizontal divergence, the relation between the changes of cloud-top SO_2 and the vertical flow was obtained for independent air parcels and the mean field. The results suggest that the supply of SO_2 by the solar-fixed mean flow is attributed to thermal tides and that the amount of SO_2 also responses to transient, localized ascending flows.

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[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS06] Science of Venus: Venus Express, Akatsuki, and beyond

convener:Takehiko Satoh(Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency), Kevin McGouldrick(University of Colorado Boulder), Hideo Sagawa(Kyoto Sangyo University), Thomas Widemann(Observatoire De Paris)

In this century, our knowledge about the earth's twin sister, Venus, has greatly been advanced through two latest missions, ESA's Venus Express and JAXA's Akatsuki. The latter, in Venus orbit since December 2015, is providing high-quality data that allow studies of atmospheric dynamics in particular. Successful missions are the trigger of ideas of new missions (Russian Venera-D and Indian Shukrayaan-1 under development, European EnVision, and some US proposals). This session invites papers of the new results from data (spacecraft and ground-based), latest results of theoretical and numerical works, and descriptions of new missions as well.

[PPS06-13] Topographic waves in the Venus atmosphere

*Anna Suzuki[1], Masahiro Takagi[1], Yasumitsu Maejima[2], Hiroki Ando[1], Norihiko Sugimoto[3], Yoshihisa Matsuda[4] (1.Kyoto Sangyo University, 2.RIKEN Center for Computational Science, 3.Keio University, 4.Tokyo Gakugei University)

[PPS06-14] Akatsuki IR2 camera data restoration towards revealing Venus's middle cloud properties

★Invited Papers

*Choon Wei Vun[1], Takehiko Satoh[2,1], Takao M. Sato[3], Takeshi Horinouchi[4] (1.SOKENDAI, 2.ISAS/JAXA, 3.Hokkaido Information University, 4.Hokakido University)

[PPS06-15] Variations of Venus night clouds as observed by Akatsuki/IR2

*Takehiko Satoh[1,2], Choon Wei Vun[2], Takeshi Horinouchi[3], Takao M. Sato[4] (1.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 2.Department of Space and Astronautical Science, The Graduate University for Advanced Studies, SOKENDAI, 3.Faculty of Environmental Earth Science, Hokkaido University, 4.Space Information Center, Hokkaido Information University)

[PPS06-16] Effect of Insoluble Sulfur on the Microphysics of the Sulfuric Acid Clouds of Venus

*Kevin McGouldrick[1] (1.University of Colorado Boulder)

[PPS06-17] Status of lightning search in Venus

*Yukihiro Takahashi[1,2], Masataka Imai[3], Mitsuteru Sato[1,2], Ralph Lorenz[4], Tatsuharu Ono[1] (1.Department of Cosmosciences, Graduate School of Science, Hokkaido University, 2.Faculty of Science, Hokkaido University, 3.AIST, 4.Applied Physics Laboratory, Johns Hopkins University)

[PPS06-18] Searching minor species on Venus atmosphere using the high-dispersion spectra taken by IRTF/iSHELL

*Hideo Sagawa[1], Takao M. Sato[2], Hajime Kita[3] (1.Faculty of Science, Kyoto Sangyo University, 2.Hokkaido Information University, 3.Japan Aerospace Exploration Agency)

Topographic waves in the Venus atmosphere

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Akatsuki observations show that large bow-shaped features extending about 10,000 km across the equator from the north polar region to the south polar region, whose zonal wavelength is estimated to be several thousand km at the cloud top level in the Venus atmosphere (Fukuhara et al., 2017). It has been pointed out that these features are gravity waves generated by the surface topography, because they stayed above Aphrodite terra for four Earth days without being advected by the atmospheric super rotation. The bow-shaped features have been also observed over Atla regio and Beta regio located in the equatorial region. Interestingly, the features have not been observed over Ishtar terra located in the north pole region. It has been also pointed out that the bow-shaped features are often identified in the late afternoon (Kouyama et al., 2017)

Young et al. (1987, 1994) investigated the vertical propagation of the gravity waves in the Venus atmosphere. Their results show that vertical winds observed by the VEGA-2 balloon could be explained by the gravity waves excited by Aphrodite. It should be noted, however, that the waves which have long zonal wavelength as seen in Akatsuki observations could not propagate up to the cloud layer. Recently, Lefevre et al. (2019) showed that the bow-shaped features could be formed at the cloud top level by the topographic waves by using a three-dimensional numerical model. Yamada et al. (2019) also showed that the gravity waves could reach the cloud top level and form the bow-shaped feature though the waves were excited thermally in their model. Though the topographic waves strongly depend on the zonal wind and the static stability of the atmosphere through which they propagate, the Venus deep atmosphere remains unclear because of the thick cloud covering the whole planet. Therefore, we investigated how the topographic waves depends on the zonal wind and the static stability in the lower atmosphere by using a regional nonhydrostatic model named Cloud Resolving Storm Simulator (CReSS). We modified CReSS for the Venus atmosphere, in which the radiative transfer process is simplified by Newtonian cooling and the solar heating is neglected. The vertical profiles of the zonal wind and the static stability are based on the previous observations. Numerical experiments are carried out by changing these profiles to take into account of their temporal variations and/or uncertainties. The range of zonal wind near the surface is between 1–5 m/s, and that of the static stability between neutral and weak stable stratification, based on Young et al. (1987). The preliminary results show that the vertical winds excited by Aphrodite have zonal and vertical wavelengths of 200-1200 km and 80-160 km, respectively. Though the horizontal wavelength is roughly consistent with the results of Lefevre et al., (2019), it seems that the vertical wavelength is not consistent. The horizonal resolution of 40 km may not be enough for the topographic waves excited by Aphrodite. It may be also interesting that the temperature deviations associated with the topographic waves have zonal and vertical wavelengths of about 1200 km and 20 km, respectively, which are different from those of the vertical winds. We will investigate how the topographic waves depends on the zonal wind and the static stability near the surface.

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Akatsuki IR2 camera data restoration towards revealing Venus’s middle cloud properties

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Akatsuki IR2 camera utilises 3 filters (1.735, 2.26, 2.32 um) to observe the Venus nightside that probes down to the lower cloud layer (~48-55 km). The IR2 camera nightside observation has been known to suffer contamination from the intense dayside light spread by the camera’s Point Spread Function (PSF). Two restoration processes were developed: Restoration by Subtraction (RS) and Restoration by Deconvolution (RD). This presentation focuses on the RD method where RS method has helped in further calibrating RD procedures. Two main improvements made in the latest RD are: PSF model to include ‘hole’ in the axisymmetry term resembling perfect internal reflection in the PtSi detector substrate , and optical fogging factor caused by fraction of reflection bouncing back by glass surfaces in the camera. During the process of restoration, we uncover the properties of the cloud layer using Radiative Transfer calculations: CO abundances, variability in cloud number density, and aerosol size distributions. In result, we can observe interesting features such as an enormous cloud few thousands km across propagating faster than the background super-rotation on Venus (2016-08-18 data), where this cloud mass has ~20% attenuation compared to the background cloud. To sum, RD method aims at improving the data quality of nightside observations to enable accurate photometric studies for the first time.

Keywords: Venus, Akatsuki, cloud

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Variations of Venus night clouds as observed by Akatsuki/IR2

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The near-IR Venus night-side data were analyzed to study the spatio-temporal variations of clouds. The data were acquired by Akatsuki/IR2 during the Orbits 24 (Aug. 16-20, 2016) and 25 (Aug. 26-30, 2016) at 3 wavelengths (1.735, 2.26, and 2.32 um). From a 2.26-um image, contamination from the day-side is cancelled by subtracting the near-simultaneous 2.32-um image (scaled by an appropriate factor, ~1.10). Then, this "cleaned night (**CLN**)" is subtracted from the original 2.26-um image, leaving only "net contamination (**NTC**)" from the day-side. To restore a 1.735-um image to 1.735**CLN**, the 2.26**NTC** is scaled by another factor (~2.7), and subtracted from the 1.735-um image.

The radiance of night-side emission in 2.26**CLN** and 1.735**CLN** can be converted to a scaling factor to describe the total aerosol content in the clouds. We use the cloud model (vertical profiles and mixing ratios of multi-modal particles) from Haus et al. (2015) and use this "cloud multiplication" factor, MF_{cloud}, to increase or decrease the opacity. The differences of two **MFC** maps actually indicate deviations of aerosol composition from that in the model. We have found interesting features in the (2.26**MFC** –1.735 **MFC**) maps: one example is the mid-latitude bright streaks in Orbit 25. The southern streak is less opaque in 2.26 um than in 1.735 um, indicative of concentration of smaller aerosol particles. This is consistent with the numerical simulation by Kashimura et al. (2019) which attributed these streaks as narrow and strong downwelling regions.

Keywords: Venus cloud, Akatsuki IR2, aerosol composition

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Effect of Insoluble Sulfur on the Microphysics of the Sulfuric Acid Clouds of Venus

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Sulfur allotropes have been suggested (Toon et al. 1982) as a possible identity of the unknown short wavelength absorber that is evident in the region of the upper clouds of Venus. That work had examined the effects on the reflected spectrum of Venus from an absorbing core of sulfur allotropes within sulfuric acid cloud droplets. However, Young (1983) pointed out that elemental sulfur is not miscible in sulfuric acid, thus negating that hypothesis. Nevertheless, the chemical arguments made by Toon et al. (1982) for the existence of sulfur allotropes in the upper clouds of Venus remain valid; these particles are likely to interact with the sulfuric acid droplets also known to be present; and amorphous sulfur allotropes still absorb at wavelengths consistent with that exhibited by this unknown absorber. Young (1983) postulated a "gumdrop" scenario in which sulfur allotropes would accumulate on the surfaces of sulfuric acid droplets, like sugar grains on a gelatinous gumdrop. Such a coating will have implications for the ability of Venus cloud droplets to grow via coalescence proesses, possibly resulting in a difference between the size distribution of droplets that have enocuntered amorphous sulfur particles, and those that have not. Here we investigate with a microphysical model the changes in size distribution that would result from such an inhibition of coalescence efficiency due to a coating of droplets with sulfur; and predict whether the modelled differences would be detectable in measurements of reflected sunlight made by the UVI instrument on Akatsuki.

Refs: Toon et al., 1982, Icarus, 51:358; Young, 1983, Icarus, 56:568.

Keywords: Venus, sulfuric acid, cloud, microphysics, atmosphere

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Status of lightning search in Venus

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The existence of lightning discharge in Venus has been controversial well over three decades, which might be attributed to the luck of conclusive observational evidence. There had been no satellite payload intentionally designed for the detection of lightning phenomena using radio wave or optical sensor. LAC, lightning and airglow camera, on board Akatsuki spacecraft, is the first sensor optimized for the lightning optical flash measurement in planets other than the Earth. Unique performance of LAC compared to other equipment used in the previous exploration of Venus is the high-speed sampling rate at 20 kHz with 32 pixels of Avalanche Photo Diode (APD) matrix, enabling us to distinguish the natural optical lightning flash from other pulsing noises, including artificial electrical noise and cosmic rays. We selected OI 777 nm line for lightning detection, which is expected to be the most prominent emission in CO2-dominant atmosphere based on the laboratory experiments.

We are conducting lightning search in about 40 passes of AKATSUKI with triggering parameter set optimized for the light curve similar to the normal lightning and also sprite type in the Earth. However, we couldn’ t find any lightning signals up to now. The total coverage of the LAC lightning hunt became 96.9 [million km2-hr], meaning 86 percent detectability of previous results with ground-based telescope by Hansell et al. (1995). Here we report the detailed strategy and the latest status of the LAC observation in 2020, and discuss the future observation strategy including ground observation with a high-speed photometer installed at Pirka telescope, a 1.6-m reflector deployed by Hokkaido University.

Keywords: Venus, lightning, Akastuki

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Searching minor species on Venus atmosphere using the high-dispersion spectra taken by IRTF/iSHELL

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Venus atmospheric chemistry can be divided into the following categories: photo-chemistry in the upper atmosphere (including the lightning-induced chemistry, if exists), cloud-related chemistry with heterogeneous reactions on the cloud droplets' surface, and thermal-equilibrium chemistry in the hot lower atmosphere. Precise measurements of the atmospheric composition give the fundamental information to understand these atmospheric chemistries. In addition, some of the minor species in Venus' lower atmosphere are considered to play a significant role as the greenhouse gas. Quantitative understanding of the minor species' distribution becomes important also from such a point of view.

The best remote-sensing approach to search for weak signals emitted/absorbed by the minor species is the high-dispersion spectroscopy at the infrared wavelengths. By using at the near-infrared wavelength, the stellar and solar occultation spectrometer SPICAV/SOIR onboard Venus Express has comprehensively obtained vertical profiles of the minor species in Venus' upper atmosphere (> ~70 km) such as H_2O, HDO, CO, SO_2, HCl, HF, and aerosols. The measurements were mostly limited around the morning and evening local times on Venus. Therefore, one of the still remained problem after the SPICAV/SOIR measurements is to understand any local time variability of these species which should be present if they are sensitive to photochemistry. And, any long-scale temporal variation of the minor species' abundance is also the subject to be studied continuously after the finish of the Venus Express mission in 2014. Motivated by these points, we carried out the high-dispersion spectroscopy (spectral resolving power ~ 75,000) of Venus' dayside hemisphere using a newly developed immersion grating Echelle spectrograph, iSHELL, attached to the IRTF 3-m telescope. The data were taken on August 6 –8, 2018 when Venus apparent diameter was 21.7 arcsec. We used three wavelength bands: L3 (3.20 –3.48 um), Lp2 (3.57 –3.95 um) and Lp3 (3.83 –4.18 um) in order to cover the absorption lines of several interested species like H_2O, HDO, HCl, CO_2, etc. The cross-disperser enabled us to measure the entire wavelength range with different dispersion orders within each of these wavelength bands. The derivation of the abundance of the observed species will be discussed in the presentation.

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[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS07] Solar System Small Bodies: Explorations of Ryugu, Bennu, and the Solar System at Large

convener:Taishi Nakamoto(Tokyo Institute of Technology), Tatsuaki Okada(Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency), Dante S Lauretta(University of Arizona), Masateru Ishiguro(Department of Physics and Astronomy, Seoul National University)

Small Solar System bodies, including asteroids, comets, satellites, and inter-planetary dust particles, are interesting and provide lots of information on the origin and evolution of our Solar System. They can be remotely sensed by telescopes, be visited by spacecraft and studied at high resolution in a variety of wavelengths from IR to visible, UV, X-rays, and gamma rays, and even with neutrons. In addition, recently spacecrafts have been sent to return samples. In this session, all the contributions on the small solar system bodies are welcome. But this year, we especially welcome contributions on recent advances on the study of Ryugu and Bennu whether obtained by rendezvous spacecraft, remote sensing, or other methods.

[PPS07-01] Technological challenges and achievements in Hayabusa2 mission

*Makoto Yoshikawa[1], Yuichi Tsuda[1], Satoru Nakazawa[1], Fuyuto Terui[1], Takanao Saiki[1] (1.Japan Aerospace Exploration Agency)

[PPS07-02] Surface evolution of carbonaceous asteroid Ryugu revealed from touchdown operation of Hayabusa2

★Invited Papers

*Tomokatsu Morota[1], Seiji Sugita[1], Yuichiro Cho[1], Masanori Kanamaru[2], ERI TATSUMI[3], Naoya Sakatani[4], Rie Honda[5], Naoyuki Hirata[6], Hiroshi Kikuchi[4], Manabu Yamada[7], yokota yasuhiro[4], Shingo Kameda[8], Moe Matsuoka[4], Hirotaka Sawada[4], Chikatoshi Honda[9], Toru Kouyama[10], Kazunori Ogawa[4], Hidehiko Suzuki[11], Kazuo Yoshioka[1], Masahiko Hayakawa[4], Naru Hirata[9], Masatoshi Hirabayashi[12], Hideaki Miyamoto[1], Tatsuhiro Michikami[13], Takahiro Hiroi[14], Carolyn M. Ernst[15], Olivier S. Barnouin[15], Sei-ichiro WATANABE[16] (1.The University of Tokyo, 2.Osaka University, 3.Universidad de La Laguna, 4.JAXA, 5.Kochi University, 6.Kobe University, 7.Chiba Institute of Technology, 8.Rikkyo University, 9.The University of Aizu, 10.AIST, 11.Meiji University, 12.Auburn University, 13.Kindai University, 14.Brown University, 15.APL/JHU, 16.Nagoya University)

[PPS07-03] Thermal evolution of Ryugu inffered from spectral characterization of experimentally-heated CI carbonaceous chondrite

*Kana Amano[1], Tomoki Nakamura[1], Fumihiko Usui[2], Satoshi Okumura[1], Michael E. Zolensky[3] (1.Tohoku University, 2.Kobe University, 3.NASA Johnson Space Center)

[PPS07-04] Morphological and spectral trends among boulders on asteroid 162173 Ryugu: implication for parent body processes

*Koki Yumoto[1], Yuichiro Cho[1], Tomokatsu Morota[1], Eri Tatsumi[1,10], Yokota Yasuhiro[2,3], Naoya Sakatani[2], Kazuo Yoshioka[1], Hirotaka Sawada[2], Rie Honda[3], Shingo Kameda[4], Manabu Yamada[5], Chikatoshi Honda[6], Toru Kouyama[7], Moe Matsuoka[2], Hidehiko Suzuki[8], Kazunori Ogawa[9,11], Masahiko Hayakawa[2], Hideaki Miyamoto[1], Chiho Sugimoto[1], Seiji Sugita[1] (1.Univ. of Tokyo, 2.JAXA, 3.Kochi Univ., 4.Rikkyo Univ., 5.PERC, Chiba Institute of Technology, 6.Univ. of Aizu, 7.AIST, 8.Meiji Univ., 9.JSEC, JAXA, 10.Instituto de Astrofisica de Canarias, 11.Kobe Univ.)

[PPS07-05] Time-dependent spectroscopic and mineralogical changes by heating of Murray CM chondrite

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Technological challenges and achievements in Hayabusa2 mission

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Hayabusa2 is a Japanese second asteroid sample return mission following Hayabusa. The principal purpose of Hayabua2 is science, especially to study organic maters and water at the time of the birth of the solar system, and to study the birth and the evolution of the solar system. In order to do these studies, the technology or engineering is very important. In this talk, we will summarize the technological challenges and achievements in Hayabusa2 mission.

The Hayabusa2 spacecraft was launched on 3 December 2014 and arrived at its target asteroid Ryugu on 27 June 2018. It stayed there until November 2019 for in situ observation and sample collection. Now Hayabusa2 is on the way back to the earth and will return to the earth in November or December 2020. During the stay around Ryugu, the spacecraft performed many descent operations, such as, deploying rovers and a lander, dropping SCI(Small Carry on Impactor) to create an artificial crater, and two touchdowns. The first touchdown operation was performed successfully on 22 February 2019, and the second touchdown was carried out near the artificial crater on 11 July 2019. By these two touchdowns we think we were able to get both the surface materials and the subsurface materials.

Hayabusa2 achieved the world's first seven engineering accomplishments during its stay around Ryugu. They are as follows:
(1) Hayabusa2 deployed small exploration robots on the surface of the asteroid that moved autonomously and corrected information of the asteroid
(2) Hayabusa2 deployed multiple (three) exploration robots on the surface of the asteroid.
(3) Hayabusa2 touched down to the specified point on the surface of the asteroid with accuracy of 60cm.
(4) Hayabusa2 created an artificial crater by releasing SCI(Small Carry on Impactor) and obtained images representing the process of crater creation
(5) Hayabusa2 touched down two different places on the same asteroid Ryugu
(6) Hayabusa2 sampled subsurface material during the process of 2nd touchdown to the proximity of the created crater
(7) Hayabusa2 released multiple objects which could be artificial satellite of the asteroid

In addition to these world's first accomplishments, we have done a lot of technological challenges and achievements. In this talk, we will summarize the technological challenges and achievements, which are very important to obtain scientific data.

Keywords: Asteroid, Sample return, Hayabusa2

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Surface evolution of carbonaceous asteroid Ryugu revealed from touchdown operation of Hayabusa2

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The Hayabusa2 spacecraft touched down on the carbonaceous near-Earth asteroid 162173 Ryugu for the first time on 21 February 2019. In the process of the touchdown operation, Hayabusa2 the optical navigation camera (ONC) had taken extremely high-resolution images of Ryugu’s surface and observed its response to the physical disturbances by the sampling projectile collision and thruster gas jets. Based on the touchdown and global observations, we report the nature of the stratigraphy of the surface materials as expressed in the color observations on Ryugu.
The ONC data show that Ryugu’s surface has almost homogeneous reflectance and color at the macro scale, but there is the regional variation in the spectral slope (b-x slope). The bluer materials are distributed at the equatorial ridge and in the polar regions, while the redder materials are widely spread over the mid-latitude regions (Sugita et al. 2019). The latitudinal variation of spectral slope suggests that exposure of Ryugu’s materials to space has led to their reddening by solar heating and/or space weathering. The ONC images obtained during the touchdown showed that a large amount of debris was produced by the impact of the projectile shot from the sampler system and the reaction control system (RCS) thrust immediately after the touchdown, and the entire field-of-view of ONC-W1 was darkened uniformly. Color changes of boulders observed during the touchdown suggest that the dark fine grains originate from the redder materials that covered the boulder surface. The stratigraphic relationship between the identified craters and the redder materials suggests that surface reddening occurred over a short period of time. These results suggest that Ryugu underwent an orbital excursion near the Sun.

Keywords: Hayabusa2, Ryugu, touchdown

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Thermal evolution of Ryugu inffered from spectral characterization of experimentally-heated CI carbonaceous chondrite

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Spectral features of C-asteroid Ryugu, the target of the Hayabusa2 mission, are expected to be similar to experimentally-heated carbonaceous chondrites, however no published spectral data of carbonaceous chondrites completely match with that of Ryugu (Kitazato et al. 2019). There are two problems: (1) no meteorite samples show reflectance at visible wavelengths darker than Ryugu, (2) most of the reported spectra of experimentally-heated carbonaceous chondrite samples cannot be compared with asteroidal spectra, because they are severely affected by adsorbed and rehydrated water. Carbonaceous chondrites exhibit a significant absorption feature at around 2.7 μm owing to the presence of hydrated minerals, however, heated samples can easily be contaminated by atmospheric water, which causes an absorption feature at around 2.9 μm.

The present study shows the results of heating experiments of the Orgueil CI carbonaceous chondrite which has experienced extensive aqueous alteration. Orgueil contains Mg-rich phyllosilicates, which suggests that the parent body of Orgueil might have formed at the farther place from the Sun than other carbonaceous chondrites. We analyzed mineral compositions, water contents, and reflectance spectra of the heated samples to evaluate the systematic changes during heating. Reflectance spectra and water contents of the heated samples were measured without exposure to the air to minimize the effects of adsorbed and rehydrated water. An unheated powdered sample of Orgueil was prepared by preheating at <150 ˚C with the purpose of removal of adsorbed water. Powdered Orgueil samples were then heated at 400, 500, 600, 700, and 900 ˚C under vacuum conditions, to demonstrate asteroidal heating processes.

S-XRD analysis provides precise mineralogical characterization of the fine-grained matrix of the samples. The results indicate that the unheated sample contains saponite, serpentine, and magnetite. The decomposition of serpentine occurs in the 500-˚C heated sample, and saponite and secondary olivine coexist in the 600-˚C sample. The 700-˚C heated sample shows reflections from olivine and Fe-Ni metals, and they become well crystalline in the 900-˚C heated sample.

The total water contents of the samples measured by the Karl Fischer titration are recorded as 7.7, 7.1, 3.9, 1.9, 0.9, and 0.5 wt.% for unheated, 400, 500, 600, 700, and 900 ˚C, respectively. Water contents decrease by heating and retained water in the samples corresponds to the amounts and types of remnant hydrated minerals.

The spectroscopic results showed that (1) moderately-heated samples (400, 500, and 600 ˚C) have darker reflectance in the visible region than unheated samples and the reflectance increases in the samples heated at high temperatures (700 and 900 ˚C), (2) the depth of the 2.7-μm absorption band decreases with increasing heating temperature and it disappears at the temperature at which hydrated minerals in the samples completely dehydrate, (3) the peak position of the 2.7-μm band of the heated Orgueil samples is nearly constant, while that of the heated Murchison samples shifts towards shorter wavelengths with increasing heating temperature according to the decrease of the Fe/Mg ratio of the remnants of hydrated minerals in the heated samples (Mogi et al. 2017, METSOC), and (4) the depth of the 2.7-μm band and the water content of the heated Orgueil and other carbonaceous chondrites form a

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positive correlation trend.

In this work, the Orgueil sample heated at 500 ˚C provides the best spectral match to Ryugu: it shows very low reflectance (~2%) at visible wavelengths and small absorption feature (~10%) around 2.72 μm. We suggest that Ryugu might have experienced heating and dehydration at a temperature around 500 ˚C, after aqueous alteration, and presently contains a small quantity of hydrated minerals equivalent to 1-2 wt.% of water at the surface.

Keywords: Asteroids, Carbonaceous chondrites, Ryugu, Reflectance spectroscopy, Hydrated minerals

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Morphological and spectral trends among boulders on asteroid 162173 Ryugu: implication for parent body processes

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The Optical Navigation Camera onboard the Hayabusa2 spacecraft revealed the abundance of m-scale boulders on a Cb-type asteroid Ryugu [1,2]. The boulder distribution, morphology, and spectrum should be related to the parent body processes and/or the evolutionary processes as a rubble-pile. Especially, the parent body processes on C-type asteroids are important in understanding the hydrothermal activity in primordial planets and the possible source of terrestrial water/organics. Initial reports have suggested a possible trend in boulder spectra and morphologies [1]. Such variety in boulders should partially be a manifestation of the parent body processes. However, the identification of the process responsible for creating the observed variation is not very straightforward. Our purpose is to determine such parent body processes by conducting a detailed investigation of the trend among boulders. In particular, analysis done by [1] cannot distinguish whether the trends reflect the presence of multiple clusters or one broad continuous cluster. Thus, to distinguish these two possibilities, statistical and quantitative analysis based on a thorough boulder counting is performed. Also, boulder spectra are affected by superficial processes, such as space weathering, solar heating, and grain size sorting [3]. The high-resolution images acquired after the initial reports are used to assess such effects. Also, we report new trends in boulder spectra and intra-boulder spectral variation revealed from high-resolution images.

Approximately 100 largest boulders within the range of 40˚N to 40˚S and 260˚E to 340˚E taken at ~0.2 m/pix were used for our analysis. The rims of boulders were marked manually, and spectra were measured within the outlines. Though the resolution of the shape model used for the photometrical correction was ~10-20 times lower than the image resolution, the error in the normalized spectra was confirmed to be small: the error in b-x slope is <~30% the global variation.

Our result show that the red-to-blue trend among boulders follows the spectral transition by heating experiments of CM chondrites with temperatures between 800 and 900 ˚C [4]. The same trend was seen with different observed phase angles, and thus is unlikely to be a manifestation of the phase reddening effect. The possible presence of multiple clusters in the spectral trend was investigated by conducting the k-means classification. The root-mean-square residual of the classification decreased with increasing number of classes, indicating no clear existence of large spectral clusters. This result is consistent with the existence of boulders which underwent different degrees of thermal metamorphism in the parent body. However, a small spectral class consistent with Type 3 boulders [1] exist, which particularly deviates from the thermal metamorphism trend. Also, the brighter half of the boulder population show a smaller size distribution. Thus, the darker boulders exhibit a volumetric preponderance over brighter boulders, which may also inherit the heterogeneity in the parent body.

We found that the power-law exponent of the 2D Fourier amplitude as a function of the spatial frequency could be an index for surface texture of boulders. The unimodal distribution of the exponent also shows

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no clear presence of morphological clusters. Thus, the rugged morphologies are consistent with a genomict-type breccia, which indicates a well-mixed nature of the material at the timing of brecciation (e.g. impact melting, cementation under aqueous environments).

High resolution imaging of the boulders revealed the spectral variation within individual boulders. These variations tend to be associated with different facets. Similar color variation was previously reported for the largest boulder Otohime [1]. By calculating the direction of the bluer facet for each boulder, we found that bluer facets are likely to be directed toward the equator. This is consistent with the preferential vulnerability to space weathering and/or thermal degradation/exfoliation of facets facing a certain direction.

We conclude that majority of boulders on Ryugu exhibit a spectral and morphological trend within a single continuous cluster. The trend may have originated from boulders with different degree of thermal metamorphism together with the genomict-type brecciation processes on the parent body. In addition, observed intra-boulder spectral variation suggests superimposition of space weathering effects.

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Keywords: Hayabusa2, Ryugu, C-type asteroid, boulder, space weathering

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Time-dependent spectroscopic and mineralogical changes by heating of Murray CM chondrite

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Many hydrous carbonaceous chondrites were found to be thermally metamorphosed after aqueous alteration. Spectroscopic observations of C-type asteroid Ryugu suggest that Ryugu is similar to parent bodies of heated hydrous carbonaceous chondrites (e.g. Kitazato et al., 2019). Three possible heat sources are proposed: decay heat of radionuclides, solar radiation, and shock-induced heat and the duration of heating decreases in this order. However, kinetics of thermal alteration of carbonaceous chondrite is poorly understood. In this study, long-duration heating experiments of Murray CM chondrite was performed to evaluate time-dependent changes of reflectance spectra and mineralogy.

A powder ($\phi < 155$ μm) and polished fragments of Murray meteorite (CM2.4–2.5; Rubin, 2007) were heated at 600˚C for the duration of 1, 10, 100, and 500 hours in vacuum at oxygen fugacity of around IW buffer. The heated samples were analyzed by conventional XRD, Synchrotron-XRD, FE-SEM/EDS, micro-Raman spectroscopy, FT-IR, and Karl-Fisher Titration method.

After 1-hour heating, the hydrous minerals (serpentine and tochilinite) were decomposed into amorphous phases and water was completely evaporated from the samples. After 10-hour heating, low crystalline secondary olivine and taenite newly formed. The amounts of these secondary minerals increased with heating duration. The absolute reflectance of the sample at 0.55 μm decreased after 1-hour heating, but continuously increased after 10-hour heating. The D and G bands in the Raman spectra, which reflect structures of amorphous carbon, of several chondrule rims did not change significantly and thus seem to be less sensitive to heating duration at 600˚C. Based on the classification of the heating stage defined by Nakamura (2005), the 1-hour heated sample corresponds to the weakly heated (stage II) chondrites and 10-hour, 100-hour, and 500-hour heated samples correspond to the moderately heated (stage III) chondrites.

We defined and quantified six parameters representing temporal changes of the spectroscopic and mineralogical features such as slope of reflectance spectra in the wavelength range from 0.38 to 0.55 μm, the absolute reflectance at 0.55 μm, the half widths and peak positions of diffractions from secondary olivine and taenite. These parameters will be used to estimate conditions of thermal alteration of naturally-heated carbonaceous chondrites and also returned samples from Ryugu.

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[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS07] Solar System Small Bodies: Explorations of Ryugu, Bennu, and the Solar System at Large

convener:Taishi Nakamoto(Tokyo Institute of Technology), Tatsuaki Okada(Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency), Dante S Lauretta(University of Arizona), Masateru Ishiguro(Department of Physics and Astronomy, Seoul National University)

Small Solar System bodies, including asteroids, comets, satellites, and inter-planetary dust particles, are interesting and provide lots of information on the origin and evolution of our Solar System. They can be remotely sensed by telescopes, be visited by spacecraft and studied at high resolution in a variety of wavelengths from IR to visible, UV, X-rays, and gamma rays, and even with neutrons. In addition, recently spacecrafts have been sent to return samples. In this session, all the contributions on the small solar system bodies are welcome. But this year, we especially welcome contributions on recent advances on the study of Ryugu and Bennu whether obtained by rendezvous spacecraft, remote sensing, or other methods.

[PPS07-06] Artificial impact crater formed by Small Carry-on Impactor on the asteroid 162173 Ryugu in the gravity-dominated regime

★Invited Papers

*Masahiko Arakawa[1], Takanao Saiki[2], Toshihiko Kadono[3], Yasuhiko Takagi[4], Koji Wada[5], Yu-ichi Iijima[2], Hiroshi Imamura[2], Chisato Okamoto[1], Yuri Shimaki[2], Kei Shiai[1], Satoru Nakazawa[2], Masahiko Hayakawa[2], Naru Hirata[6], Hajime Yano[2], Hirotaka Sawada[2], Kazunori Ogawa[2], Rie Honda[7], Ko Ishibashi[5], Naoya Sakatani[2], Tomoaki Toda[2], Hajime Hayakawa[2], Seiji Sugita[8], Tomokatsu Morota[8], Shingo Kameda[9], ERI TATSUMI[13], Chikatoshi Honda[6], yokota yasuhiro[2], Toru Kouyama[10], Manabu Yamada[5], Hidehiko Suzuki[11], Kazuo Yoshioka[8], Yuichiro Cho[8], Moe Matsuoka[2], Patrick Michel[12] (1.Kobe University, 2.Japan Aerospace Exploration Agency, 3.University of Occupational and Environmental Health, 4.Aichi Toho University, 5.Chiba Institute of Technology, 6.University of Aizu, 7.Kochi University, 8.The University of Tokyo, 9.Rikkyo University, 10.National Institute of Advanced Industrial Science and Technology, 11.Meiji University, 12.Observatoire de la Côte d'Azur, 13.Instituto de Astrofisica de Canarias)

[PPS07-07] Assessing the Small carry-on Impactor debris operated by the Hayabusa2 mission: an evaluation by FT-IR, micro-Raman, STXM and NanoSIMS.

*Motoo Ito[1], Yoshinori Takano[2], Takuji Ohigashi[3], Hayato Yuzawa[3], Yoko Kebukawa[4], Kento Kiryu[4], Masayuki Uesugi[5], Naotaka Tomioka[1], Yu Kodama[7], Hiroshi Naraoka[6], Toru Yada[8], Masanao Abe[8] (1.Kochi Institute for Core Sample Research, JAMSTEC, 2.Biogeochemistry Program, JAMSTEC, 3.UVSOR, Institute for Molecular Science, 4.Yokohama National University, 5.JASRI, 6.Kyushu University, 7.Marine Works Japan, 8.JAXA)

[PPS07-08] Subsurface structure inferred from the relation between craters and their surrounding boulders on asteroid Ryugu

*Sei-ichiro WATANABE[1,2], Hiroki Akahane[1], Tomokatsu Morota[3,1], Tatsuhiro Michikami[4], Naru Hirata[5], Naoyuki Hirata[6], Yuri Shimaki[2], Rina Noguchi[2], Rie Honda[7], Shingo Kameda[8], Manabu Yamada[9], Naoya Sakatani[2], Kazunori Ogawa[2], ERI TATSUMI[10], Toru Kouyama[11], yokota yasuhiro[2,7], Yuichiro Cho[3], Hidehiko Suzuki[12], Masahiko Hayakawa[2], Moe Matsuoka[2], Chikatoshi Honda[5], Kazuo Yoshioka[3], Hirotaka Sawada[2], Seiji Sugita[3], Masahiko Arakawa[6], Hayabusa2 Science Team[13] (1.Nagoya University, 2.JAXA, 3.University of Tokyo, 4.Kindai University, 5.University of Aizu, 6.Kobe University, 7.Kochi University, 8.Rikyo University, 9.Chiba Institute of Technology, 10.University of La Laguna, 11.National Institute of Advanced Industrial Science and Technology, 12.Meiji University, 13.Hayabusa2 Project)

[PPS07-09] Highly Porous Asteroid 162173 Ryugu Derived from Lowest Temperatures in a Day

*Tatsuaki Okada[1,2], Tetsuya Fukuhara[3], Satoshi Tanaka[1], Takehiko Arai[4], Naoya Sakatani[1], Yuri Shimaki[1], Hiroki Senshu[5], Hirohide Demura[6], Kentaro Suko[6], Tomohiko Sekiguchi[7], Toru Kouyama[8], Ayumu Ohsugi[1,2] (1.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency,

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[PPS07-10] Thermophysical Properties of Ryugu Estimated from a Box-A Observation

*Yuri Shimaki[1], Hiroki Senshu[2], Naoya Sakatani[1], Tatsuaki Okada[1,3], Tetsuya Fukuhara[4], Satoshi Tanaka[1,5], Makoto Taguchi[4], Takehiko Arai[6], Hirohide Demura[7], Kentaro Suko[7], Tomohiko Sekiguchi[8], Toru Kouyama[9], Jun Takita[10], Sunao Hasegawa[1] (1.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 2.Chiba Institute of Technology, 3.University of Tokyo, 4.Rikkyo University, 5.The Graduate University for Advanced Studies, SOKENDAI, 6.Ashikaga University, 7.University of Aizu, 8.Hokkaido University of Education, 9.National Institute of Advanced Industrial Science and Technology (AIST), 10.Hokkaido Kitami Hokuto High School)

Artificial impact crater formed by Small Carry-on Impactor on the asteroid 162173 Ryugu in the gravity-dominated regime

*Masahiko Arakawa[1], Takanao Saiki[2], Toshihiko Kadono[3], Yasuhiko Takagi[4], Koji Wada[5], Yu-ichi Iijima[2], Hiroshi Imamura[2], Chisato Okamoto[1], Yuri Shimaki[2], Kei Shiai[1], Satoru Nakazawa[2], Masahiko Hayakawa[2], Naru Hirata[6], Hajime Yano[2], Hirotaka Sawada[2], Kazunori Ogawa[2], Rie Honda[7], Ko Ishibashi[5], Naoya Sakatani[2], Tomoaki Toda[2], Hajime Hayakawa[2], Seiji Sugita[8], Tomokatsu Morota[8], Shingo Kameda[9], ERI TATSUMI[13], Chikatoshi Honda[6], yokota yasuhiro[2], Toru Kouyama[10], Manabu Yamada[5], Hidehiko Suzuki[11], Kazuo Yoshioka[8], Yuichiro Cho[8], Moe Matsuoka[2], Patrick Michel[12]

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The Japanese asteroid explorer Hayabusa2 conducted an impact experiment by using a Small Carry-on Impactor (SCI) on the surface of Ryugu, which constituted the first impact experiment on an asteroid, on April 5th, 2019, and successfully formed an artificial impact crater larger than 10 m in size. The SCI crater has a semicircular shape and an elevated rim around the crater. We found a large boulder named as Iijima-boulder with the size of 5m on the crater floor and it could be moved about 3m northeast during the crater formation. There was another large boulder named as Okamoto-boulder at the south edge of the SCI crater, but we could not detect finite displacement of this boulder after the SCI impact. The Okamoto boulder might have a deep root below the surface and this boulder could stop the ejecta excavation flow toward the south region so that the SCI crater did not grow southward to became a semicircular shape. The size-frequency distribution of the boulders on the SCI crater wall was found to be different from that outside of the SCI crater: the sub-meter sized boulders were deficient on the crater wall. Moreover, a circular depression like a pit was recognized at the center of the SCI crater and it might indicate a cohesive subsurface layer.

The ejecta curtain was observed by a Deployable CAMera3 (DCAM3) from the beginning of the crater formation for more than 10 min. We found that the ejecta curtain continued to grow more than 200 s and the ejecta curtain growth was asymmetric and heterogeneous. We never observed the ejecta curtain growth toward the south, and this feature is consistent with the fact that the crater growth was prohibited by Okamoto-boulder placed at the south region. The observed ejecta curtain growing northward were separated into several rays and this heterogeneity could be due to large boulders covering the surface. The detachment of the ejecta curtain from the ground was never observed during the crater growth and beyond the duration of the crater formation time of 300 s. The ejecta was then confirmed to be deposit on the surface by the gravity of Ryugu.

Our observations of the SCI crater and the ejecta curtain showed that the artificial impact crater was formed in the gravity dominated regime although the surface gravity was as small as 10^{-5}G and the surface was covered with large boulders. Thus, the crater scaling laws in the gravity dominated regime are appropriate for Ryugu and the crater chronology on Ryugu should be revised according to crater size scaling laws that are suitable for the non-cohesive surfaces. This new finding on the suitable scaling laws for a small C-type asteroid could feed collisional evolution models of asteroid populations and their migration within the solar system.

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Keywords: Impact experiment, Asteroid, Impact crater

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Assessing the Small carry-on Impactor debris operated by the Hayabusa2 mission: an evaluation by FT-IR, micro-Raman, STXM and NanoSIMS.

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On-going mission of the JAXA Hayabusa2 (the C-type asteroid Ryugu) is a combination of an asteroidal sample return and detailed spectroscopic observations to understand the Solar System evolution from the point of view of organics, and water as hydrous minerals [1]. The Hayabusa2 spacecraft was thought to be successfully obtained the Ryugu samples (an expected total amount of ~ 100 mg) from surface and subsurface on Feb. and Apr. 2019 and will return to the Earth on Dec. 2020. To obtain the fresh subsurface samples of the Ryugu asteroid, Small Carry-on Impactor (SCI) [2] was used to generate an artificial crater on the surface. A driving force of the SCI was made by HMX (High-Melting Explosive; cyclotetramethylenetetranitramine; $C_4H_8N_8O_8$, 296.15) together with HTPB (Hydroxyl Terminated Polybutadiene), IDP (Isodecyl palargonate; $C_{19}H_{38}O_2$) and IPDI (Isophorone diisocyanate; $C_{12}H_{18}N_2O_2$) [2]. Takano and coworkers [3] reported analytical results of SEM-EDS (Scanning Electron Microscopy / Energy Dispersive X-ray Spectroscopy), TD-GC/MS (thermal desorption-gas chromatography/mass spectrometry), SPME (Solid-phase micro extraction)-GC/MS, and isotope mass spectrometry for N and C isotopes. They found volatiles of aliphatic and aromatic carbon structures, and the several functional groups (hydroxyl, aldehyde, nitrile, and carboxyl) [3].

The explosion products generated by their chemical reactions with HMX, HTPB, IDP and IPDI should be investigated prior to analysis of the Ryugu samples because those materials might be possible contaminants in the subsurface samples in the sample container. It is, therefore, necessary to analyze the SCI fragments and its products using the same analysis techniques. These results will provide relevant information to the initial analysis in advance the arrival of the Ryugu samples to the Earth.

In this study, we will report analytical results of the experimental explosion-products of the HMX mixture under Ar condition utilizing an optical microscope for micrometer-scale texture, SEM-EDS for texture and major elements, microFT-IR for functional groups, micro-Raman for structures of carbonaceous materials, STXM (Scanning Transmission X-ray Microscopy) for sub-micrometer-scale functional groups of carbon, nitrogen and oxygen, and NanoSIMS (nano-scale Secondary Ion Mass Spectroscopy) for hydrogen, carbon and nitrogen isotopes.

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Keywords: Hayabusa2 mission, Small carry-on Impactor

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Subsurface structure inferred from the relation between craters and their surrounding boulders on asteroid Ryugu

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The Hayabusa2 spacecraft reveals the surface geography of C-type asteroid Ryugu [1, 2, 3, 4]. Ryugu is a 1-km across rubble-pile body formed by the reaccumulation of impact fragments from the parent asteroid. It has ~100 impact craters [2, 3] and many boulders across the surface [2, 4]. Focusing on the relation between craters and their surrounding boulders, we found that the number densities of boulders inside and outside larger craters are almost the same, whereas the number density of boulders inside a smaller crater is lower than that outside the crater. The tendency may reflect the subsurface structure of Ryugu. In order to reconstruct the subsurface structure, we quantitatively investigate the number densities of boulders inside and outside craters having different sizes and depths.

Using the high-resolution images taken by an optical camera ONC-T onboard the Hayabusa2 spacecraft, we measured boulders with mean diameters $s > 0.8$ m aroud selected craters and obtained the cumulative size frequency destributions (CSFDs) of these boulders inside and outside each crater. We used ONC-T images of craters taken from an altitude of 2.7, 1.7, or 0.9 km from the surface of Ryugu. We analized total 21 craters; 2 craters newly found in this work and 19 craters from a list compiled in [3]. From the crater list we included all circular depressions (with and without rims) having depths shallower than 5-6 m based on the data in [5] and located within +/-20 deg from the equator. From regression analyses of boulder CSFDs around each crater, we calculated number densities of boulders ($s > 1$ m) inside $N_{b,in}$ and outside $N_{b,out}$ the crater and the ratio $N_{b,in}/N_{b,out}$. To check the result, we analized the boulder CSFD around the region where an artificial crater was excavated by an impactor SCI onboard the Hayabusa2 spacecraft [6] before and after the SCI impact using the same method.

Owing to the regional variation of boulder density, we found no clear dependence of $N_{b,in}$ on the crater depth d. However, we obtained a remarkable dependence of $N_{b,in}/N_{b,out}$ on d (Fig. 1): (A) $N_{b,in}/N_{b,out}$ ~ 0.5 for craters having $d =< 2.2$ m, which is consistent with boulders around the SCI crater ($d = 2$ m), (B) $N_{b,in}/N_{b,out}$ ~ 1 or larger for craters having $d >= 4$ m, (C) in the intermidiate range of crater depth ($2.2 \text{ m} < d < 4$ m) $N_{b,in}/N_{b,out}$ are scattered and $N_{b,in}/N_{b,out}$ ~ 0.5 in the eastern hemisphere (40-230 degE) vs. $N_{b,in}/N_{b,out}$ ~ 1 in the western hemisphere (230-40 degE), though the number of such craters in each hemisphere is only three or four.

From these results, we reconstructed a three-layered subsurface structure of Ryugu, surface and subsurface boulder-rich layers and a boulder-poor layer sandwiched by the two. The depth of the boundary between the boulder-poor layer (the second layer) and the lower boulder-rich layer (the third layer) is estimated to be ~2.2 m in the western side and ~4 m in other regions. Such a layered structure may have been formed by the so-called Brazil-nut effect [7]. The western side having the thinner boulder-poor layer may be relatively young, which is consistent with a stablity analysis under a past rapid rotation of Ryugu [8].

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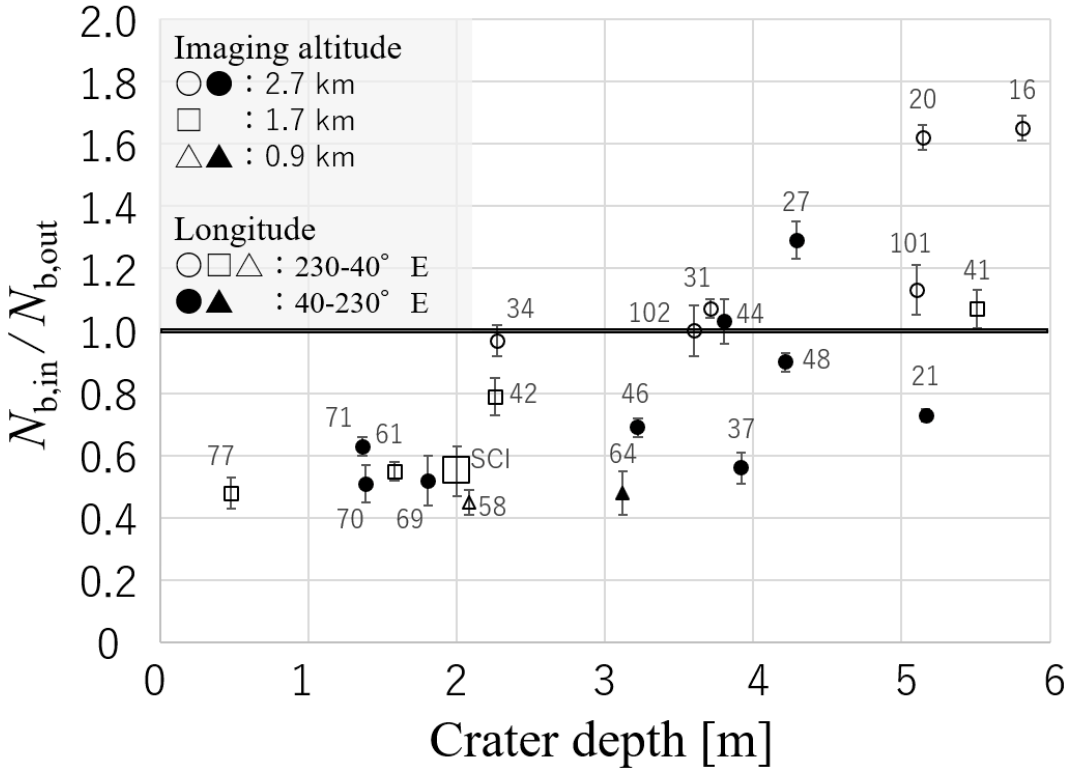
Keywords: Hayabusa2, Solar System small bodies, subsurface structure, Brazil-nut effect



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Highly Porous Asteroid 162173 Ryugu Derived from Lowest Temperatures in a Day

*Tatsuaki Okada[1,2], Tetsuya Fukuhara[3], Satoshi Tanaka[1], Takehiko Arai[4], Naoya Sakatani[1], Yuri Shimaki[1], Hiroki Senshu[5], Hirohide Demura[6], Kentaro Suko[6], Tomohiko Sekiguchi[7], Toru Kouyama[8], Ayumu Ohsugi[1,2]

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Introduction: Thermal inertia is the index of thermophysical properties of materials on earth and planetary bodies, which is derived from the temperature profile in a day-night cycle. Lower thermal inertia indicates a granular or porous materials, while higher thermal inertia suggests a dense, consolidated materials. In the Hayabusa2 mission, global, local, and close-up thermal images have been taken using a thermal infrared imager TIR to investigate the distribution of thermal inertia on the C-type asteroid 162173 Ryugu [1]. As a result comparing with the calculations for a given uniform thermal inertia from 50 to 1000 [J m^{-2} K $^{-1}$ $s^{-0.5}$: hereafter, tiu] on the asteroid shape model, and confirming the temperatures of boulders of various size range from < 1 to 100 m scales, it is concluded that the global thermal inertia of Ryugu is about 300 ±100 tiu, which lower than the typical thermal inertia of carbonaceous chondrites, and that Ryugu is a rubble-pile asteroid composed of highly-porous materials, accreted from impact fragments of a "porous" parent body, and the most part of the parent body was in the low degree of consolidation [2].

Thermal Inertia Estimate by TIR: There are several ways to derive the thermal inertia of an asteroid: 1) peak temperature in a day, 2) delay of peak temperature from the local noon, 3) fitting the diurnal temperature curves (hopefully considering the surface roughness), 4) cooling rate after sunset, 5) warming rate after sunrise, 6) lowest temperatures just before sunrise. For the initial analysis, we have taken the methods 1) to 3) to derive thermal inertia, but not considering the surface roughness, which is enough to characterize the thermal inertia much higher than the case of sandy or granular regolith (<100 tiu), and much lower than the typical primitive meteorites (> 600 tiu) or even dense rocks (> 1000 tiu) [2]. Afterwards, we considered the surface roughness at the same time to fit the diurnal temperature profiles much better to derive it thermal inertia of 225 ±45 tiu, with the roughness of 0.41 ±0.08 [3].

In this study, we used the method 6), when we observed the asteroid from a large phase angle of > 40° and at the solar distance of 0.98 to 0.99 au, during Box-B observations on 22 to 24 August 2019. The surface roughness is not considered but it is less effective in the nighttime. Temperatures before sunrise correspond to the apparent thermal inertia of 200 to 300 tiu, which is basically the same as the values derived from the daytime observations.

Acknowledgments: The authors appreciate all the members of the Hayabusa2 Project and supporting staff for their technical assistance and scientific discussions. This research is partly supported by the JSPS KAKENHI No. J17H06459 (Aqua Planetology), and the Core-to-Core program "International Network of Planetary Sciences".

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Keywords: Hayabsua2, Thermal Infrared Imager, Thermal Inertia, Lowest Temperature

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Thermophysical Properties of Ryugu Estimated from a Box-A Observation

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TIR has acquired many one-asteroid rotation thermal images of Ryugu, during the proximity phase in 2018–2019. High-resolved thermal images were obtained during the Mid-Altitude Observation Campaign on August 1, 2018, with the resolution of ~4.5 m/pixel, at the sub-solar latitude of 8°S, the solar phase angle of ~20°, and the heliocentric distance of 1.06 AU. The diurnal temperature profiles of Ryugu showed flat patterns. A thermophysical model using a shape model of rough surface well reproduced the diurnal temperature profiles. By comparing the observation and calculation results, the global thermal inertia of Ryugu was estimated to be 225 ±45 J m^{-2} $s^{-0.5}$ K^{-1}, and the global surface roughness was determined as 0.41 ±0.08 (Shimaki et al., submitted to Icarus). Because of the sub-solar latitude, we cannot determine the thermophysical properties in a part of the northern hemisphere. Here we report the thermophysical properties of Ryugu determined by a Box-A observation on November 14, 2018, with the resolution of ~20 m/pixel, at the sub-solar latitude of 2°S, the solar phase angle of 4.8°, and the heliocentric distance of 1.35 AU. The diurnal temperature profiles showed a peak around the late afternoon. We confirmed that the thermophysical model well reproduces the observed temperature profiles. The global distribution of the thermal inertia is similar to that determined by the previous study, however, we see an offset of the values and the global thermal inertia was estimated to be ~300 J m^{-2} $s^{-0.5}$ K^{-1}. The global surface roughness was estimated to be ~0.3, with the small values around the equatorial ridge.

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Keywords: Hayabusa2, Thermal Infrared Imager, Asteroid Ryugu

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[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS07] Solar System Small Bodies: Explorations of Ryugu, Bennu, and the Solar System at Large

convener:Taishi Nakamoto(Tokyo Institute of Technology), Tatsuaki Okada(Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency), Dante S Lauretta(University of Arizona), Masateru Ishiguro(Department of Physics and Astronomy, Seoul National University)

Small Solar System bodies, including asteroids, comets, satellites, and inter-planetary dust particles, are interesting and provide lots of information on the origin and evolution of our Solar System. They can be remotely sensed by telescopes, be visited by spacecraft and studied at high resolution in a variety of wavelengths from IR to visible, UV, X-rays, and gamma rays, and even with neutrons. In addition, recently spacecrafts have been sent to return samples. In this session, all the contributions on the small solar system bodies are welcome. But this year, we especially welcome contributions on recent advances on the study of Ryugu and Bennu whether obtained by rendezvous spacecraft, remote sensing, or other methods.

[PPS07-11] Spectral heterogeneities at the surface of Ryugu as seen by the NIRS3 spectrometer

*Lucie Riu[1], NIRS3 Team, Hayabusa2 Science Team (1.Institut of Space and Astronautical Science (ISAS/JAXA))

[PPS07-12] The ESA Hera mission: rendezvous with a binary asteroid and planetary defense

★Invited Papers

*Patrick Michel[1], Tatsuaki Okada[2], Michael Kueppers[3], Ian Carnelli[4], Paolo Martino[5], Adriano Campo Bagatin[6], Benoit Carry[1], Sebastien Charnoz[7], Julia de Leon[8], Alan Fitzsimmons[9], Simon Green[10], Carsten Guettler[11], Alain Herique[12], Martin Jutzi[13], Ozgur Karatekin[14], Naomi Murdoch[15], Petr Pravec[16], Holger Sierks[11], Colin Snodgrass[17], Paolo Tortora[18], Kleomenis Tsiganis[19], Stephan Ulamec[20], Jean-Baptiste Vincent[20], Kai Wuennemann[21], Andy Cheng[22], Andy Rivkin[22], Nancy Chabot[22], Olivier S Barnouin[22], Carolyn Ernst[22], Derek C Richardson[23], Angela Stickle[22], Masahiko Arakawa[24], Akiko Nakamura[24], Hideaki Miyamoto[25], Seiji Sugita[25], Makoto Yoshikawa[2] (1.Universite Cote D Azur Observatoire De La Cote D Azur CNRS Laboratoire Lagrange, 2.ISAS JAXA, 3.ESA ESAC, 4.ESA HQ, 5.ESA ESTEC, 6.University of Alicante, 7.IPGP, 8.Instituto de Astrofisica de Canarias, 9.Queen's University, 10.The Open University, 11.Max Planck Institute, 12.IPAG, 13.University of Bern, 14.Royal Observatory of Belgium, 15.ISAE-Supaero, 16.Czech Academy of Sciences, 17.The University of Edinburgh, 18.University of Bologna, 19.University of Thessaloniki, 20.DLR, 21.Natural History Museum Berlin, 22.APL JHU, 23.University of Maryland, 24.Kobe University, 25.The University of Tokyo)

[PPS07-13] Science of DESTINY+ mission

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[PPS07-14] Multiple Asteroid Flyby Tour Design Utilizing Low-Thrust and Gravity-Assist for DESTINY+ Mission

*Ozaki Naoya[1], Takayuki Yamamoto[1], Nishanth Pushparaj[2], Diogene Alessandro Dei Tos[1], Onur Celik[2], Ferran Gonzalez-Franquesa[2], Roger Gutierrez Ramon[2], Kanako Machii[4], Takuya Chikazawa[5], Tomoko Arai[3], Yasuhiro Kawakatsu[1], Kazutaka Nishiyama[1], Takeshi Takashima[1] (1.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 2.SOKENDAI, the Graduate University for Advanced Studies, 3.Planetary Exploration Research Center, Chiba Institute of Technology, 4.University of Electro-Communications, 5.University of Tokyo)

[PPS07-15] Twinkle: a visible and near-infrared space-based observatory for exoplanet and solar system spectroscopy

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Spectral heterogeneities at the surface of Ryugu as seen by the NIRS3 spectrometer

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Asteroid Ryugu has been the prime target of the Hayabusa2 spacecraft which performed orbital characterization of the asteroid for a 1.5 yr with on his board the near-infrared spectrometer NIRS3. NIRS3 acquired data throughout the overall proximity phase resulting into a complete dataset of 101 spectral observations of Ryugu. Each observation was performed at various time, spacecraft altitude, observational conditions (incidence/emergence angles), surface temperature, resulting into a very rich dataset for mineralogical characterization. Based on the global mapping observations, that provides a resolution of 20m/px, Ryugu has been identified as a very dark asteroid (average albedo ~1.9%) with very homogeneous surface properties: a slight red slope and a sharp 2.72 um absorption feature attributed to the presence of OH [1]. Morphological and spectral heterogeneities have been highlighted at higher spatial resolution with the ONC camera and the TIR thermal infrared spectro-imager suggesting irregularities at finer scale: bright boulders of possible exogenous origin [2], hot spots inside craters [3], slope difference inside craters [4]. Based on the last two findings, we decided to perform a survey of the 86 craters that were identified at the surface of Ryugu [5] using the global NIRS3 dataset. The methodology applied aimed at evaluating the spectral properties (*e.g.,*spectral slope, absorption features, albedo) inside each crater and compared them to its vicinity. To smooth out potential calibration artifacts or biases based on photometry or thermal corrections, we used all NIRS3 observations to perform this analysis. For each crater, we look for all NIRS3 observations that falls inside the crater with a spot size smaller or equal to the crater. We also extract the spectra of the vicinity of the crater for the same day of NIRS3 observation to perform spectral comparison. For the majority of craters, several NIRS3 spectra are available, the results are thus combined. As an example, we display in Figure 1 the analysis of crater #ID69 [5] that corresponds to a hot spot as detected by TIR [3], that was analyzed based on the high-resolution observation of NIRS3 on October 31st 2018.

We observe that the spectral properties inside and outside the crater are very similar (ratio close to 1 and very flat, Fig.1c). However, the ratio display an increase in the band depth showing that the absorption feature attributed to the presence of hydrated minerals is larger in the crater. For the majority of craters, we observe that the 2.72 um band depth is larger inside compared to the surroundings, but changes in the slope and albedo are often observed. Several possibilities can explain this observation such an increase in the hydration degree, a change in surface properties (grain size for example), fresher material that was less altered by space weathering. The followings steps will be to cluster all craters based on their spectral similarities, morphologies and surface types to outline a story for Ryugu’ s surface formation and evolution and decipher between the different scenario that account for such differences.

Figure 1- (a) Map of the crater based on [5], the blue squares corresponds to the NIRS3 spectra inside the crater, the orange squares corresponds to the spectra outside. (b) Inside spectra (grey = individual, red = average) and outside spectra (black = average), corresponding respectively to the spectra extracted from locations in blue and orange on (a). The vertical blue line corresponds to the position of the 2.72um band. (c) Ratio of the average spectra inside the crater divided by the average spectra outside the crater.

[1] Kitazato, et al. (2019), Science, 10.1126/science.aav8032. [2] Tatsumi et al. (2020), Nature

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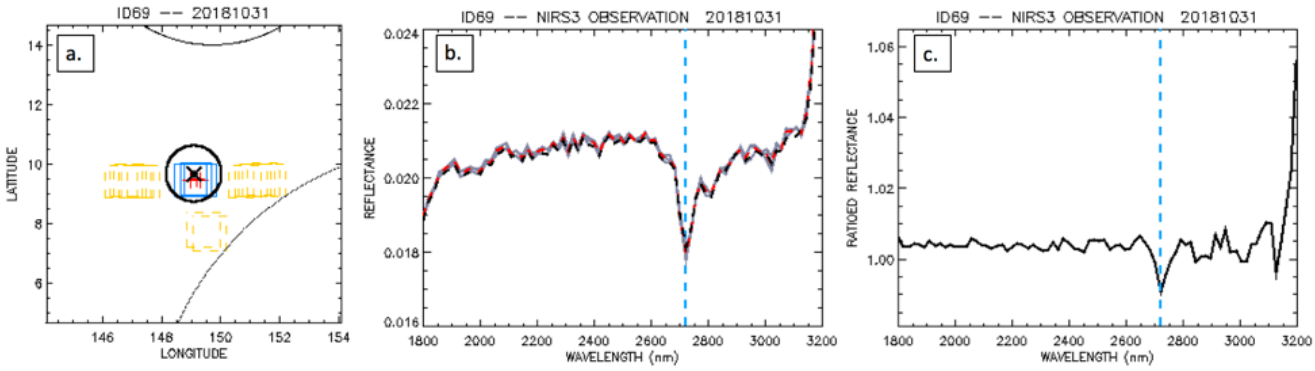
Astronomy, under review. [3] Sakatani et al. (2019) Asteroid Science, #2081. [4] Morota et al. (2020), Science, under review. [5] Hirata et al. (2019), Icarus, https://doi.org/10.1016/j.icarus.2019.113527.

Keywords: Ryugu, NIR spectroscopy , Craters characterization



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The ESA Hera mission: rendezvous with a binary asteroid and planetary defense

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The Hera mission has been approved for development and launch in 2024 in the new ESA Space Safety Programme by the ESA Council at Ministerial Level, Space19+, in November 2019.

Hera will contribute to the first deflection test of an asteroid, in the framework of the international NASA- and ESA supported Asteroid Impact and Deflection Assessment (AIDA) collaboration.

Hera will rendezvous for the first time with a binary asteroid, (65803) Didymos, and in particular its secondary, of only 160 m in diameter. So far, no mission has visited such a small rock in space. Moreover, for the first time, internal and subsurface properties will be directly measured.

As a crucial contribution to planetary defense, Hera will perform the measurements necessary to understand the effect of the NASA DART impact on Didymos' secondary in 2022, in particular its mass, its internal structure, the direct determination of the momentum transfer and the detailed characterization of the crater left by DART. These measurements will also provide unique information on many current issues in asteroid science.

The scientic legacy of the Hera mission will extend far beyond the core aims of planetary defense. Hera is thus the European contribution to the international asteroid exploration era.

Acknowledgement: Funding support from ESA and from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870377 (project NEO-MAPP) is acknowledged.

Keywords: Asteroids, Binary Asteroids, Impact Physics, Planetary Defense, Cubesats, Space Mission

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Science of DESTINY+ mission

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DESTINY+ (Demonstration and Experiment of Space Technology for INterplanetary voYage, Phaethon fLyby and dUst Science) was selected in 2017 as a mission for JAXA/ISAS small-class program. It is a joint mission of technology demonstration and scientific observation. It will test high performance electric propelled vehicle technology and high-speed flyby of asteroid (3200) Phaethon and possibly asteroid 2005UD, which a break-up body from Phaethon as an extended mission. Engineering challenges include an up-close encounter at a distance of 500 km from Phaethon with radio-optical hybrid navigation guidance and control, and autonomous imaging based on optical information for target tracking during a high-speed flyby of 33km/sec. The science goal is to understand the nature and origin of cosmic dust brought onto the Earth, in the context of exogenous contribution of carbon and organics for possible prebiotic seeds of the terrestrial life. Phaethon is a parent body of Geminid meteor shower, and thus a known source to periodically provide dust to the Earth, via the dust stream. The science objectives are two folded: (1) in-situ analyses of velocity, arrival direction, mass and chemical composition of interplanetary and interstellar dust particles around 1 au, the dust trail, and nearby Phaethon, and (2) flyby imaging of Phaethon to study its geology, for understanding dust ejection mechanism of active asteroid and the surface compositional variation. Here, we present the latest status of science mission of DESTINY+ with the current understanding of Phaethon on the basis of the recent ground-based and space-based telescopic observation.

Keywords: Meteor shower parent body, Active asteroids, Cosmic dust, Flyby, Phaethon, DESTINY+

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Multiple Asteroid Flyby Tour Design Utilizing Low-Thrust and Gravity-Assist for DESTINY+ Mission

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DESTINY+mission is a candidate for JAXA’s Epsilon small-class program to be launched in the 2020s. To enable lower cost and higher frequency deep space missions, the spacecraft will demonstrate advanced technologies that include a highly efficient solar electric propulsion system. For the science mission, the spacecraft will perform high-speed flyby observations; exploring the asteroid (3200) Phaethon as the nominal mission and several more asteroids as an extra mission. This paper presents the DESTINY+ mission analysis for multiple asteroid flybys utilizing electric propulsion and Earth gravity-assist techniques. We discuss candidate asteroids that the spacecraft can potentially explore. The target asteroids should be finally selected considering technical constraints, such as remaining propellant, and scientific returns. Multiple asteroid flyby tours are beneficial as precursor missions for future full-scale missions that include asteroid sample return missions.

Keywords: DESTINY+, Asteroid Flyby, Near Earth Asteroid

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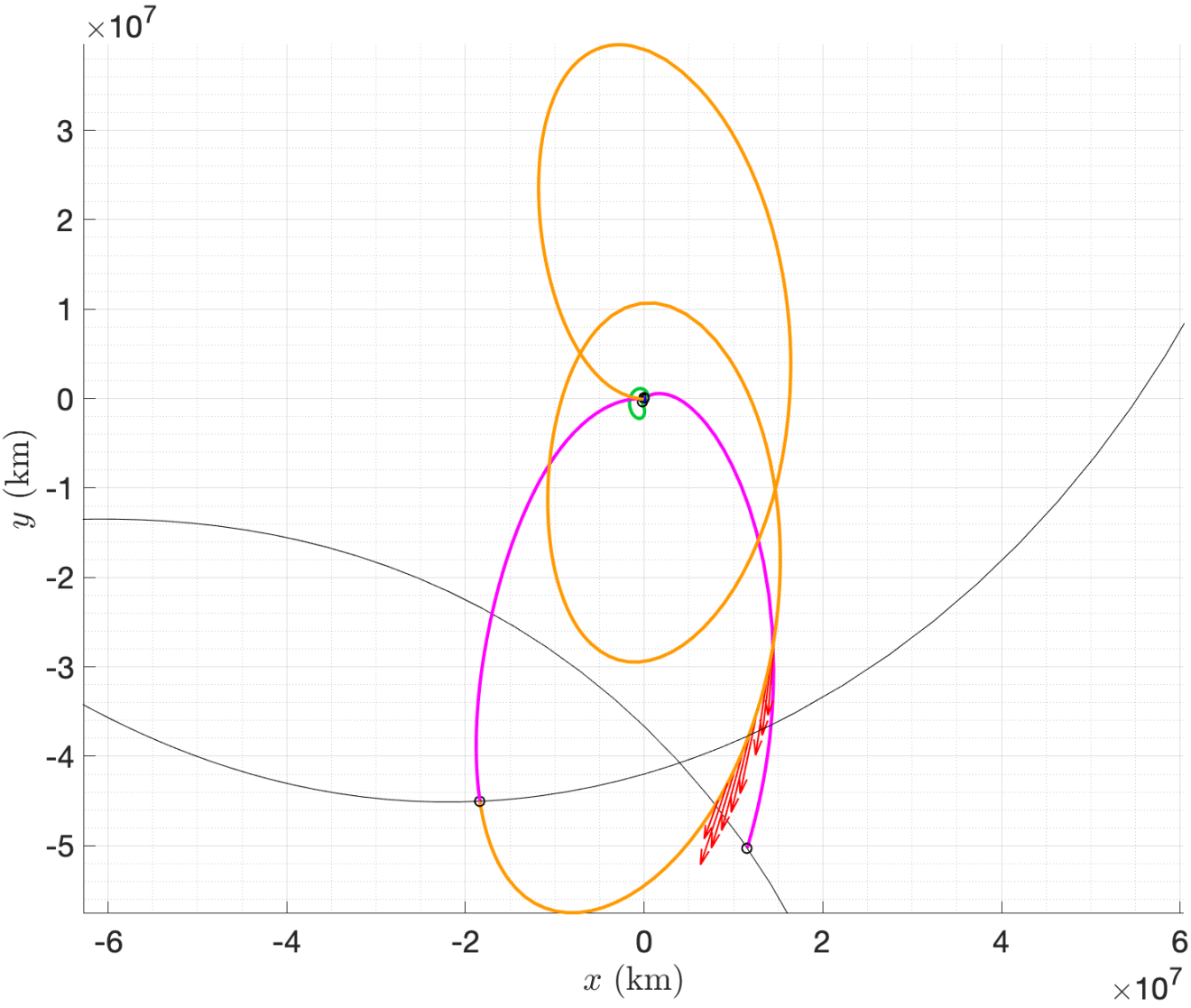

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Twinkle: a visible and near-infrared space-based observatory for exoplanet and solar system spectroscopy

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The Twinkle Space Mission is a space-based observatory that has been conceived to measure the atmospheric composition of exoplanets, study bright stars and brown dwarfs, and reveal the surface mineralogy of Solar System objects. The satellite is based on a high-heritage platform and will carry a 0.45 m telescope with a visible and infrared spectrograph providing simultaneous wavelength coverage from 0.5 - 4.5 μm. The spacecraft will be launched into a Sun-synchronous low-Earth polar orbit and will operate for a baseline lifetime of seven years.

Twinkle’ s rapid pointing and non-sidereal tracking capabilities will enable the observation of a diverse array of Solar System objects, including asteroids and comets. Twinkle aims to provide a visible and near-infrared spectroscopic population study of asteroids and comets to study their surface composition as well as obtaining high-SNR spectra of the outer planets and their moons. Its wavelength coverage, and position above the atmosphere, will make it particularly well-suited for studying hydration features that are obscured by telluric absorption from the ground, as well as searching for other spectral signatures such as organics, silicates and CO_2.

Twinkle is available for researchers around the globe in two ways:

1) joining its collaborative multi-year survey programme, which will observe hundreds of exoplanets and solar system objects; and

2) accessing dedicated telescope time on the spacecraft, which can be freely schedule for any combination of science cases.

I will present an overview of Twinkle’ s capabilities and discuss the broad range of small bodies the mission could observe, demonstrating the huge scientific potential of the spacecraft.

Keywords: space-based visible and near-infrared spectroscopy

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[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS07] Solar System Small Bodies: Explorations of Ryugu, Bennu, and the Solar System at Large

convener:Taishi Nakamoto(Tokyo Institute of Technology), Tatsuaki Okada(Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency), Dante S Lauretta(University of Arizona), Masateru Ishiguro(Department of Physics and Astronomy, Seoul National University)

Small Solar System bodies, including asteroids, comets, satellites, and inter-planetary dust particles, are interesting and provide lots of information on the origin and evolution of our Solar System. They can be remotely sensed by telescopes, be visited by spacecraft and studied at high resolution in a variety of wavelengths from IR to visible, UV, X-rays, and gamma rays, and even with neutrons. In addition, recently spacecrafts have been sent to return samples. In this session, all the contributions on the small solar system bodies are welcome. But this year, we especially welcome contributions on recent advances on the study of Ryugu and Bennu whether obtained by rendezvous spacecraft, remote sensing, or other methods.

[PPS07-16] OSIRIS-REx: Prospects for the Return of Pristine Carbonaceous Regolith from Asteroid (101955) Bennu

*Dante S Lauretta[1], Hannah H Kaplan[2], Humberto Campins[3], Harold C Connolly[4], Daniella N DellaGiustina[1], Jason P Dworkin[5], Heather L Enos[1], Daniel P Glavin[5], Timothy D Glotch[6], Dathon R Golish[1], Victoria E Hamilton[2], Romy D Hanna[7], Erica R Jawin[8], Timothy J McCoy[8], Amy A Simon[5], Nicholas Porter[1], Dennis Reuter[5] (1.University of Arizona, Tucson, AZ, USA, 2.Southwest Research Institute, Boulder, CO, USA , 3.University of Central Florida, Orlando, FL, USA, 4.Rowan University, Glassboro, NJ, USA, 5.NASA Goddard Space Flight Center, Greenbelt, MD, USA, 6.Stony Brook University, Stony Brook, NY, USA, 7.University of Texas, Austin, TX, USA, 8.Smithsonian Institution National Museum of Natural History, Washington, DC, USA)

[PPS07-17] Overcoming the Challenges of Sample Collection at Nightingale

★Invited Papers

*Michael C Moreau[1], Dante Lauretta[2] (1.NASA Goddard Space Flight Center, 2.University of Arizona)

[PPS07-18] The Measured Gravity and Global Geophysical Properties of (101955) Bennu

*Daniel Jay Scheeres[1], J W McMahon[1], A S French[1], A B Davis[1], D N Brack[1], S Chesley[2], D Farnocchia[2], Y Takahashi[2], R S Park[2], J Leonard[3], P Antreasian[3], K Getzandanner[4], A Liounis[4], D E Highsmith[4], D Rowlands[4], E Mazarico[4], M Moreau[4], P Tricarico[5], O S Barnouin[6], M G Daly[7], R W Gaskell[5], E E Palmer[5], J Weirich[5], C L Johnson[8], M M Al Asad[8], J A Seabrook[7], J Roberts[7], C W Hergenrother[9], M C Nolan[9], D S Lauretta[9] (1.University of Colorado Boulder, 2.Jet Propulsion Laboratory, 3.KinetX, 4.Goddard Space Flight Center, 5.Planetary Sciences Institute, 6.Applied Physics Laboratory, 7.York University, 8.University of British Colombia, 9.Lunar and Planetary Laboratory, University of Arizona)

[PPS07-19] Apparently Layered Boulders with Multiple Textures on Bennu's Surface

*Kana Ishimaru[1], Dathon R Golish[1], Nicholas Porter[1], Manar M Al Asad[3], Ronald Ballouz[1], Daniellla N DellaGuistina[1], Bashar Lizk[1], Kevin John Walsh[2], Dante S Lauretta[1] (1.Lunar and Planetary Laboratory, University of Arizona, 2.Southwest Research Institute, 3.Department of Earth, Oceans, and Atmospheric Sciences, The University of British Columbia)

[PPS07-20] The Phenomenon of Particle Ejections from Asteroid Bennu

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OSIRIS-REx: Prospects for the Return of Pristine Carbonaceous Regolith from Asteroid (101955) Bennu

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The primary objective of the OSIRIS-REx mission to asteroid (101955) Bennu is to return pristine carbonaceous regolith that may hold clues to the origins of life. The 500-m near-Earth asteroid Bennu was chosen as a target for sample return based on its orbital characteristics and its spectral properties that suggested an affinity to hydrated, organic-rich carbonaceous chondrites. Primitive chondritic meteorites formed early in solar system history. They provide the opportunity to study the materials, processes, and events that formed our planetary system, including the delivery of pre-biotic organics and volatiles to Earth. The OSIRIS-REx spacecraft arrived at Bennu in December 2018. Proximity operations focused on global mapping using a suite of cameras, spectrometers, and scanning lidar to characterize Bennu’s surface properties, particle size distribution, and composition. With this information, the OSIRIS-REx team performed an extensive site selection process, ultimately designating a primary and a back-up sample site, named Nightingale and Osprey, respectively.

Characterization of Bennu’s surface demonstrates that this asteroid is the ideal target to meet the mission objective of returning hydrated and organic-rich material from the early solar system. Bennu’s near-infrared spectral signature is dominated by a 2.7-μm absorption feature that arises owing to bound hydroxyl molecules and is most consistent with Mg-bearing phyllosilicates. Broadband filter photometry suggests a high abundance of the iron oxide mineral magnetite. Thermal infrared spectra exhibit silicate stretching and bending modes; these modes are also consistent with volumetrically dominant phyllosilicates and the presence of magnetite. These observations indicate that Bennu is compositionally similar to the aqueously altered carbonaceous chondrites and, in particular, the highly altered CI and CM chondrites. Given the enormous (>15 m) boulders on the surface, this aqueous alteration likely occurred on a precursor parent body with a diameter of order 100 km. Catastrophic disruption of this object resulted in the subsequent rubble-pile re-accumulation of Bennu.

Recent observations of Bennu reveal widespread carbonate spectral features. Correlation of these features with imagery shows that, in many cases, they are associated with bright veins that transect exposed boulder surfaces. These veins range in measured thickness from 3 to 14 cm, with lengths of 30 to 60 cm. Further, we observe organics and carbonates occurring together in visible to near-infrared spectra of Bennu. These organic-carbonate spectral mixtures indicate that the abundances, grain sizes, or outcroppings of these materials on Bennu are distinct from those of meteorites and other asteroids. The carbonate detection implies that Bennu’s parent body experienced extensive aqueous alteration, similar

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to, or possibly more intense, than indicated in the carbonaceous chondrite meteorite record. If the observed bright veins are carbonates, this would indicate hydrothermal deposition and crystallization at larger scales than previously anticipated or observed for carbonaceous asteroids, where alteration generally has been presumed to occur locally (at the micron scale) in lithified systems resembling meteorites. We investigate the implications for Bennu’ s geologic history and hydrothermal conditions on its parent body.

Keywords: (101955) Bennu, OSIRIS-REx, Sample Return, Asteroid, Small Bodies

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Overcoming the Challenges of Sample Collection at Nightingale

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The OSIRIS-REx mission will collect a sample of near-Earth asteroid (101955) Bennu and return it to Earth. The returned sample will provide valuable constraints on the earliest stage of rocky planet formation and the origin of life. The data collected at the asteroid, combined with the analysis of the returned sample, will also improve our understanding of hazardous asteroids. In preparation for retrieving a sample, the OSIRIS-REx spacecraft has been flying in close proximity to Bennu since December of 2018, conducting a campaign of challenging maneuvers and scientific observations.

The sample will be acquired using a technique called Touch and Go, or TAG. The spacecraft will contact the surface of Bennu with with its Touch-and-Go Sample Acquisition Mechanism (TAGSAM), mounted on the end of a 3-m-long robotic arm. Contact with the surface is for a few seconds before the spacecraft backs away. When contact is detected, pressurized gas will mobilize fine-grained material, some of which will be captured with TAGSAM. TAG begins from a safe home orbit with the spacecraft approximately 1 km from the surface. The spacecraft will depart from this orbit and descend over the sunward side of Bennu towards the location of the TAG site. During a four-hour transit, the spacecraft will take images of Bennu’ s surface with a navigation camera and process these images to update navigation information onboard. As OSIRIS-REx nears the surface, the spacecraft will perform two maneuvers to precisely target the TAG location.

Earth based observations of Bennu, combined with the experience of the Hayabusa mission at (25143) Itokawa, suggested that Bennu would have large flat areas containing fine-grained regolith, ideal for our collection technique. However, the earliest global observations of Bennu revealed a dramatic, rocky world with no obvious hazard-free regions. Subsequent high-resolution imaging of candidate TAG sites revealed that even the best candidates have very few areas containing clearly resolvable particle sizes of 2 cm or smaller, as required for collection. In response to these challenges, the Site Selection and Sample Acquisition campaigns changed. The project switched the TAG autonomous guideance technique from an originally planned lidar-based navigation update to an image-based navigation method called Natural Feature Tracking (NFT). A new observation campaign, Reconnaissance A, was added during October 2019 that collected high-resolution imagery of the top four candidate TAG sites to search for sampleable material and provide data needed to build onboard feature maps. Finally, an onboard hazard avoidance capability was developed to keep the spacecraft safe from large hazards in close proximity to the targeted TAG location. The highest-resolution (8 cm/pixel) images collected of the primary sample site, Nightingale, provide direct evidence of abundant sampleable material.

This talk will describe the challenges of asteroid Bennu, the factors that went into selection of the Nightingale site for TAG, and the preparations for the TAG event planned for summer 2020. The latest images of Nightingale and the backup TAG site, Osprey, will be shown.

Keywords: small bodies, asteroid sample return, Bennu, OSIRIS-REx

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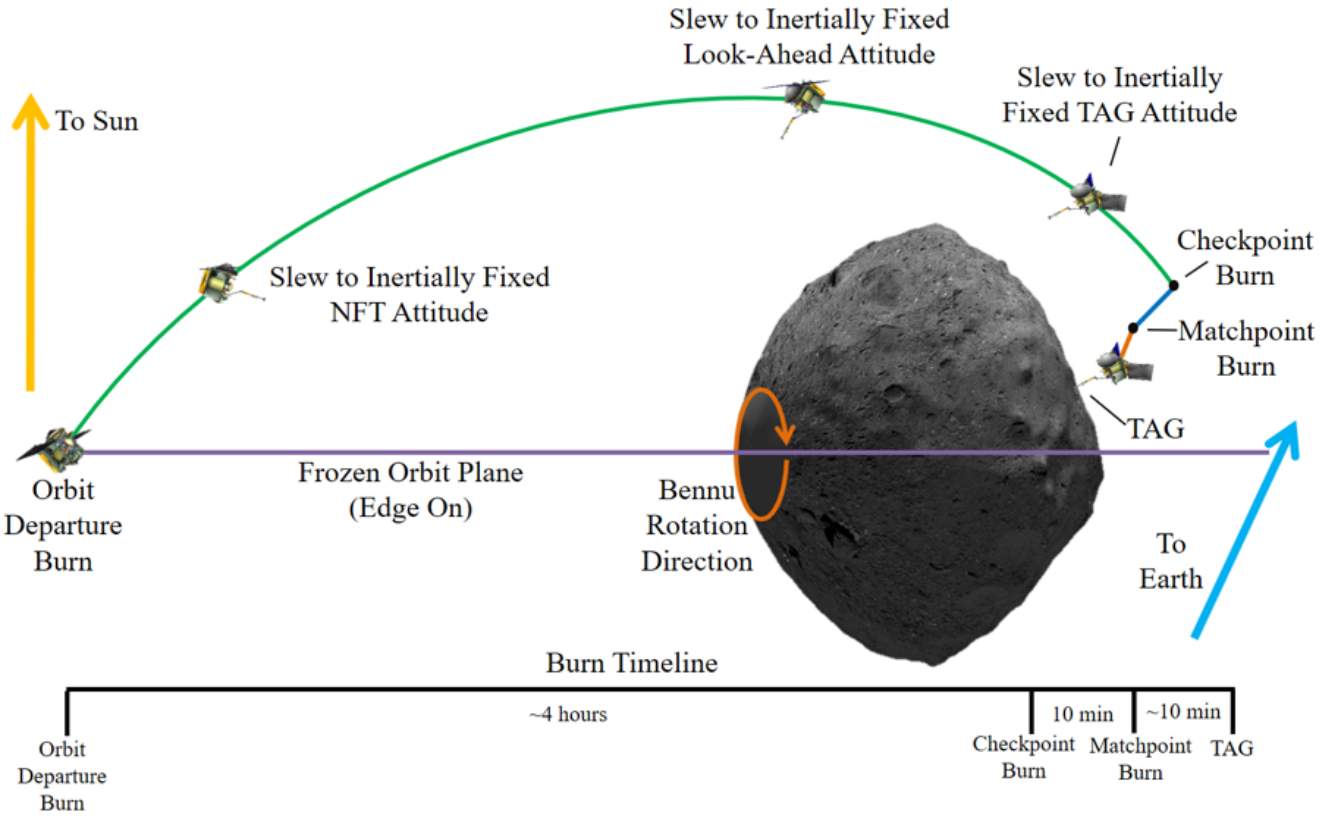

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The Measured Gravity and Global Geophysical Properties of (101955) Bennu

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Introduction: Current estimates of asteroid (101955) Bennu’ s gravity have been determined, based on a series of independent solutions from different teams involved on the OSIRIS-REx mission. In addition to classical radio science techniques for estimating a body's gravity field coefficients, the discovery of particles ejected from Bennu that persist in orbit for multiple revolutions provides a unique opportunity to probe the gravity field to higher degree and order than possible by using conventional spacecraft tracking [1]. However, the non-gravitational forces acting on these particles must also be characterized, and their impact on solution accuracy must be assessed, requiring the different gravity field estimates to be compared and reconciled.

Given the measured gravity field of Bennu, rigorous constraints on its internal density heterogeneity can be found by comparing the measured field with the constant density field computed from the asteroid shape. These results in turn provide unique insight into the global geophysical processes that drive the external and internal morphology of small rubble-pile asteroids such as Bennu.

Finally, definitive results on the surface and close-proximity force environment of Bennu can be derived and updated from the initial analysis based on the total mass and constant density shape. Several aspects of the environment are highly sensitive to the gravity field and are expected to change from earlier results [2, 3, 4].

We assess the current gravity field solutions and uncertainties, update the surface and proximity environment models, and provide the geophysical implications and interpretations of these measurements.

Geophysical Models: Using the determined density inhomogeneity patterns, we investigate specific geophysical aspects of Bennu. Current estimates show the measured *J2* and *J4* gravity coefficients to be larger than the constant density values. If these trends stay consistent with the final gravity field estimates, it points to a combination of an over-dense equator and under-dense center. The evaluation of the other gravity field coefficients will constrain the degree to which the interior density is inhomogeneous, applying the simple theory outlined in [5].

An over-dense equator could be consistent with transport of material to the equator which is subsequently compacted. This would match with the lower slope region within the rotational Roche lobe. If this is paired with a lower-density interior, then it could be consistent with a long-ago period of rapid spin and failure of the interior of the body along with preferential transport of material to the equator.

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An alternate hypothesis holds that the asteroid took on its shape when it was initially formed and has not shifted since [6]. This theory is consistent with a stronger rubble pile that has not changed its shape or rearranged material over many YORP cycles. Tests of this hypothesis require additional simulations of how rubble-pile asteroids coalesce after the catastrophic disruption of their parent body.

Acknowledgements: This material is based upon work supported by NASA under Contract NNM10AA11C issued through the New Frontiers Program. Part of this research was conducted at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA. We are grateful to the entire OSIRIS-REx Team for making the encounter with Bennu possible.

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Keywords: Bennu, Geophysics, Internal Density

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Apparently Layered Boulders with Multiple Textures on Bennu's Surface

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The OSIRIS-REx mission is exploring asteroid (101955) Bennu, carbonaceous near-Earth asteroid whose surface is covered with boulders of various sizes larger than 50 m [1]. Bennu is a top-shaped, rubble-pile asteroid with diameter of about 500 m [2]. Because of its small size, the collisional lifetime of Bennu is much shorter than the age of the solar system [3]. It is probably a fragment of a larger “parent-body” asteroid with diameter of approximately 100 km [4]. The OSIRIS-REx Camera Suite (OCAMS) [5] provided high-resolution images (<2 cm/pix) of the surface of Bennu. Some boulders appear to have layering in multiple, distinct units demarcated by different textures [6]. The layer-like texture might have formed by parent-body processing [1, 7]. In this work, layered boulders on the asteroid surface were identified and categorized by texture and average normal albedo. We offer two hypotheses about how the apparent layering could have originated in the parent body.

We used OSIRIS-REx Laser Altimeter (OLA) altimetry data and PolyCam images with a scale of ~1.5 cm/pix in the Small Body Mapping Tool (SBMT) [8]. The images typically had phase angles between 30 and 50°, and our search was up to 80° north or south latitudes. The total search explored ~80% of the entire surface of the asteroid under similar illumination and pixel scale.

Identifying layered boulders with multiple textures: SBMT [8] was used to examine the surface by projecting images onto a shape model. Fourteen boulders were identified as apparently layered boulders with multiple textures. We selected three large boulders (Figure 1) that show clear variations in texture for detailed photogeological analysis.

Categorizing the textures: Textural differences can be caused by variation in composition and the size of the constituent particles. Both these aspects can result in variation of the normal albedo. A global normal albedo map was utilized with SAOImageDS9 [9] to calculate the average albedo of each texture in the three analyzed boulders. In SAOImageDS9, a region was selected for each texture, and the average within the region was calculated. To obtain normal albedo values with higher precision, local shape models were created for some boulders with OLA data, and boulder images were registered onto a corresponding shape model using USGS’ s Integrated Software for Imagers and Spectrometers 3 (ISIS3, [10]). Albedo ranges are (from darkest to brightest): bin 1, 3.0 to 3.4%; bin 2, 3.5 to 3%; bin 3, 4.0 to 4.2%; bin 4, 4.3 to 4.5%; and bin 5, 6.0 to 6.5%.

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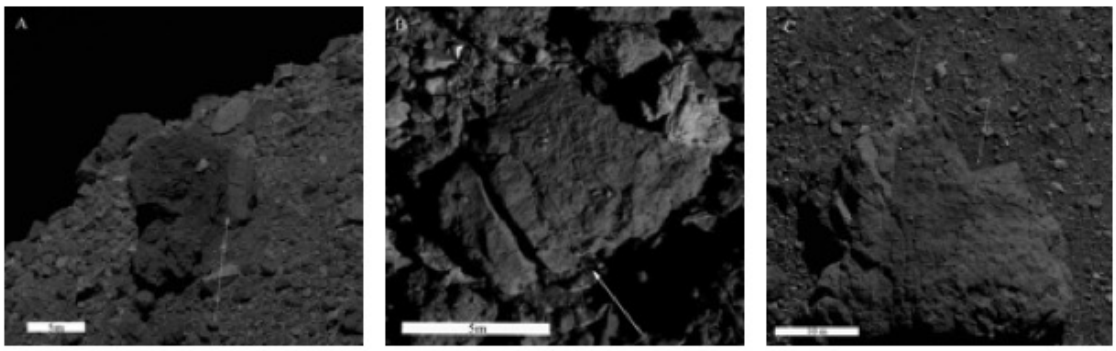
Hypotheses of the formation of layered boulders with multiple textures: This work is designed to test two hypotheses of multi-texture layered boulder formation. One is brecciation in the parent body. Boulders could be fractured by thermal fatigue [6], impact, or internal pressure, and fragments with various textures could be melded together by melting or internal pressure. Second, Bland and Travis [11] modeled mud convection in a 100-km asteroid parent body and showed that particle size sorting could occur. Catastrophic disruption of a parent body with a size-sorted interior could produce some rock fragments that include a boundary between two textures.

[1] DellaGiustina D. N. et al. (2019) *Nature Astronomy, 3,* 341-351. [2] Barnouin O. S. et al. (2019) *Nature Geoscience, 12,* 247-252. [3] Bottke W. F. et al. (2005) *Icarus, 179,* 63-94. [4] Lauretta D. S. (2015) *Meteoritics & Planetary Sci., 50,* 834849. [5] Rizk B. et al. (2018) *Space Sci Rev, 214*, 26. [6] Molaro J. L. et al. (2020) *in revision.* [7] Walsh K. J. et al. (2019) *Nature Geoscience, 12*, 242-246. [8] Ernst C. M. et al. (2018) *Lunar and Planetary Science Conference, 49,* Abstract #1043. [9] Joye W. A. & Mandel E. (2003) *Astronomical Data Analysis Software and Systems XII ASP Conference Series, 295,* 489-492. [10] Keszthelyi L. et al. (2013) *Lunar and Planetary Science Conference, 44,* Abstract #2546. [11] Bland P. A. & Travis B. J. (2017) *Sci. Adv., 3,* e1602514.

Keywords: Bennu, OSIRIS-REx, Asteroid



Figures. PolyCam images of multi-textured boulders which are selected for detailed photogeological analysis. They are all large (>10 m) and clearly show boundaries between different textures. (A) An image of a boulder (93° E, 5° N) acquired on April 5, 2019 at a scale of 3.8 – 4 cm/pix. It has both a dark and rugged texture and brighter and smoother texture. The arrow indicates a linear boundary which divides the two textures. (B) An image of a boulder (25.4° N, 190° E) acquired on March 29, 2019 at a scale of 4.8 cm/pix. It also has both a dark and rough texture and a brighter and smoother texture, divided by a linear boundary indicated by the arrow. (C) An image of a boulder (25° S, 3° E) acquired on March 21, 2019 at a scale of 4.7 cm/pix. This boulder contains three textures with two boundaries, which are indicated by the arrows. The texture on the right is the brightest, the one in the middle is the darkest, and the one on the left has medium brightness.

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The Phenomenon of Particle Ejections from Asteroid Bennu

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The OSIRIS-REx spacecraft has been operating in proximity to near-Earth asteroid (101955) Bennu since December 2018. Particle ejections off the surface of the asteroid were first discovered[i] in images from 6 January 2019, 1 week after the spacecraft entered orbit and 4 days before Bennu perihelion. This phenomenon was serendipitously captured in the NavCam 1[ii] optical navigation images, intended to image background stars while maintaining Bennu in the field of view. Prior to arrival at Bennu, an extensive natural satellite imaging campaign conducted to search for orbiting objects greater than 10 cm yielded null results.

The first optically observed particle ejection event on 6 January 2019 shows more than 200 star- like point-source objects and trailed (higher-velocity) objects located off the limb of Bennu. A second image minutes later shows objects in common with the earlier image that have moved away from Bennu, implying the movement of discrete particles. The included figure[i] shows (A) a composite image of two exposures taken by the NavCam on 6 January 2019 in immediate succession: a short-exposure image (1.4 ms), showing the asteroid, and a long-exposure image (5 s), showing the particles; and (B) two long-exposure images (5 s, spaced 7.27 min apart) registered on the center of Bennu and differenced to highlight any moving particles. Particles moving at high velocity appear as streaks in a single image (red), and paths of particles moving more slowly (yellow) are identified from individual particles detected in the earlier image that also are present in the later image, farther from Bennu’ s limb.

This first observation triggered an immediate mission risk assessment, which concluded that the size and velocity of these particles (0.07–3.3 m/s, <1 to ~10 cm)[i] did not pose risks to keeping the spacecraft in its 1.6 x 2.0 km frozen orbit. The operations teams quickly worked to build new observation campaigns to improve the frequency and data quality in observing the active asteroid activity. In the subsequent year of operations, the team has detected multiple large ejection events, more than a dozen small events (<20 observed particles), as well as a persistent background level of particles in the Bennu environment. A pipeline was established which automates the detection of potential particles, identifies object pairs between images, reconstructs the event location and timing, and solves for various dynamical and physical properties of each particle.

A forthcoming special collection in the *Journal of Geophysical Research: Planets* will characterize this phenomenon, from reconstruction of the event dynamics to proposed mechanisms for particle release.

This work is supported by NASA under Contracts NNM10AA11C, NNG12FD66C, and NNG13FC02C. OSIRIS-REx is the third mission in NASA’ s New Frontiers Program. Dante Lauretta of the University of Arizona, Tucson, is the principal investigator, and the University of Arizona also leads the science team and the science observation planning and data processing. Lockheed Martin Space Systems in Denver built the spacecraft and is providing flight operations. Goddard Space Flight Center and KinetX Aerospace are responsible for navigating the OSIRIS-REx spacecraft.

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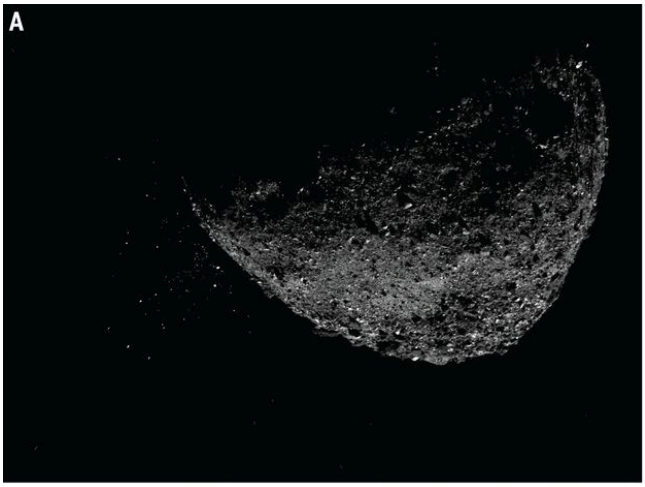
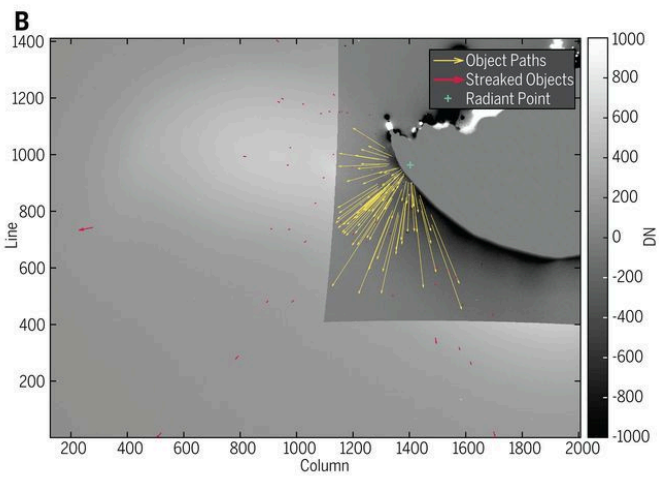
Keywords: Bennu, OSIRIS-REx, Particles, Active, Asteroid, NASA





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[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS07] Solar System Small Bodies: Explorations of Ryugu, Bennu, and the Solar System at Large

convener:Taishi Nakamoto(Tokyo Institute of Technology), Tatsuaki Okada(Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency), Dante S Lauretta(University of Arizona), Masateru Ishiguro(Department of Physics and Astronomy, Seoul National University)

Small Solar System bodies, including asteroids, comets, satellites, and inter-planetary dust particles, are interesting and provide lots of information on the origin and evolution of our Solar System. They can be remotely sensed by telescopes, be visited by spacecraft and studied at high resolution in a variety of wavelengths from IR to visible, UV, X-rays, and gamma rays, and even with neutrons. In addition, recently spacecrafts have been sent to return samples. In this session, all the contributions on the small solar system bodies are welcome. But this year, we especially welcome contributions on recent advances on the study of Ryugu and Bennu whether obtained by rendezvous spacecraft, remote sensing, or other methods.

[PPS07-21] Evolution of thermally metamorphosed C-complex asteroids inferred from a heated CM chondrite Jbilet Winselwan

★Invited Papers

*Wataru Fujiya[1], Hisato Higashi[1], Yuki Hibiya[2], Shingo Sugawara[1], Akira Yamaguchi[3], Makoto Kimura[3], Ko Hashizume[1] (1.Ibaraki University, College of Science, 2.Japan Agency for Marine-Earth Science and Technology, 3.National Institute of Polar Research)

[PPS07-22] Aggregate structure of comet 67P/Churyumov-Gerasimenko

*Sota ARAKAWA[1,2], Kazumasa Ohno[3,2] (1.NAOJ, 2. Tokyo Tech, 3.UCSC)

[PPS07-23] Numerical Simulations of Spinup of Asteroids and the Formation of Top-Shaped Asteroids

*Keisuke Sugiura[1], Hiroshi Kobayashi[2], Sei-ichiro WATANABE[3], Hidenori Genda[1], Ryuki Hyodo[4], Shu-ichiro Inutsuka[2] (1.Tokyo Institute of Technology, Earth Life Science Institute, 2.Nagoya University, Department of Physics, 3.Nagoya University, Department of Earth and Environmental Sciences, 4.JAXA, ISAS, Department of Solar System Sciences)

[PPS07-24] YORP Effect on Asteroid Ryugu

*Masanori Kanamaru[1], Sho Sasaki[1], Tomokatsu Morota[2], Yuichiro Cho[2], Naru Hirata[3], Naoyuki Hirata[4], Hiroki Senshu[5], Yuri Shimaki[6], Satoshi Tanaka[6], Tatsuaki Okada[6], Tomohiro Usui[6], Seiji Sugita[2], Sei-ichiro WATANABE[7] (1.Osaka University, 2.The University of Tokyo, 3.The University of Aizu, 4.Kobe University, 5.Chiba Institute of Technology, 6.ISAS/JAXA, 7.Nagoya University)

[PPS07-25] Likelihood for rubble-pile near-Earth asteroids to be 1st or Nth generation: focus on Bennu and Ryugu

*Kevin John Walsh[1], Ronald Ballouz[2], William F Bottke[1], Chrysa Avdellidou[3], Harold C Connolly Jr.[4], Marco Delbo[3], Daniella N DellaGiustina[2], Erica R Jawin[5], Timothy McCoy[5], Patrick Michel[3], Tomokatsu Morota[6], Michael C Nolan[2], Steven R Schwartz[2], Seiji Sugita[6], Dante S Lauretta[2] (1.Southwest Research Institute Boulder, 2.Lunar and Planetary Laboratory, University of Arizona, 3.Laboratoire Lagrange, Université Côte d'Azur, 4.Dept. of Geology, Rowan University, 5.Smithsonian Institution National Museum of Natural History, 6.University of Tokyo)

Evolution of thermally metamorphosed C-complex asteroids inferred from a heated CM chondrite Jbilet Winselwan

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Some C-complex asteroids are thermally metamorphosed as indicated by their reflectance spectra (e.g., Hiroi et al., 1993). However, the thermal history of these asteroids is poorly understood. CM chondrites are aqueously altered in their parent body, and some of them apparently underwent post-alteration thermal metamorphism (e.g., Nakamura, 2005). In this work, we study Jbilet Winselwan (JW), a thermally metamorphosed CM chondrite, to constrain the heat source for thermal metamorphism and to investigate the evolution of thermally metamorphosed C-complex asteroids.

Sulfide minerals in JW are pyrrhotite with abundant pentlandite blebs, suggesting mild heating (Kimura et al., 2011). Mass losses in thermogravimetric analysis are 0.98 and 4.1 wt% for temperature ranges of 200-400 and 400-770 ˚C, which correspond to OH^-/water release from tochilinite and phyllosilicate, respectively (Garenne et al., 2014). These values are much lower than the corresponding values of Murchison (3.1 wt% for 200-400 ˚C and 6.8 wt% for 400-770 ˚C). Large clumps of tochilinite/cronstedtite intergrowth (TCI), which are commonly found in CMs, are rare. TCIs in JW have lower S/SiO_2 and higher FeO/SiO_2 ratios (~0.16 and ~3.2, respectively) than expected from typical CMs (Rubin et al., 2007). These observations suggest that tochilinite, unstable at high temperatures of >170 ˚C (Zolensky, 1984), is decomposed by heating. The decomposition of TCIs has also been confirmed for other thermally metamorphosed CMs and an experimentally heated Murchison sample (Nakato et al., 2008).

Ca-sulfate grains are commonly surrounding calcite grains, indicating that Ca-sulfate precipitated subsequently after calcite. The Ca-sulfate is identified as anhydrite ($CaSO_4$) using Raman spectroscopy. Gypsum ($CaSO_4 \cdot 2H_2O$), stable at <110 ˚C (Prieto-Taboada et al., 2015), is absent. The absence of gypsum also indicates that JW underwent heating. Because we found substantial amounts of Ca-sulfate, Ca-sulfate is one of the main carriers of sulfur. We propose that sulfur in Ca-sulfate was supplied from TCIs decomposed by heating.

The ^{53}Mn-^{53}Cr age (half-life: 3.7 Myr) of JW calcites measured by SIMS is 4564.8 (+1.2/-1.5) Ma, significantly older than the ages of typical CMs (~4563 Ma) (Fujiya et al., 2012). The older age of JW calcites indicates an earlier onset of aqueous alteration. Therefore, JW contained a larger amount of radioactive ^{26}Al (half-life: 0.7 Myr) than typical CMs when aqueous alteration took place, which is consistent with a higher peak temperature experienced by JW. Thus, the energy for the heating was most likely provided by ^{26}Al decay.

In summary, the aqueous alteration and calcite formation in JW initiated ~4564.8 Ma. Then, the temperature kept increasing, which led to thermal metamorphism associated with the TCI decomposition and subsequent anhydrite precipitation. These processes were likely driven by ^{26}Al decay. It is currently unclear whether JW was located at the inner part of the CM parent asteroid, or it is derived from a different parent asteroid than typical CMs. We will conduct Cr- and Ti-isotope analyses to investigate a genetic relationship between JW and typical CMs.

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Keywords: C-complex asteroids, Thermal metamorphism, CM chondrite, Jbilet Winselwan

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Aggregate structure of comet 67P/Churyumov-Gerasimenko

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The Rosetta mission to comet 67P/Churyumov-Gerasimenko has provided plenty of data to understand what comets are made of. The thermal and mechanical properties of dust aggregates encapsulate information on their internal structure. In this study, we investigate whether the comet is made of homogeneous or hierarchical aggregates using theoretical models of the thermal inertia and tensile strength of dust aggregates (Arakawa et al. 2019, Tatsuuma et al. 2019). We found that it is difficult to explain the tensile strength of the comet if the comet is a homogeneous aggregate constituted by micron-sized dust grains. Then we also calculated the thermal inertia and tensile strength of hierarchical aggregates. We analytically derived the physical properties of hierarchical dust aggregates and compared our theoretical model with experimental data of the tensile strength of hierarchical aggregates (Blum et al. 2014, Brisset et al. 2016). We found that the thermal inertia and tensile strength of the comet are consistent with the hierarchical aggregate constituted by cm- or dm-sized aggregates, which is basically consistent with the result of Blum et al. (2017). These findings indicate that the icy planetesimals may form via accretion of cm- or dm-sized compressed dust aggregates in the solar nebula.

Keywords: Comet, Thermal inertia, Tensile strength

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Numerical Simulations of Spinup of Asteroids and the Formation of Top-Shaped Asteroids

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The asteroids Ryugu and Bennu visisted by the spacecraft Hayabusa2 and OSIRIS-REx, respectively, have so-called “spinning top” shapes. The characteristics of the top shapes are as follows: pronounced equatorial ridges, cone-like surfaces from low latitudes to mid latitudes, and mostly axisymmetric shapes. Many top-shaped asteroids such as the asteroid 1999 KW4 have rapid rotations with rotation periods of about 3 hours. The axisymmetric shapes and the rapid rotations of the top-shaped asteroids suggest that top shapes are formed through the deformation due to spinup and rapid rotations of asteroids. However, how rapid-rotating asteroids deform and how top shapes form are not well understood.

Ryugu, Bennu, and many other asteroids are rubble-pile bodies, and thus friction of granular materials plays an important role for the deformation of rapid-rotating asteroids. Thus investigation of friction angles required for the formation of top shapes may lead to constrain properties of top-shaped asteroids. Although the major spinup mechanism is considered to be the Yarkovsky-O’Keefe-Radzievskii-Paddack (YORP) effect, spinup can also be caused by reaccumulation of fragments after collisional catastrophic disruption. Spinup rate caused by the YOPR effect is much smaller than that caused by gravitational reaccumulation. Thus investigation of spinup rates required for the formation of top shapes may even constrain formation mechanisms.

In this study, we investigate the deformation of rubble pile bodies due to spinup using a Smoothed Particle Hydrodynamics (SPH) code. The code includes friction model for granular material and can treat dynamics of granular bodies. We simulate spinup of a uniform spherical body with the radius of 500 m and the density of 1.19 g/cm^3. The spinup rate is set to beta x 8.954 x 10^{-10}[rad/s^2], where beta is a parameter and beta = 1 gives acceleration from the period of 3.5 h to 3.0 h in about 10 rotations. We mainly change the friction angle phi_d and the spinup rate beta.

All the simulations with beta = 1 result in axisymmetric deformation. The spinup with phi_d < 40 degrees results in quasi-static and internal deformation, that with 50 degrees < phi_d < 60 degrees results in dynamical and internal deformation, and that with phi_d > 70 degrees results in dynamical and surface landslides. Especially, the simulation with phi_d = 80 degrees produces an axisymmetric top shape.

The simulation with phi_d = 80 degrees but with slower spinup rate beta = 0.05 results in non-axisymmetric landslide and the formation of a non-axisymmetric shape. Thus Our simulations show that fast spinup with beta ~ 1 of spherical body with phi_d > 70 degrees produces axisymmetric top shapes.

The friction angle phi_d > 70 degrees is much larger than that of cohesionless granular materials. This suggests that the other strength of granular materials such as cohesion is also important for the formation of top shapes. The YORP spinup gives beta << 1, while gravitational accumulation of fragments gives beta > 1. Thus our results suggest that top shapes are possibly formed through fast spinup due to reaccumulation of fragments or coalescence of remnants after collisional catastrophic disruption. Another

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possibility is multiple non-axisymmetric landslides. The timescale for the YORP spinup is mainly shorter than collisional lifetime for 1-km sized asteroids, and they probably experience multiple cycles of YORP acceleration and non-axisymmetric landslides. Multiple non-axisymmetric landslides at different places may lead to the formation of axisymmetric top shapes.

Keywords: top shapes, spinup of asteroids, numerical simulation, SPH method

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YORP Effect on Asteroid Ryugu

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The Yarkovsky and YORP effects are recoil force induced by thermal radiation from a surface of an asteroid, which secularly alter the orbit and the spin state of the body, respectively. The combined effect of Yarkovsky and YORP is a key to shed light on the dynamical evolution of asteroid 162173 Ryugu such as the orbital migration from the main belt to a near-Earth orbit and the formation mechanism of the spinning top shape. In this presentation, we aim to investigate the spin-down process of Ryugu from the fast rotation in the past to the current mild spin and compare its time scale with the surface age of the asteroid estimated from the crater statistics.

We conducted a numerical simulation of the YORP effect on asteroid Ryugu based on the orbit, the spin state and the 3-dimensional shape as revealed by Hayabusa2. Given a polyhedral shape model of 49,152 surface facets constructed by the stereo-photoclinometry (SPC), we computed the net torque on Ryugu to change the rotation period and the spin pole direction. As a result, Ryugu is currently decreasing the spin rate (spinning down) in the so-called YORP time scale of 1.2 million years. On the other hand, the obliquity of Ryugu, that is, the tilt angle of the spin pole is increasing toward the obliquity of 180 degrees. The attached figure shows the obliquity dependence of the YORP effect on Ryugu. The solid and dashed curves represent the rate of change of the obliquity and the spin rate of Ryugu. Note that the obliquity curve has the asymptotic nodes where the spin pole becomes stabilized at 0, 90 and 180 degrees. For Ryugu, there are thresholds around the obliquity of 36 and 144 degrees which determine the subsequent evolution of the spin state. The vertical dotted line at the obliquity of 172 degrees denotes the current value of Ryugu, where the spin rate is decreasing and the spin pole approaches an obliquity perpendicular to the orbital plane.

Moreover, we surveyed various initial spin states and confirmed that only limited combinations of the initial period and obliquity could reach the current spin state of Ryugu. The time scale of the spin evolution was at most 2.3 million years, which is shorter than the surface age of approximately 9 million years (Sugita et al., 2019). This study indicates that Ryugu experienced a disturbance of the spin state such as impact cratering or an Earth flyby at least in this few million years.

Keywords: Asteroid, Ryugu, YORP effect

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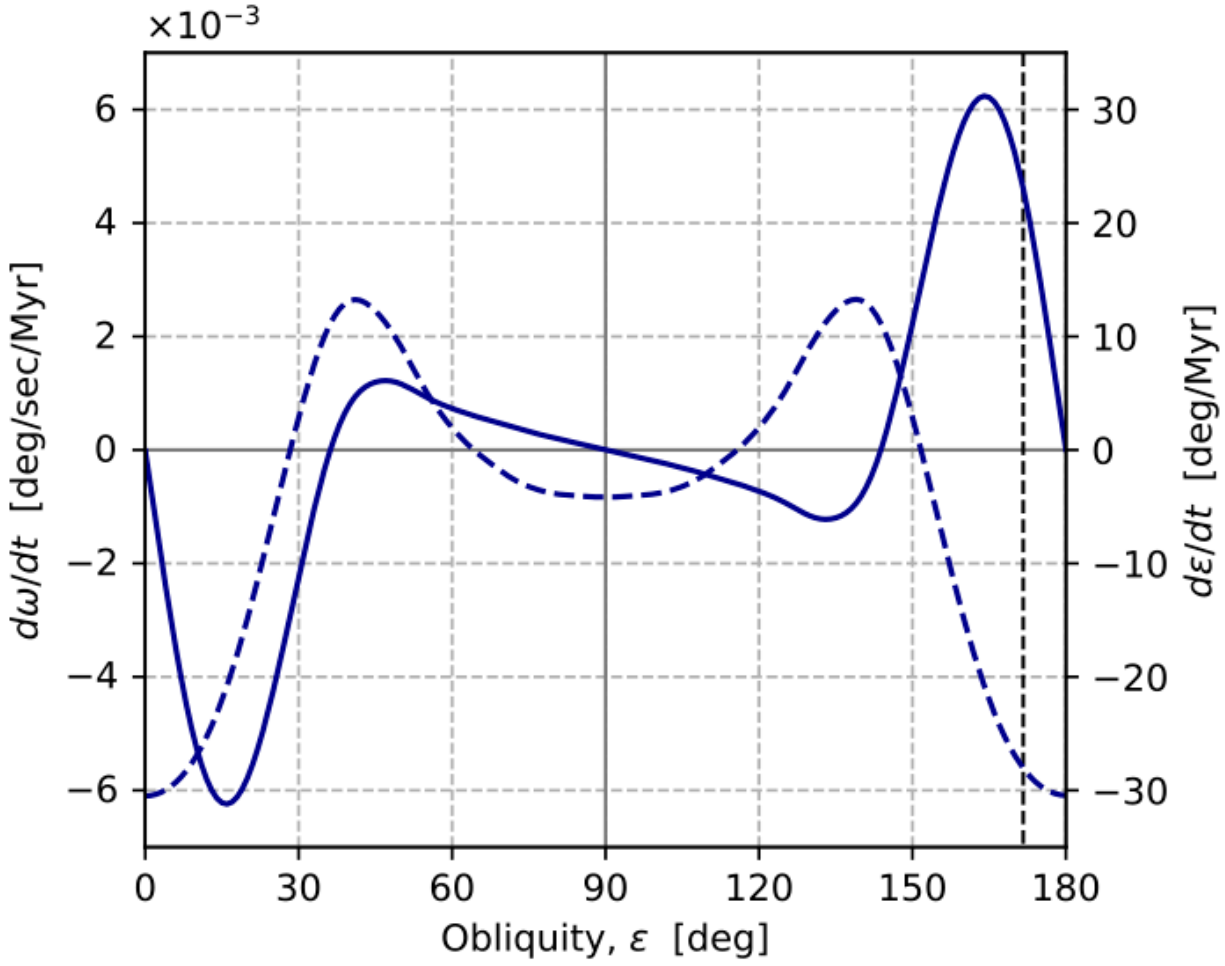

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Likelihood for rubble-pile near-Earth asteroids to be 1st or Nth generation: focus on Bennu and Ryugu

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Each asteroid collision and/or disruption event in the Main Belt produces an asteroid family consisting of a vast number of remnant objects. These families contain a distribution of sizes with many km-sized objects and fewer larger objects. All of these remnants themselves are subject to the collisional environment in the Main Belt, and many will be disrupted and destroyed, with some of the larger remnants being broken into smaller families of their own. Over time, the original family and all the subsequent generations of families drift around the Main Belt, and some small fraction of them find the dynamical pathways leading to orbits as near-Earth asteroids (NEAs). The smaller bodies, which drift faster and further, preferentially find the escape routes out of the Main Belt, which is reflected in the size of the population of NEAs. To best interpret the geology of km-sized NEAs currently being visited by space missions, we aim to determine how likely NEAs are to be 1st generation remnants from a disruption event in the Main Belt.

We created a model that tracked the survival of asteroid disruption remnants to understand the likelihood that they are direct rubble-pile products of a large asteroid family (1st generation) or the product of a slightly larger rubble pile that itself is the product of a larger asteroid family (2nd generation...up to Nth generation). The competition is between the very large numbers of the 1st generation km-sized family members racing against time to reach an escape route before being destroyed in a collision—versus 5- to 10-km rubble piles, moving much more slowly but more resistant to immediate destruction, being broken up eventually and having some of their remnants escape. We find that for scenarios in the inner Main Belt, the total number of escaping bodies is dominated by 1st generation rubble piles. For older families, those whose age is two or three times the collisional lifetime of the NEA of interest, the bodies reaching escape routes can be equal contributions of 1st and Nth generation rubble piles. Thus, the answer to whether a specific NEA is more likely a 1st or Nth generation rubble pile depends on knowledge of its parent family and that family's age.

Keywords: Near-Earth Asteroids, Rubble Pile Asteroids

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[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS08] Mars and Mars system: results from a broad spectrum of Mars studies and aspects for future missions

convener:Hideaki Miyamoto(University of Tokyo), Tomohiro Usui(Japan Aerospace Exploration Agency), Yuki Harada(Kyoto University), Sushil K Atreya(University of Michigan Ann Arbor)

NASA's Magnetospheric Multiscale (MMS) formation flying satellites have been making unprecedentedly high time resolution measurements of collisionless plasmas in and around Earth's magnetosphere since it was launched in 2015. After completing its nominal mission in 2018, MMS has continued its observations including targeting the magnetic reconnection in the Earth's magnetotail.
The major purpose of this session is to summarize the new world of electron physics that MMS has so far revealed and also to consider a future observation plan recently submitted by the mission team for the extended mission of MMS especially during the coming several years.
The collaboration with multiple missions including Geotail, Cluster II, THEMIS, Arase and other solar terrestrial probes while MMS focuses into electron scale is the key to understanding multiscale phenomena in the Earth's magnetosphere.
We solicit contributions from satellite observations, numerical simulations, laboratory observations, and theories that relate MMS observations. Contributions to the possible future observation plans are especially welcome.
This is a joint session with American Geophysical Union (AGU).
We hope this session will promote further international collaboration among Japan, United States and space physicists all over the world.

[PPS08-01] On possibility of visualization of Martian space environment with diffuse aurora: Relations between magnetic field structure and solar energetic electron penetration into the upper atmosphere observed by MAVEN

*Kanako Seki[1], Takuya Hara[2], Dave A Brain[3], Rob J. Lillis[2], Naoki Terada[4], Hiromu Nakagawa[4], Darvin E. Larson[2], Dave L. Mitchell[2], Gina A. Dibraccio[5], Nicholas McCord Schneider[3], Sonal K. Jain[3], Janet G. Luhmann[2], Bruce M. Jakosky[3] (1.Graduate School of Science, University of Tokyo, 2.Space Sciences Laboratory, University of California, Berkeley, 3.LASP, University of Colorado, Boulder, 4.Graduate School of Science, Tohoku University, 5.Goddard Space Flight Center, NASA)

[PPS08-02] Low electron temperatures observed at Mars by MAVEN on dayside crustal magnetic field lines

★Invited Papers

*Shotaro Sakai[1,2], Thomas E. Cravens[3], Laila Andersson[4], Christopher M. Fowler[5], David L. Mitchell[5], Christian Mazelle[6], Edward M. B. Thiemann[4], David A. Brain[4], Kanako Seki[1] (1.Graduate School of Science, University of Tokyo, 2.Graduate School of Science, Tohoku University, 3.Department of Physics and Astronomy, University of Kansas, 4.Laboratory for Atmospheric and Space Physics, University of Colorado Boulder, 5.Space Science Laboratory, University of California, Berkeley, 6.IRAP, Université de Toulouse, CNRS, CNES, UPS-OMP)

[PPS08-03] A warm layer in the nightside mesosphere of Mars

*Hiromu Nakagawa[1], Sonal K Jain[2], Nicholas M Schneider[2], Franck Montmessin[3], Roger V Yelle[4], Fayu Jiang[4], Loic Verdier[3], Takeshi Kuroda[1], Nao Yoshida[1], Hitoshi Fujiwara[5], Takeshi Imamura[6], Kaori Terada[1], Naoki Terada[1], Kanako Seki[7], Hannes Groller[4], Justin I Deighan[2] (1.Planetary Atmosphere Physics Laboratory, Department of Geophysics, Graduate School of Science, Tohoku University, 2.Laboratory for Atmospheric and Space Physics, University of Colorado, 3.Laboratoire Atmosphères, Milieux, Observations Spatiales, 4.Lunar and Planetary Laboratory, University of Arizona, 5.Faculty of Science and Technology, Seikei University, 6.Graduate School of Frontier Sciences, The University of Toky, 7.Graduate School of Science, The University of Tokyo)

[PPS08-04] **Studying martian dust storms, clouds, and associated meteorology using observations from Indian and foreign satellite missions**

*JAGABANDHU PANDA [1], Bijay Kumar Guha[1] (1.National Institute of Technology Rourkela)

[PPS08-05] Greeley et al. (2006) revisited: the size distribution and frequency of dust devils at the Gale crater

*Kazunori Ogohara[1] (1.School of Engineering, University of Shiga Prefecture)

[PPS08-06] Observations of the Martian atmosphere by NOMAD on ExoMars Trace Gas Orbiter
★Invited Papers

*Ann Carine Vandaele[1], Frank Daerden[1], Ian R. Thomas[1], Shohei Aoki[1,2], Cédric Depiesse[1], Justin T. Erwin[1], Lori Neary[1], Bojan Ristic[1], Yannick Willame[1], Jean-Claude Gérard[2], Giuliano Liuzzi[3], Geronimo Villanueva[3], Jon Mason[4], Manish R. Patel[4], Francesca Altieri[5], Giancarlo Bellucci[5], Miguel Lopez-Valverde[6], Jose-Juan Lopez-Moreno[6] (1.Royal Belgian Institute for Space Aeronomy, Brussels, Belgium, 2.Laboratory for Planetary and Atmospheric Physics, University Liège, Belgium, 3.NASA Goddard Space Flight Center, Greenbelt, MD, USA, 4.School of Physical Sciences, The Open University, Milton Keynes, UK, 5.Istituto di Astrofisica e Planetologia Spaziali (IAPS/INAF), Rome, Italy, 6.Instituto de Astrofisica de Andalucia (IAA/CSIC), Granada, Spain)

On possibility of visualization of Martian space environment with diffuse aurora: Relations between magnetic field structure and solar energetic electron penetration into the upper atmosphere observed by MAVEN

*Kanako Seki[1], Takuya Hara[2], Dave A Brain[3], Rob J. Lillis[2], Naoki Terada[4], Hiromu Nakagawa[4], Darvin E. Larson[2], Dave L. Mitchell[2], Gina A. Dibraccio[5], Nicholas McCord Schneider[3], Sonal K. Jain[3], Janet G. Luhmann[2], Bruce M. Jakosky[3]

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MAVEN observations revealed existence of a new type of aurora, diffuse aurora, which illuminates an extended region of Martian upper atmosphere in terms of longitude and latitude and does not related to the crustal magnetic fields [Schneider et al., 2015; 2018]. The diffuse aurora is considered to be caused by the SEP (solar energetic particle) electrons [Gerard et al., 2017]. Since Mars has no global intrinsic magnetic field, direct interaction between the solar wind and Martian upper atmosphere results in the draping of the interplanetary magnetic field (IMF) around Mars and forms the induced magnetosphere. The diffuse aurora observation in the northern hemisphere, where the crustal field is absent, indicates penetration of the high-energy electrons of ~100 keV down to the altitudes around 70 km most likely along the draped IMF around the planet. However, to what extent the draped magnetic field configuration around Mars controls the SEP electron penetration to the atmosphere is far from understood.
In this study, we investigated three SEP events observed by MAVEN in December 2014, March 2015, and September 2017. The pitch angle (PA) distributions of the high-energy (30-210 keV) electrons observed in the Martian ionosphere are analyzed in details. In order to achieve a good coverage in the 2-D (PA-energy) phase space, data obtained during a SEP event is accumulated and binned. Using the elevation angle of the local magnetic field, we also sorted the data so as to investigate the SEP electron loss below the MAVEN periapsis (~150 km altitude). The obtained PA distributions in the ionosphere are compared with the distributions of the source electrons in the magnetosheath. The results show that the field-aligned component is pronounced for the penetrating electrons and it does not significantly depend on the initial PA distributions in the magnetosheath. The observation also indicates that the highest energy of the SEP electrons lost into the Martian atmosphere depends on the magnetic field configuration draped around the planet. The SEP electron loss into the atmosphere is larger in higher SZA, suggesting the deeper penetration of draped magnetic fields in the nightside than dayside. These results support the scenario that the solar energetic electrons penetrate into the ionosphere along the draped magnetic field and the altitude to which they can penetrate depends on the magnetic field configuration. In other words, global diffuse aurora observations can give a new tool to visualize Martian space environment for understanding interaction between the solar wind and Martian upper atmosphere, especially the dynamics of the nightside ionosphere.

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Keywords: aurora, space weather, magnetic field structure

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Low electron temperatures observed at Mars by MAVEN on dayside crustal magnetic field lines

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The ionospheric electron temperature is important for determining the neutral/photochemical escape rate from the Martian atmosphere via the dissociative recombination of O_2^+. The Langmuir Probe and Waves instrument onboard MAVEN (Mars Atmosphere and Volatile EvolutioN) measures electron temperatures in the ionosphere. The current paper studies electron temperatures in the dayside for two regions where: (1) crustal magnetic fields are dominant and (2) draped magnetic fields are dominant. Overall, the electron temperature is lower in the crustal-field regions, namely, the strong magnetic field region, which is due to a transport of cold electrons along magnetic field lines from the lower to upper atmosphere. The electron temperature is also greater for high solar extreme ultraviolet (EUV) conditions, which is associated with the local EUV energy deposition. The current models underestimate the electron temperature above 250 km altitude in the crustal-field region. Electron heat conduction associated with a photoelectron transport in the crustal-field regions is altered due to kinetic effects, such the magnetic mirror and/or ambipolar electric field because the electron mean free path exceeds the relevant length scale for electron temperature. The mirror force can affect the electron and heat transport between low altitudes, where the neutral density and related electron cooling rates are the greatest, and high altitudes, while the ambipolar electric field decelerates the electron's upward motion. These effects have not been included in current models of the electron energetics, and consideration of such effects on the electron temperature in the crustal-field region should be considered for future numerical simulations.

Keywords: Mars, Electron temperature, Crustal magnetic field, MAVEN, Ionosphere, Atmospheric escape

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A warm layer in the nightside mesosphere of Mars

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We report a new set of stellar occultation measurements for nightside temperature profiles made by the MAVEN/IUVS that provide evidence for a recurring layer of warm air between 70 - 90 km altitudes in the nightside mesosphere of Mars during Ls = 0º - 180º in Martian Year 33-34. The nightside profiles reveal a recurring peak of atmospheric temperature around 80 km over the equator to the middle latitudes in the northern hemisphere. The predictions of the Mars Climate Database have a warm layer with much smaller amplitudes. The observed peak amplitudes are larger than those predicted by the model by up to 90 K. Wavenumber-3 structures are seen in the warm layer that are potentially signatures of thermal tides or stationary planetary waves, with amplitudes two-times larger than predicted.

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Studying martian dust storms, clouds, and associated meteorology using observations from Indian and foreign satellite missions

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Dust and water ice are the two major constituents in the Martian atmosphere, which significantly affect its climatic system. The dust activities over Mars could be ranging from dust devils, i.e., a few meters across, to dust storms, i.e., thousands of kilometers or more. The occurrence of dust storm events can modulate the global weather and climate by influencing the radiation budget and interacting with the primary circulation. The impact also strongly depends upon its vertical structure. Therefore, in the present study, we analyzed the aerosol profiles and associated atmospheric features during a dust storm event in early Martian southern summer based on the observations from Mars Colour Camera (MCC) onboard the Indian Mars Orbiter Mission (MOM) during October 11 and October 20, 2014 (Figure 1a). The dust storm is found to be a local-scale in nature (area calculated ~ 4.68×10^5 km^2), happened within the north-eastern portion of the Lunae Planum region on October 11, 2014, which is observed to be relatively larger during October 20. Analysis of dust and water ice extinction and temperature profile derived from the observations of Mars Climate Sounder (MCS) onboard Mars Reconnaissance Orbiter (MRO) is carried out before, during and after the dust storm period. Dustiness is found to have increased drastically at the HATDM (High Altitude Tropical Dust Maximum) layer but with a temporal delay of ~2°L_S after the dust storm disappearance (here L_S is the areocentric solar longitude). The delayed variation consequently explained the convective boundary layer growth during the dust storm scenario and is also exclusively reflected in the increased heating rate at different levels of the atmosphere. The vertical mixing time scale of dust is also found to be effective in a global dust storm scenario, which indicated a similar mechanism irrespective of the spatial extension (regional or global) of a dust storm. On the other hand, the clouds play an important role in controlling the water vapor profile; consequently, they influence transport and exchange of water with ground reservoirs and could be used to track the water vapor transport over a synoptic-scale. Again, the clouds are mostly present in the middle atmosphere, where they can interact with the dustiness. The dust and water ice are linked mechanistically by the ability of dust particles to nucleate water ice clouds, or it may modulate the air temperature by heating/cooling of itself, which consequently impacts the clouds present in the atmosphere. Therefore, we aimed to investigate the clouds over the entire tropical and subtropical latitudes over Mars. The thick clouds appear as a belt over the tropical latitude and are popularly known as Aphelion Cloud Belt (ACB), due to its appearance in the aphelion season (L_S = 0 –180°). Analysis of water ice column opacity suggests its spatial extension of nearly -20 –40°N during L_S ~ 45 –135°, wherein the three phases of ACB are identified. The cloud belt shows a northerly movement within the three phases of it, where an influence of upper-tropospheric dustiness is evident. Further, the tropical clouds are primarily dominated by the orographic clouds over the highly elevated terrains or volcanos, e.g., Olympus Mons and Arsia Mons (Figure 1b). The cloud appearance over these volcanos are found to be strongly controlled by the air temperature during the aphelion period and is more influenced by the elevated dustiness and by the circulation pattern during the perihelion period.

Keywords: dust storms, clouds, Lunae Planum, Aphelion Cloud Belt , Arsia Mons , Olympus Mons

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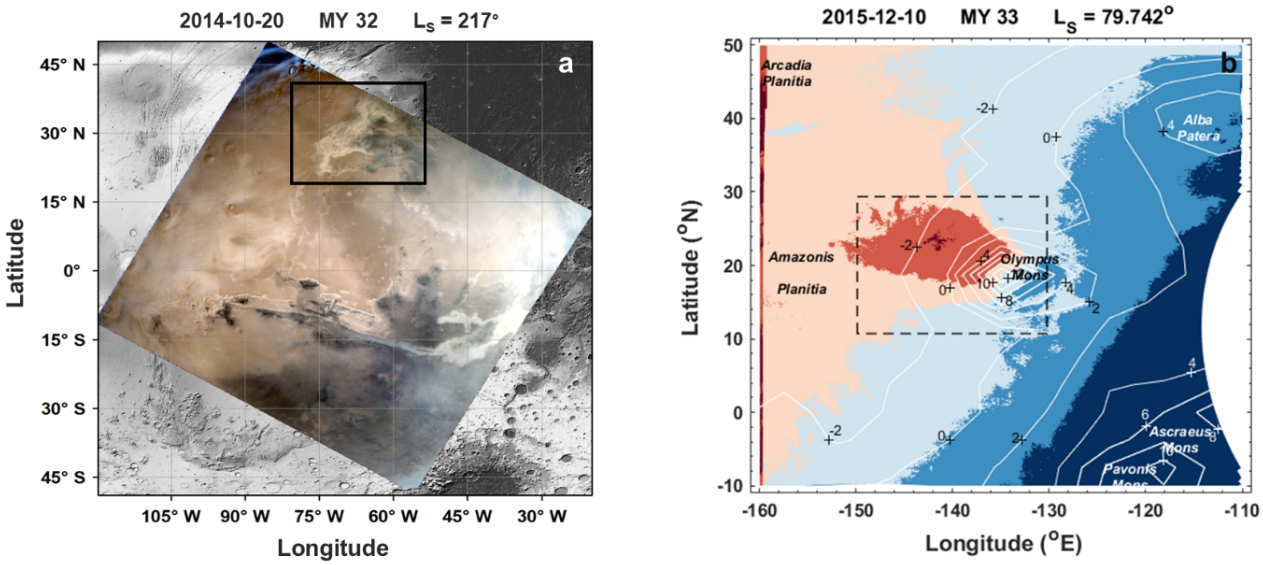

Figure 1. MOM/MCC images: (a) of visible band on October 20, 2014, i.e., Ls ~ 217°, MY 32 showing a small-scale dust storm event within the far north of the Lunae Planum region (marked by solid rectangle), (b) of blue band on December 12, 2015, i.e., Ls ~ 79°, MY 33 showing water ice clouds observed over the western sides of calderas of Olympus Mons and nearby region (marked by dashed rectangle).

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Greeley et al. (2006) revisited: the size distribution and frequency of dust devils at the Gale crater

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Many dust devils have been observed by the Pathfinder, the Spirit rover, and the Phoenix lander. The most useful statistical summary of dust devils is found in the two papers by R. Greeley and co-authors (Greeley et al., 2006; 2010). They detected visually dust devils, counted the number of the dust devils, and measured their size, lifetime, and speed. The distributions of the diameter, speed and local time, and the seasonal variation of the dust devil frequency they reported are quality statistical information describing properties of Martian dust devils near the Spirit site because of the large number of dust devils visually detected. They showed that dust devils tended to occur in the early afternoon in the southern summer season and peaked the frequency around the southern summer solstice. This can be explained by the diurnal and seasonal variations in the thickness of the boundary layer (Rennó et al., 1998)

On the other hand, there may be atmospheric phenomena that change the thickness of the boundary layer and the stability. Stationary and traveling waves in low latitudes may modify the atmospheric conditions regarding dust devil occurrences although amplitudes of the diurnal and seasonal variations are larger than those of such waves. If the atmospheric waves can modify the conditions of dust devil occurrences significantly, we can find the correlation between the phase of the waves around the Spirit rover and dust devils frequency observed by the Spirit/Navcam. However, Greeley et al. (2006; 2010) neither reported the number of dust devils observed on each sol nor listed time stamps of each observed dust devil. The correlation between the atmospheric waves and dust devil frequency cannot be investigated only based on information they showed in their paper. Therefore, we again detect dust devils from images the Spirit took, estimate the diameter of the dust devils and record the time of the occurrences.

Keywords: Mars, dust devil

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Observations of the Martian atmosphere by NOMAD on ExoMars Trace Gas Orbiter

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The NOMAD (“Nadir and Occultation for MArs Discovery”) spectrometer suite on board the ExoMars Trace Gas Orbiter has been designed to investigate the composition of Mars' atmosphere, with a particular focus on trace gases, clouds and dust probing the ultraviolet and infrared regions covering large parts of the 0.2-4.3 μm spectral range [1,2].

Since its arrival at Mars in April 2018, NOMAD performed solar occultation, nadir and limb observations dedicated to the determination of the composition and structure of the atmosphere. Here we report on the different discoveries highlighted by the instrument: investigation of the 2018 Global dust storm and its impact on the water uplifting and escape, its impact on temperature increases within the atmosphere as inferred by GCM modeling and observations, the dust and ice clouds distribution during the event, ozone measurements, dayglow observations and in general advances in the analysis of the spectra recorded by the three channels of NOMAD.

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Keywords: Mars exploration , Atmosphere composition, ESA mission

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[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS08] Mars and Mars system: results from a broad spectrum of Mars studies and aspects for future missions

convener:Hideaki Miyamoto(University of Tokyo), Tomohiro Usui(Japan Aerospace Exploration Agency), Yuki Harada(Kyoto University), Sushil K Atreya(University of Michigan Ann Arbor)

A wealth of new data from the US, European, Russian, and the Asian exploration missions are contributing to improved understanding of geologic and climate evolution and the habitability of Mars. Eight spacecraft are currently operating at Mars, with six in orbit (Odyssey, MRO, MAVEN, Mars Express, Mangalyaan and TGO) and two on the surface (MSL-Curiosity and InSight), the largest number ever at any given time. In addition, Mars 2020, ExoMars and the Emirates Mars Mission are all scheduled to be launched in 2020. JAXA's MMX mission to explore Phobos, Deimos, and Mars is scheduled for a 2024 launch. This shows that the scientific community, international space agencies and the general public are committed to the exploration of the fascinating world of Mars. Synergistic investigations of ongoing or already completed missions together with modeling studies and earth-based observations are gradually revealing the nature of Earth's most closely resembling planet, which took a different evolutionary track than the other terrestrial planets. Seasonally, temporally and episodically variable phenomena seen on the surface and the atmosphere indicate that Mars is presently active. Thus, this session is planned to discuss recent results from a broad spectrum of Mars studies encompassing the interior, surface, atmosphere, plasma environment, and the Mars system including its two satellites. Abstracts on instrumentation and future mission plans are also encouraged for this session, as both the presenters and the audience would greatly benefit from ensuing discussions and feedbacks.

[PPS08-07] Strong seasonal and diurnal variability of water D/H on Mars as revealed with ExoMars/NOMAD

★Invited Papers

*Geronimo Luis Villanueva[1], Giuliano Liuzzi[1,2], Matteo James Crismani[1], Shohei Aoki[3], Ann-Carine Vandaele[3], Michael Jon Mumma[1], Michael D Smith[1], Frank Daerden[3], Ian R Thomas[3], Miguel Angel Lopez-Valverde[4], Bojan Ristic[3], Manish R Patel[5], Giancarlo Bellucci[6], Jose Juan Lopez-Moreno[4] (1.NASA Goddard Space Flight Center, 2.Department of Physics, American University, USA, 3.Royal Belgian Institute for Space Aeronomy, Belgium, 4.Instituto de Astrofísica de Andalucía, Spain, 5.Open University, UK, 6.Istituto di Astrofisica e Planetologia, Italy)

[PPS08-08] Retrievals of ice clouds, dust and ozone from NOMAD/UVIS on board Exomars TGO

*Yannick Willame[1], Ann C. Vandaele[1], Arianna Piccialli[1], Cédric Depiesse[1], Frank Daerden[1], Ian R. Thomas[1], Bojan Ristic[1], Jon Mason[2], Manish R. Patel[2], Giancarlo Bellucci[3], Jose-Juan Lopez-Moreno[4], NOMAD Team (1.Royal Belgian Institute for Space Aeronomy (IASB-BIRA), av. Circulaire 3, 1180 Brussels, Belgium, 2.School of Physical Sciences, The Open University, Milton Keynes, UK, 3.Istituto di Astrofisica e Planetologia Spaziali (IAPS/INAF), Via del Fosso del Cavaliere, 00133 Rome, Italy, 4.Instituto de Astrofisica de Andalucia (IAA/CSIC), Granada, Spain)

[PPS08-09] Evolution of hydrological and glaciological activities on early Mars before late Tharsis formation

*Arihiro Kamada[1], Takeshi Kuroda[1], Yasumasa Kasaba[1], Naoki Terada[1], Hiromu Nakagawa[1], Katsushige Toriumi[1] (1.Graduate School of Science, Tohoku University)

[PPS08-10] Permittivity of subsurface on Mars and its importance for electromagnetic wave reflection method such as radar sounder and ground penetrating radar

*Makito Kobayashi[1], Takafumi Niihara[1], Hideaki Miyamoto[1], Atsushi Kumamoto[2], Toshiyuki Nishibori[3] (1.University of Tokyo, 2.Tohoku University, 3.Japan Aerospace eXploration Agency)

[PPS08-11] TIMINGS OF MARTIAN WRINKLE RIDES, A GLOBAL INVESTIGATION

*Trishit Ruj[1], KENJI KAWAI[1] (1.Department of Earth and Planetary Science, School of Science, The University of Tokyo)

[PPS08-12] **Displacement-Length Ratios and Contractional Strains of Wrinkle Ridges in Thaumasia Minor and Solis Planum, Mars**

DIPAYAN DASGUPTA[1], *ABHIK KUNDU[1] (1.Asutosh College, Kolkata, India)

Strong seasonal and diurnal variability of water D/H on Mars as revealed with ExoMars/NOMAD

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We present the first complete dataset of retrievals of water D/H vertical profiles derived from the Nadir and Occultation for Mars Discovery (NOMAD) instrument, onboard ExoMars Trace Gas Orbiter (TGO). NOMAD is a spectrometer operating in the spectral ranges between 0.2 and 4.3 μm onboard ExoMars TGO. NOMAD has 3 spectral channels: a solar occultation channel (SO –Solar Occultation; 2.3-4.3 μm), a second infrared channel capable of nadir, solar occultation, and limb sounding (LNO –Limb Nadir and solar Occultation; 2.3-3.8 μm), and an ultraviolet/visible channel (UVIS –UV visible, 200- 650 nm). The infrared channels (SO and LNO) have high spectral resolution ($\lambda/d\lambda$ ~10,000-20,000) provided by echelle grating in combination with an Acousto Optic Tunable Filter (AOTF) which selects diffraction orders.

Deuterated water (HDO) is primarily quantified by probing the v1 band at 3.7 μm, corresponding to the orders 118-122 of the NOMAD/SO channel. We used information from all of these orders to quantify HDO. Water is measured with NOMAD at different diffraction orders across the whole SO wavelength range. Some strong bands, such as the v1 and v3 of water at 3.7 μm (orders 166-170), allow to probe high altitudes where the atmosphere is thin, yet these bands become too optically thick at lower altitudes (<30 km). We therefore complement the water measurements by also probing weaker bands, such as the 2v2 at 3.3 μm (orders 133-136) and lines in the 3 μm region (orders 147-149). At altitudes when different orders provide similar sensitivities, we verified that the retrievals of water were consistent between the orders. This multi-order quantification strategy ensures maximum altitude coverage and self-consistency across the database.

Measurements of water vapor vertical profiles are a key diagnostic to the escape processes acting on water on Mars. Since its first scientific operation started on 21/April 2018, the ExoMars/NOMAD instrument suite has regularly conducted solar occultation measurements that are able to provide water vapor vertical profiles with unprecedented vertical resolution (< 1 km). The occultations sample the dawn and dusk terminators, allowing us to investigate diurnal changes, while the broad range of dates (April/2018 –September/2019) spans almost a full Mars year, and permits the investigations of the seasonal cycle on the D/H. For the retrieval analysis, we employed the Planetary Spectrum Generator (PSG).

Our initial analysis of two D/H profiles measured with NOMAD reveal strong variability before and after the dust storm of 2018, indicative of a strong effect of the climatology on the water cycle and isotopic signatures. In this paper, we advance these pioneering measurements to the whole planet and a broad range of seasons. Our latest results show dramatic variability of the D/H across seasons and over short time scales. The D/H is expected to vary due to the Vapor Pressure Isotope Effect (VPIE), which produces

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an isotopic fractionation at condensation (e.g., cloud formation and frost/ground fog formation), yet the observed localized (in time and space) anisotropies are certainly higher than was predicted by current atmospheric models. In this presentation, we will discuss different possible scenarios that may explain this variability and will discuss how these short-term processes impact our ability to estimate water loss from atmospheric D/H measurements.

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Retrievals of ice clouds, dust and ozone from NOMAD/UVIS on board Exomars TGO

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The NOMAD (“Nadir and Occultation for MArs Discovery”) spectrometer suite on board the ExoMars Trace Gas Orbiter (TGO) has been designed to investigate the composition of Mars' atmosphere using a suite of three spectrometers operating in the UV-visible and infrared. NOMAD is a spectrometer operating in ultraviolet (UV), visible and infrared (IR) wavelengths covering large parts of the 0.2-4.3 μm spectral range [1].

The UV-visible “UVIS” instrument covers the spectral range from 200 to 650 nm and can perform solar occultation, nadir and limb observations [2]. The main purpose of UVIS is dedicated to the analysis and monitoring of ozone and aerosols such as dust and ice clouds. In the present work we will present preliminary results of UV retrievals recorded in nadir geometry: spatial and seasonal distribution of ice clouds, dust and ozone.

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Evolution of hydrological and glaciological activities on early Mars before late Tharsis formation

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The present Mars is cold and arid environment with little stable water on surface. However, the planetary environment on early Mars would have been quite different from that on the current Mars. Many observations have shown geological evidences for the past Martian environment, which should have been moderate enough to allow both the large-scale surface runoff and ice-sheet activities. These well-known geological evidences are called as “valley networks (VNs)”.The orientation of VNs in the boundary between the Late Noachian and Early Hesperian (3.85-3.6 Ga) should have been influenced by the Tharsis bulge, which is the largest volcanic plateau centered near the equator in the western hemisphere of Mars, but the formation epoch of the Tharsis bulge is still under debate [e.g. Phillips et al. 2001; Anderson et al. 2001].Recent work such as Bouley et al. [2016] suggested that the Tharsis rise might have been largely emplaced after the formation of the valley networks during the Noachian and Hesperian boundary. The location of the pole of Mars has shifted due to the great mass of volcanic material in the load of Tharsis. This phenomenon is called as “True Polar Wander”.

We have developed a paleo-Mars global climate model (PMGCM) assuming a $CO_2/H_2O/H_2$ atmosphere under the ‘Faint Young Sun’ condition (with a solar luminosity of ~75% of the current value) for surface pressures of between 0.5 and 2 bar, and obliquity between 20 and 60 degrees. The PMGCM has a hydrologic cycle module, which includes ocean thermodynamics and processes of water vapor advection, convection, condensation and precipitation, as well as the calculations of surface fluvial activities assuming the rainfall infiltration (base or direct runoff) and surface erosion and transportation associated with river channel activities [Kamada et al., 2020]. Also, here we implemented the pre-True Polar Wander topography [Bouley et al., 2016] to investigate the global water cycle of early Mars before late Tharsis formation. In addition, we newly developed a surface glaciological scheme and implemented into the PMGCM, which estimates the surface erosion and transportation associated with glacier activities from the accumulation, ablation, spatial velocity and temperature fields of the surface ice.

When we assumed an H_2-rich ancient Martian atmosphere and dense surface pressures (more than 1.5 bar), the PMGCM showed that the global mean annual temperature of early Mars would exceed the melting point of water in all obliquity cases, as shown in Kamada et al. [2020] which assumed the current Martian topography. However, with lower obliquities, precipitation was rather restricted in both polar regions, with less precipitation in the regions of observed VNs. In contrast, with higher obliquities, there were enough snow precipitation in southern low to middle latitudes, because larger obliquities brought larger seasonal variations in the middle to high latitudes and mixed atmosphere more complicatedly. Additionally, apparent ice sheets were formed alongside the VNs regions, which should help surface or basal glacial dynamical movements on early Mars.

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Our fluvial diagnosis model in the PMGCM showed that there would have been almost no apparent precipitation-fed surface runoffs and accompanied sediment transport in southern low to middle latitudes, and fluvial activities would have been limited to seashore or lakeshore regions. Instead, in higher obliquity cases, glaciers with basal temperatures above the melting point of water would make basal sliding and bring lots of melt-water, which would feed surface runoff in Martian southern low to middle latitudes when we assumed the terrestrial-like geothermal heat flux (30 mW m^{-2}). Moreover, such surface runoff activities would erode soft deformable bed-rock, and form U-shaped and V-shaped valleys over the long time. Our simulation results would suggest that observed VNs would have formed by glacial activities rather than riverine activities.

Keywords: Mars, hydrology, glaciology, paleo climate

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Permittivity of subsurface on Mars and its importance for electromagnetic wave reflection method such as radar sounder and ground penetrating radar

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Recent planetary explorations have successfully acquired a large amount of high- resolution remote-sensing data of extraterrestrial bodies, especially the moon and Mars. However, the surfaces of solid bodies not having the condense atmosphere are generally covered by regolith, which is an essential problem for previous remote-sensing techniques such as cameras and spectroscopies to obtain critical information to understand the evolution of solid bodies. Hence, subsurface explorations schemes, such as using seismic waves and electromagnetic waves, have been applied or being discussed. Especially, the ‘electromagnetic wave reflection method’ such as radar sounder (MARSIS and SHARAD) and ground penetrating radar (RIFMAX and WISDOM) is capable of obtaining information of subsurface within a short time and visualizing the subsurface structures without contacting the surface, and then the method would be widely used in the future landing/rover missions.

The electromagnetic wave reflection method uses the electrical property of EM waves that reflects from the boundary of the materials having the different permittivity and has the potential to visualize the subsurface structures based on the travel time of the reflected wave. The estimation of subsurface structures needs the velocity of EM waves in a medium, and the velocity is decided by the relative permittivity of medium such as rocks. However, the value of permittivity is controlled by many parameters such as frequency, temperature, water content, bulk density, chemical composition, and so on, and it is required to use the permittivity under the condition according to its state. Especially, on the Martian surface, the temperature is lower than the terrestrial condition and the water content in the soils or rocks is basically zero. So, it is required to measure the permittivity under low temperature and dry condition. We developed the measurement system which is capable of measuring the real part of permittivity of regolith simulant with 5 % measurement error under the low temperature and dry condition using the coaxial probe method. We found that the permittivity values become about 7-20 % lower at -60 ˚C, which is the average temperature on the Martian surface, compared with the room temperature. Using the measured permittivity, we calculated the permittivity structure on the subsurface on Mars. As a result, the calculated permittivity is higher about 60 % than assumed before at 1.5 km depth, which is the estimated depth to exist a water-filled lake on the Martian south polar by Orosei et al. (2018). Our results suggest that it is important to measure the permittivity of rocks under the proper condition and use it for the interpretations of the electromagnetic wave reflection method such as radar sounder and ground penetrating radar on Mars.

Keywords: Relative permittivity, Electromagnetic wave reflection method, Radar sounder, Ground penetrating radar (GPR)

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TIMINGS OF MARTIAN WRINKLE RIDES, A GLOBAL INVESTIGATION

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Wrinkle ridges are common compressional structure found on the surface of Mars. These structures are observed on the surface with volcanic floors that have suffered crustal shortening with an indefinite depth of extent of the associated low angle thrust fault and have the potential to comment on the thermal evolution of the planet. However, wrinkle ridges are also frequent on the large crater floors and the region surrounding the volcanic patera. Here, in this research work, we updated the existing global map of Martian wrinkle ridge structures (Knapmeyer et al., 2006; 2008) and thereafter, used the Buffer Crater Counting (BCC) technique to extract the age of the wrinkle ridges. We have categorized and divided the wrinkle ridges into several groups, depending on their morphological and orientational pattern. We restricted our observation on 70° on each hemisphere. We carried our mapping and crater counting (in ArcGIS) using high-resolution Context (CTX) camera images (6 m/pixel; Malin et al., 2007), Thermal Emission Imaging System (THEMIS) (Christensen et al., 2004) global mosaic and High-Resolution Stereo Camera (HRSC)-MOLA blended Digital Elevation Models (DEM) (200 m/pixel; Fergason et al., 2018).

Our result suggests that most of the Martian wrinkle ridges are formed around the mid-phase of early Hesperian i.e., ~3.50 to ~3.60 Ga old. It includes Tempe Terra (~3.59 Ga), Lunae planum (~3.58), Solis Planum (~3.52), Thaumasia Planum (~3.59 Ga) as a part of Tharsis region. However, we have found that the age of the Tharsis surrounding wrinkle ridges are older than those of their counterparts in the Tharsis bulge (Chryse Planitia ~3.63 Ga; the eastern part of the Coprates rise ~3.65 Ga). Their orientation nature of the Tharsis-circumferential implies the influence of the origin of the compressional stress from the Tharsis volcano-tectonic province. The ages of the wrinkle ridges within Tharsis bulge also corresponds to the ages of the Noachis Terra/Terra Sabaea region of the southern highlands (~3.60 Ga), wrinkle ridges on the eastern part of the Hellas basin (~3.50 and ~3.52 Ga), wrinkle ridges associated with the southern part of the Circum Hellas Volcanic Province (i.e., ~3.48 to ~3.64 Ga), wrinkle ridges on the Hesperia Planum (trending ENE ~3.54 Ga and trending ~3.46 Ga), and wrinkle ridges on the west of Arcadia Planitia (~3.56 Ga). However, wrinkle ridges on the Syrtis Major Planum (radial ~3.40 Ga and concentric ~3.39 Ga). There are two sets of wrinkle ridges on the Amenthes Planum region. Dichotomy parallel wrinkle ridges are ~3.49 Ga old. However, dichotomy perpendicular ridges are younger and in this preliminary investigation, we are getting age of ~2.68 Ga. This age indicates a much younger age than the surroundings and possibly needs fresh reinvestigation.

Keywords: MARS, TECTONICS, WRINKLE RIDGE, Buffer Crater Count

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Displacement-Length Ratios and Contractional Strains of Wrinkle Ridges in Thaumasia Minor and Solis Planum, Mars

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Statistical analyses of the planetary tectonic structures such as faults, joints and dikes are established means to comprehend stress-strain conditions throughout the history of planetary bodies. The geometric properties of the tectonic structures have been used by earlier workers to infer the rudimentary mechanical controls that helped in their origin and evolution [1]. Studies confirm that within the fault on terrestrial and planetary surfaces the maximum displacement (D_{max}) is proportional to its length (L). The D_{max}-L ratios are therefore utilized to delineate an average long-term equilibrium stress field [2, 3]. Wrinkle ridges, formed above to blind thrust faults, are compressional structures found abundantly on Mars [4]. Wrinkle Ridges in Thaumasia Minor and Solis Planum were studied using MOLA/HRSC Blended DEMs. Topographic profiles, across trends, were extracted for each wrinkle ridge near their midpoints [cf. 2] to evaluate their height and maximum displacement (D_{max}). Displacement and length values of the wrinkle ridges were plotted on a graph. The D_{max}-L ratios (γ) for wrinkle ridges of both the regions are calculated by a linear fit method [cf. 2, 5]. The γ value of ridges in Thaumasia Minor was found to be (2×10^{-3}) while that in Solis Planum is found to be (1.2×10^{-3}). The contractional strains (ε) in Thaumasia Minor and Solis Planum are estimated to be ~0.14% and ~0.1% respectively (fault plane dip θ is assumed to be 25°). These estimated values indicate that the Thaumasia Minor is more affected by compressional tectonics than the adjacent Solis planum.

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Keywords: Displacement-length ratio, Contractional strain, Wrinkle ridge

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[E] Oral | P (Space and Planetary Sciences)：P-PS Planetary Sciences

[P-PS08] Mars and Mars system: results from a broad spectrum of Mars studies and aspects for future missions

convener:Hideaki Miyamoto(University of Tokyo), Tomohiro Usui(Japan Aerospace Exploration Agency), Yuki Harada(Kyoto University), Sushil K Atreya(University of Michigan Ann Arbor)

A wealth of new data from the US, European, Russian, and the Asian exploration missions are contributing to improved understanding of geologic and climate evolution and the habitability of Mars. Eight spacecraft are currently operating at Mars, with six in orbit (Odyssey, MRO, MAVEN, Mars Express, Mangalyaan and TGO) and two on the surface (MSL-Curiosity and InSight), the largest number ever at any given time. In addition, Mars 2020, ExoMars and the Emirates Mars Mission are all scheduled to be launched in 2020. JAXA's MMX mission to explore Phobos, Deimos, and Mars is scheduled for a 2024 launch. This shows that the scientific community, international space agencies and the general public are committed to the exploration of the fascinating world of Mars. Synergistic investigations of ongoing or already completed missions together with modeling studies and earth-based observations are gradually revealing the nature of Earth's most closely resembling planet, which took a different evolutionary track than the other terrestrial planets. Seasonally, temporally and episodically variable phenomena seen on the surface and the atmosphere indicate that Mars is presently active. Thus, this session is planned to discuss recent results from a broad spectrum of Mars studies encompassing the interior, surface, atmosphere, plasma environment, and the Mars system including its two satellites. Abstracts on instrumentation and future mission plans are also encouraged for this session, as both the presenters and the audience would greatly benefit from ensuing discussions and feedbacks.

[PPS08-13] The Giant Sinkholes of Mars: Furthering our Understanding of the Red Planet's Hydrosphere

★Invited Papers

*Alexis Palmero Rodriguez[1], Hideaki Miyamoto[2], Victor Baker[3] (1.Planetary Science Institute, 2.University of Tokyo, 3.University of Arizona)

[PPS08-15] Constraining the Formation of Mars with N-body simulations of Terrestrial Planet Formation

*Patryk Sofia Lykawka[1], Takashi Ito[2] (1.School of Interdisciplinary Social and Human Sciences, Kindai University, 2.National Astronomical Observatory of Japan)

[PPS08-16] Extensive delivery of Martian ejecta to its moons: The gateway to a time-resolved history of Mars

*Hidenori Genda[1], Ryuki Hyodo[2], Kosuke Kurosawa[3], Tomohiro Usui[2], Kazuhisa Fujita[2] (1.Earth-Life Science Institute, Tokyo Institute of Technology, 2.JAXA ISAS, 3.Planetary Exploration Research Center, Chiba Institute of Technology)

[PPS08-17] Morphological characteristics of small craters of Phobos

*Ryodo Hemmi[1], Hideaki Miyamoto[1] (1.The University of Tokyo)

[PPS08-18] The MMX Rover: objectives, science goals, and contributions to the MMX mission

*Hideaki Miyamoto[1], Patrick Mitchel[2], Stephan Ulamec[3], Ute Böttger[3], Matthias Grott[3], Naomi Murdoch[4], Pierre Vernazza[5], MMX Rover team (1.University of Tokyo, 2.Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, 3.Deutsches Zentrum für Luft- und Raumfahrt e.V. , 4.Institut Supérieur de l'Aéronautique et de l'Espace, 5.Laboratoire d'Astrophysique de Marseille)

The Giant Sinkholes of Mars: Furthering our Understanding of the Red Planet's Hydrosphere

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One of the greatest puzzles in the exploration of our Solar System is the history of water on Mars. There is mounting evidence gathered over 50 years of research indicating that early in its history, oceans repeatedly formed on Mars, first in the presence of a globally interconnected hydrosphere and hundreds of millions of years later in connection to the massive disruption of vast aquifers.

Evidence of the aquifers includes the presence of chaotic terrains (zones of collapse) that are associated with catastrophic flood channels. The nature of the aquifers remains a mystery. Some researchers suggest that they might form part of a global hydrosphere confined beneath kilometers of permafrost. This hypothesis suggests that southern circum-Chryse may have had a crust exceeding abundant in volatiles. However, there is another view- that the terrain disruptions that we observe are zones where subterranean rivers transported groundwater from distal regions. The location of the aquifers that fed into the proposed underground rivers remains uncertain, though some workers have suggested the subsurface of the Tharsis volcanic rise as a likely source location. If this hypothesis is correct, subterranean river flow was a key component of Mars hydrology, which we are just beginning to understand.

The former presence of subterranean rivers has been inferred from the mapping of subsidence patterns in highland regions that adjoin large outflow channel systems. These studies suggest that the rivers flowed through immense conduits with diameters of ~10 km and perhaps larger. These features have no terrestrial analogs and hence might reflect some unique conditions that developed on Mars.

Here, we further test this hypothesis and refine its implications towards our understanding of the planet's early geologic history. We present the first identification of potential sinkholes that occur within and near the proposed region of subsidence. We used the sinkholes diameters, and their floor depths are proxies to the conduit dimensions and their distribution within the Martian upper crust. Our preliminary results confirm the gigantic nature of the conduits and appear to position their distribution at discrete elevation ranges that connect tectonic trends and unconformities that we are tracing throughout the study areas. The results outline and constrain the locations of the potential aquifers to a few areas of the Martian western hemisphere at sufficient elevations to generate the hydraulic head required to produce the subsurface flows. In this respect, we identified an unconformity in the highlands that might trace an area of collapse created when the source aquifers were drained. The area, we find, was subsequently buried by lavas.

Our results depict Mars' early hydrosphere as an extremely dynamic planetary feature and highlight the role of subterranean river flow as a substitute to surface water drainage as an essential modifier to the planet's ancient landscapes.

Keywords: Mars, Hydrosphere, Caves, Habitability

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Constraining the Formation of Mars with N-body simulations of Terrestrial Planet Formation

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Reproducing the orbits and masses of the terrestrial planets Mercury, Venus, Earth, and Mars remains elusive. To address that question, we investigated terrestrial planet formation by performing extensive N-body simulations of primordial protoplanetary disks representative of typical models in the literature. Those disks consisted of embryos and planetesimals placed up to ~1-4 au (depending on the disk model).

First, we employed our classification algorithm to identify the systems that formed planet analogs of the Venus-Earth pair (in terms of orbit and mass) plus Mercury or/and Mars in the same system. From the analysis of the terrestrial planets formed in such 3- or 4-planet system analogs, we obtained detailed properties regarding the formation and evolution of a vast number of identified Mars analogs. These properties include a-e-i-mass distributions, delivery of water/volatiles, number of giant impacts, accretion histories, and many others.

In this presentation, we also discuss the dependence of the results on the initial conditions (models considered), which allowed us to discuss the conditions that a protoplanetary disk must satisfy in order to satisfy the main properties of Mars and to form simultaneously the four terrestrial planets.

Keywords: Solar System, Terrestrial Planets, Planet Formation, Mars

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Extensive delivery of Martian ejecta to its moons: The gateway to a time-resolved history of Mars

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Mars has experienced continuous asteroidal impacts throughout its history. These have produced impact-generated Mars ejecta, and a fraction of this debris is delivered to the moons of Mars: Phobos and Deimos. We studied the amount and condition of recent delivery of impact ejecta from Mars to its moons. Using state-of-the-art numerical approaches, we report that the amount of delivered materials is 10-100 times more than previously estimated, and the delivered materials are physically and chemically different from the Martian meteorites, which are all igneous rocks with a limited range of ages. We show that Mars ejecta mixed in the regolith of its moons potentially covers all its geological eras and consists of all types of rocks, from sedimentary to igneous.

Phobos and Deimos, the two small moons of Mars, are the target bodies of the Japan Aerospace eXploration Agency (JAXA) sample return mission Martian Moons eXploration (MMX). The plan for MMX is to collect samples of more than 10 g of Phobos regolith. Assuming a typical and expected grain size, at least 30 Martian grains would exist in the returned sample. These grains will provide a wealth of time-resolved geochemical information about the evolution of Martian surface environments.

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Morphological characteristics of small craters of Phobos

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The surface of Phobos is covered by plenty of small (up to meter-sized) craters. Although most of them show a bowl-shaped morphology, some of them represent concentric, flat-floored, or central-mound geometries [1], which is considered to be related to the existence of a surface layer with a thickness comparable to their crater depth [2]. Also, the blue unit of the sub-Mars side of Phobos was interpreted as a massive landslide deposit extended from the W-NW inner wall of Stickney crater [3], which remains enigmatic. If these layered deposits having a certain thickness covered small craters, they could have been partially modified or obliterated. We have recently investigated the topographic profiles of sub-kilometer craters of Phobos by creating 20 m/pixel MRO/HiRISE stereo-derived digital terrain model (DTM), and found that their crater depth/diameter ratios (d/D) are comparable between the red and blue units in a diameter range of 100 to 1,000 m, and the inner wall of a crater inside the blue unit is affected by a post-crater depositional event [Hemmi and Miyamoto, in revision]. Thus, in this study, we aim to quantitatively characterize the morphology of craters smaller than 100 m in diameter by using a highest resolution DTM.
Here we performed noise reduction and bundle adjustment of HiRISE stereo-pair images of Phobos [4] by means of the U.S. Geological Survey's ISIS3, and then created a highest-resolution (~6.5-m/pixel) DTM by using our stereo-derived DTM and the multi-view shape-from-shading technique [5]. Consequently, the resulted DTM enables us to measure precise measurements of the small craters' depths and to study unique crater floor geometries in detail. We will discuss the results of morphometric measurements of these craters in comparison with those of craters larger than 100 m at the meeting.

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Keywords: Phobos, HiRISE, DTM

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The MMX Rover: objectives, science goals, and contributions to the MMX mission

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The Martian Moons eXploration (MMX) will carry the small (~25kg) rover, which is mainly contributed by the Centre National d’ Etudes Spatiales (CNES) and the German Aerospace Center (DLR). The rover is designed as a scout, a demonstrator, and an in-situ science investigator, and will survive >100 days on the surface of Phobos. The primary objective of the rover is increasing the landing safety of the MMX mothership, which is planned to obtain >10 g of samples including at depth >2cm from each of two sampling sites. Scientific objectives of the rover include 1) understanding the physical properties and mechanical behaviors of Phobos regolith, 2) in-situ geological and geochemical survey of the roving area; 3) mineralogical study of the surface material at the landing/roving area; 4) understanding the thermal properties of the surface; and 5) studying the heterogeneity of the surface at various scales. The scientific payload of the rover consists of four instruments, such as the IR radiometer; miniRad, which is designed mainly to characterize the thermal properties of the regolith; NavCams, which is composed of two cameras in stereo and will observe the soil and landscape in front of the rover in color; RAX, which is a Raman spectrometer for characterizing the composition of the ground just below the rover; and WheelCams, which consists of two cameras looking at the interface between the wheel of the rover and the surface to characterize the behavior of regolith. The rover is in a significantly important position in multi-scale observations between the global observations of the MMX mothership and the very localized precise information obtained from the returned sample. The rover team is now composed of 39 Co-Is and 23 collaborators and is working together with all science sub teams (SST) of the MMX mission, especially the Surface Science and Geology SST (Science Sub Team).

Keywords: MMX, rover, Phobos, Mars, exploration

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM11] Heliosphere and Interplanetary Space

convener:Kazumasa Iwai(Institute for Space–Earth Environmental Research (ISEE), Nagoya University), Yasuhiro Nariyuki(Faculty of Education, University of Toyama), Ken Tsubouchi(University of Electro-Communications), Masaki N(Japan Aerospace Exploration Agency, Institute of Space and Astronautical Science)

[PEM11-01] Stream Interaction Regions in the Inner Heliosphere: Insights from the First Four Orbits of Parker Solar Probe

★Invited Papers

*Robert Colby Allen[1], George Ho[1], Lan K Jian[2], David Lario[2], Dusan Odstrcil[2], Charles Nick Arge[2], Sam T Badman[4,5], Steward D Bale[4,5,7,8], John W Bonnell[5], Anthony W Case[9], Eric R Christian[2], Christina M. S. Cohen[3], Thierry Dundok de Wit[10], Keith Goetz[11], Peter R Harvey[5], Carl J Henney[12], Matt E Hill[1], Shaela I Jones[2,6], Justin C Kasper[13,9], Kelly E Korreck[9], Davin Larson[5], Roberto Livi[5], Robert J MacDowall[2], David M Malaspina[14], Glenn M Mason[1], M Leila Mays[2], David J McComas[15], Ralph McNutt Jr.[1], Don G Mitchell[1], Marc Pulupa[5], Nour Raouafi[1], Nathon Schwadron[16], Michael L Stevens[9], Sarah K Vines[1], Phyllis L Whittlesey[5], Mark Wiedenbeck[17] (1.Johns Hopkins University Applied Physics Laboratory, 2.NASA/Goddard Space Flight Center, 3.California Institute of Technology, 4.Physics Department, University of California Berkeley, 5.Space Sciences Laboratory, University of California Berkeley, 6.Catholic University of America, 7.The Blackett Laboratory, Imperial College London, 8.School of Physics and Astronomy, Queen Mary University of London, 9.Smithsonian Astrophysical Observatory, 10.LPC2E, CNRS, 11.School of Physics and Astronomy, University of Minnesota, 12.Air Force Research Laboratory, Space Vehicles Directorate, 13.Climate and Space Sciences and Engineering, University of Michigan, 14.Laboratory for Atmospheric and Space Physics, University of Colorado Boulder, 15.Princeton University, Department of Astrophysical Sciences, 16.University of New Hampshire, Space Science Center, 17.Jet Propulsion Laboratory)

[PEM11-02] Hinode Observation of Sun’s Polar Regions over a solar cycle

*Daikou Shiota[1], Masumi Shimojo[2] (1.National Institute of Information and Communications Technology (NICT), 2.National Astronomical Observatory of Japan)

[PEM11-03] Coronal radio sounding using Akatuski spacecraft: variation in the solar cycle

*Shota Chiba[1], Takeshi Imamura[1], Munetoshi Tokumaru[2], Ayumi Asai[3], Hiroaki Isobe[4], Daikou Shiota[5], Takuma Matsumoto[6], Hiroki Ando[7] (1.Graduate School of Frontier Sciences, The University of Tokyo, 2.Institute for Space-Earth Environmental Research, Nagoya University, 3.Astronomical Observatory, Kyoto University, 4.Faculty of Fine Arts, Kyoto City University of Arts, 5.National Institute of Information and Communications Technology (NICT), 6.Nagoya University, Ta Lab, 7.Kyoto Sangyo University)

[PEM11-04] Global distribution of the solar wind speed during Cycle 22-24

*Munetoshi Tokumaru[1], Ken'ichi Fujiki[1], Kazumasa Iwai[1], Nobuhiko Nishimura[1], Ryuya Maeda[1] (1.Institute for Space-Earth Environmental Research, Nagoya University)

[PEM11-05] Next generation interplanetary scintillation observation telescope using 2D phased array system

*Kazumasa Iwai[1], Munetoshi Tokumaru[1], Ken'ichi Fujiki[1] (1.Institute for Space–Earth Environmental Research (ISEE), Nagoya University)

Discussion

Stream Interaction Regions in the Inner Heliosphere: Insights from the First Four Orbits of Parker Solar Probe

*Robert Colby Allen[1], George Ho[1], Lan K Jian[2], David Lario[2], Dusan Odstrcil[2], Charles Nick Arge[2], Sam T Badman[4,5], Steward D Bale[4,5,7,8], John W Bonnell[5], Anthony W Case[9], Eric R Christian[2], Christina M. S. Cohen[3], Thierry Dundok de Wit[10], Keith Goetz[11], Peter R Harvey[5], Carl J Henney[12], Matt E Hill[1], Shaela I Jones[2,6], Justin C Kasper[13,9], Kelly E Korreck[9], Davin Larson[5], Roberto Livi[5], Robert J MacDowall[2], David M Malaspina[14], Glenn M Mason[1], M Leila Mays[2], David J McComas[15], Ralph McNutt Jr.[1], Don G Mitchell[1], Marc Pulupa[5], Nour Raouafi[1], Nathon Schwadron[16], Michael L Stevens[9], Sarah K Vines[1], Phyllis L Whittlesey[5], Mark Wiedenbeck[17]

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The first four orbits of Parker Solar Probe (PSP) consists of many observations of stream interaction regions (SIRs), which form when fast solar wind streams overtake slower solar wind. While it is known that SIRs accelerate ions in the heliosphere and can trigger geomagnetic storms, the temporal and radial evolution of SIRs is still an active topic of research. During the first four orbits of PSP, SIRs were observed by PSP at small heliospheric distances, as well as at 1 au by the Advanced Composition Explorer (ACE), Wind, and Solar Terrestrial Relations Observatory (STEREO) missions. These SIRs are observed not only at different heliospheric distances, but also at different points in the temporal development of the stream interface. Through analyzing the various SIRs together, insight can be gained in regards to the spatial and temporal evolution of SIR characteristics, as well as to the mechanisms of particle acceleration and transport along the SIR interface. The general characteristics of SIRs observed by PSP during the first four orbits are presented, and an in-depth comparison of a few of the SIR events is conducted to further analyze the evolution of SIR streams in the inner heliosphere. These observations show examples of a fast solar wind stream steepening into an SIR, with evidence of locally accelerated particles via compressive mechanisms at the interface distinguishable from observations of particles likely accelerated at shocks formed at larger heliospheric distances.

Keywords: Stream Interaction Regions, Corotating Interaction Regions, Solar Wind, Acceleration

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Hinode Observation of Sun’s Polar Regions over a solar cycle

*Daikou Shiota[1], Masumi Shimojo[2]

1. National Institute of Information and Communications Technology (NICT), 2. National Astronomical Observatory of Japan

Observations of the magnetic fields in the Sun’s polar regions are of crucial importance to understand the long-term variation of solar magnetism. As a consequence of the magnetic variation the three-dimensional structure of global solar corona and solar wind also show a drastic long-term variation and, as a result, fast solar wind emanates from the polar regions around solar minima. The first Hinode observation of the polar region reveals the fine structure of photospheric vector magnetic fields of the polar areas: the existence of many patchy magnetic concentrations with intrinsic field strengths of over 1 kG distributed across the entire polar region (Tsuneta et al. 2008) around the solar minimum. Following the first polar observation, the monitoring of the polar regions has been continued for 12 years. Since 2012, which was before the solar maximum of this cycle, the time variations in the distribution of the whole polar regions during the polarity reversal period have been monitored with periodic SP observations during a month at the proper timing (March for the south pole and September for the north pole). The monitoring revealed that the distributions of large magnetic patches show yearly variations associated with the solar activity cycle while small magnetic patches does not change. The polarity reversal of the northern polar region progressed prior to that of the south in the early stage of the this cycle: The decrease of large negative patched in the north polar region is earlier than the decrease of large positive patches in the southern polar region as similar to shown in the previous work (Shiota et al. 2012). As most of the negative magnetic patches in the north polar region had disappeared by 2013, the average magnetic field of the north polar region became nearly zero and had remained so until 2015. we can see significant increase in the large positive patches after 2016. On the other hand, the reversal process progressed so quickly. Now, the Sun comes the solar minimum state, the polarity reverse seems to complete in this cycle.

Keywords: Sun's polar region, solar magnetism

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Coronal radio sounding using Akatuski spacecraft: variation in the solar cycle

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Radio occultation observation is one of the limited means to approach the dark and hot coronal region. Quasi-periodic density fluctuations that are considered to be acoustic waves were detected by radio occultation observations in 2011 using radio waves transmitted from the Japanese Venus explorer Akatsuki and received at the ground station during the superior conjunction period. The acoustic waves were considered to have been generated from the nonlinearity of Alfven waves that originate from the photosphere. However, since the observation was limited to a certain period of the 11-year solar activity cycle, to what extent the suggested features are typical and the variability in the solar cycle are uncertain. In this research, we analyze radio occultation observations carried out during the superior conjunction periods from 30 May 2016 to 15 June 2016 and from 29 December 2017 to 20 January 2018 as well as the observations in 2011. Solar offset distances of about 2 to 10 solar radii were probed intermittently 11 times in the former period and 10 times in the latter period. The time series data of frequency and intensity of radio waves received at the ground station are analyzed. Radial velocities of the solar wind are estimated from intensity spectra, and wavelet analysis is applied to the frequency time series to detect quasi-periodic density fluctuations that are thought to be manifestations of acoustic waves. The solar wind velocities near the Sun obtained by the radio occultation observations and those at far distances measured by IPS (Interplanetary Scintillation) observations are compared. We also aim to clarify the dependence on the solar activity by analyzing all observational data from 2011 to 2018.

Keywords: radio sounding observation, solar corona, solar wind acceleration

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Global distribution of the solar wind speed during Cycle 22-24

*Munetoshi Tokumaru[1], Ken'ichi Fujiki[1], Kazumasa Iwai[1], Nobuhiko Nishimura[1], Ryuya Maeda[1]

1. Institute for Space-Earth Environmental Research, Nagoya University

Observations of interplanetary scintillation (IPS) at 327 MHz have been conducted since 1980s at ISEE of Nagoya University using multi-station system. The IPS observations enable reliable determination of global distribution of the solar wind (SW) speed via the computer assisted tomography analysis. We investigated long-term variation of the solar wind speed distribution for the period between 1985 and 2020, which covers solar cycles (SCs) 22-24. The solar activity dropped significantly during this period, and peculiar aspects of the solar wind structure have been reported from several studies for SC24. Derived SW data clearly demonstrate that global distribution of SW speed changes systematically with the solar cycle. At solar minima, the fast SW develops over the polar region, and the slow SW is located at equatorial region. At solar maxima, the fast SW diminishes in size, and the slow SW dominates at all latitudes. This solar cycle variation of SW show good correlation with polar field strength. One of prominent features found for SC24 data is an increase in fast wind area at low latitudes. Another features of SC24 data is enhanced North-South asymmetry of slow wind distribution, particularly for the period between 2011 and 2015; i.e. at solar maximum of SC24. These are considered as heliospheric responses to the peculiar solar activity in SC24.

Keywords: interplanetary scintillation, solar wind, solar cycle, space weather

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Next generation interplanetary scintillation observation telescope using 2D phased array system

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1. Institute for Space–Earth Environmental Research (ISEE), Nagoya University

There are still many important issues in the heliospheric physics, such as the acceleration and propagation of the solar wind, propagation of coronal mass emissions (CMEs) in the inner heliosphere, the global structure of the heliosphere, and its variations associated with the solar activity. These issues are also important for the space weather forecasting. Interplanetary scintillation (IPS) is a radio scattering phenomenon caused by the disturbances in the solar wind. The IPS observation using ground-based radio telescopes has been an important technique to investigate the global structure of the heliosphere. We, Nagoya University, have observed the solar wind velocity and density irregularities for several decades using our own large radio telescopes at 327 MHz. Recently, the unusual solar actively makes complex solar wind distributions, which requires more detailed IPS observations. Detecting CME structures is also required to forecast the arrival of CMEs. In this study, we investigated the design of next generation IPS observation instruments, and developed their pathfinders.
Multi-point IPS observations throughout the year are required for more detailed reconstructions of the solar wind velocity distributions. In order to realize the IPS observation even in the snowfall season, we considered a flat two-dimensional phased array with a wide field of view. This structure is also resistant to natural disasters such as typhoons by eliminating the drive unit. The real time digital signal processing of the receiver system is required for the digital multi beam forming that observes multiple directions simultaneously. This system will enable us to take several all-sky IPS maps within a day to track fast CMEs. This system is also able to detect the passage of CMEs and derive their structures by tracking a specific radio source. One of the important development parts in this project will be the digital signal processing part that requires about 1000 units of digital boards. We designed and developed a low-cost digital board dedicated to the IPS observation using ADCs and FPGAs, and found that the digital board has enough performance. The developed prototype is able to process 8 signals simultaneously and has a size of 37cm x 27cm, which is a reasonable size for the mass-production.

Keywords: Heliosphere, Interplanetary scintillation, phased array, instrument , Radio telescope, coronal mass emissions (CMEs)

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM11] Heliosphere and Interplanetary Space

convener:Kazumasa Iwai(Institute for Space–Earth Environmental Research (ISEE), Nagoya University), Yasuhiro Nariyuki(Faculty of Education, University of Toyama), Ken Tsubouchi(University of Electro-Communications), Masaki N(Japan Aerospace Exploration Agency, Institute of Space and Astronautical Science)

This session aims to secure comprehensive insights into physical processes of plasmas and fields in the heliosphere. Presentations of the recent studies from any approaches (integrated observation/theoretical modeling/massive numerical simulation) are welcomed. Topics are not restricted to any specific issues: phenomenological studies on solar flares/CME/solar wind, and related fundamental physics problems such as shocks/waves/turbulence/particle transport and acceleration can be the main target, including heliospheric high-energy phenomena and their impact on the Earth's environment.

[PEM11-07] **Ion scale waves and kinetic instabilities in the inner heliosphere**

*Jungjoon Seough[1], Yasuhiro Nariyuki[2], Peter Yoon[1,3,4], Kyung-Suk Cho[1] (1.KASI, 2.UT, 3.UMD, 4.KHU)

[PEM11-08] Effects of initial density fluctuations on linear and nonlinear evolution of parametric decay instabilities of circularly polarized Alfven waves

*Yasuhiro Nariyuki[1] (1.Faculty of Education, University of Toyama)

[PEM11-09] **Search of energy source of 1-16Hz Whistler Mode Waves Detected by Kaguya in the Lunar Polar Orbit**

*Tomoko Nakagawa[1], Futoshi Takahashi[2], Hisayoshi Shimizu[3], Yoshifumi Saito[4] (1.Information and Communication Engineering, Tohoku Institute of Technology, 2.Department of Earth and Planetary Sciences, Faculty of Science, Kyushu University, 3.Earthquake Research Institute, University of Tokyo, 4.Solar System Science Division, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency)

[PEM11-10] Relationship between the inner heliosheath thickness and the pickup ion density

*Ken Tsubouchi[1] (1.University of Electro-Communications)

Discussion

Ion scale waves and kinetic instabilities in the inner heliosphere

*Jungjoon Seough[1], Yasuhiro Nariyuki[2], Peter Yoon[1,3,4], Kyung-Suk Cho[1]

1. KASI, 2. UT, 3. UMD, 4. KHU

The coherent electromagnetic waves at ion scales have been frequently observed in the inner heliosphere during the first perihelion of Parker Solar Probe. It is expected that ion- scale waves, propagating preferentially quasi-parallel to the mean magnetic field, are locally driven by the ion velocity-space micro-instabilities that are closely associated with turbulent heating and thermodynamic processes in the expanding solar wind. In the present study, we discuss the underlying physical processes of how the ion-scale waves are generated in the inner heliosphere, where Parker Solar Probe has explored. Here we present a recently developed expanding box model based upon the velocity moment-based quasilinear kinetic analysis. This model incorporates the kinetic physics, such as plasma heating driven by Alfven-wave turbulence and micro-instabilities calculated by a self-consistent manner, into the large-scale fluid description. The theoretical results may help us understand the observational features, not only the presence of abundant ion-scale waves but also the solar wind thermodynamics, such as the evolution of temperature and its anisotropy.The coherent electromagnetic waves at ion scales have been frequently observed in the inner heliosphere during the first perihelion of Parker Solar Probe. It is expected that ion-scale waves, propagating preferentially quasi-parallel to the mean magnetic field, are locally driven by the ion velocity-space micro-instabilities that are closely associated with turbulent heating and thermodynamic processes in the expanding solar wind. In the present study, we discuss the underlying physical processes of how the ion-scale waves are generated in the inner heliosphere, where Parker Solar Probe has explored. Here we present a recently developed expanding box model based upon the velocity moment-based quasilinear kinetic analysis. This model incorporates the kinetic physics, such as plasma heating driven by Alfven-wave turbulence and micro-instabilities calculated by a self-consistent manner, into the large-scale fluid description. The theoretical results may help us understand the observational features, not only the presence of abundant ion-scale waves but also the solar wind thermodynamics, such as the evolution of temperature and its anisotropy.

Keywords: Parker Solar Probe, ion cyclotron wave, kinetic instability, turbulence

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Effects of initial density fluctuations on linear and nonlinear evolution of parametric decay instabilities of circularly polarized Alfven waves

*Yasuhiro Nariyuki[1]

1. Faculty of Education, University of Toyama

The parametric decay instability [Goldstein, ApJ, 1978; Derby, ApJ, 1978] is regarded as an important process of damping of large amplitude, low-frequency Alfven waves in the solar wind. Since Alfvenic fluctuations and anisotropic spectra are widely observed in the solar wind, nonlinear evolution of decay instabilities can be related to the formation of the anisotropic spectra of magnetohydrodynamic turbulence in the solar wind. Recently, Shoda and Yokoyama[ApJL, 2018] discussed the relationship between the multi-dimensional decay instability and nonlinear processes such as the phase mixing and the perpendicular cascade.

In this presentation, we discuss roles of initial density fluctuations on the decay instabilities of Alfven waves. Since not only parallel propagating waves but also obliquely propagating waves are unstable to the decay instability [Vinas+Goldstein, JPP, 1991], oblique initial density fluctuations with finite amplitude can preferentially be excited, even if their linear growth rates are not large. In such a case, the growth of the parallel propagating mode is usually suppressed. Numerical results of three-dimensional MHD simulation also show an opposite case, in which the linear growth of the parallel propagating modes is promoted by the effects of the multi-dimensionality. Dependence of linear and nonlinear evolution on wave number spectra of initial waves will be demonstrated.

Keywords: Alfven wave, parametric instability, solar wind plasma

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Search of energy source of 1-16Hz Whistler Mode Waves Detected by Kaguya in the Lunar Polar Orbit

*Tomoko Nakagawa[1], Futoshi Takahashi[2], Hisayoshi Shimizu[3], Yoshifumi Saito[4]

1. Information and Communication Engineering, Tohoku Institute of Technology, 2. Department of Earth and Planetary Sciences, Faculty of Science, Kyushu University, 3. Earthquake Research Institute, University of Tokyo, 4. Solar System Science Division, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency

The moon is exposed to the solar wind or magnetospheric plasmas due to the lack of global magnetic field or the dense atmosphere like those of the Earth. Most of the incident plasmas are absorbed by the lunar surface, but a small fraction of protons are scattered back into the solar wind in the form of ions, or neutral atoms to be re-ionized through charge exchange. The solar wind particles that came across intense local crustal magnetic field so called as the magnetic anomalies are more strongly reflected back due to the Lorentz force. Electrons that came into the region near intense magnetic anomalies are mirror reflected and/or accelerated by local electric field generated by difference of penetration depth of ions and electrons.

These plasmas have energy that can generate various wave activities (Harada and Halekas, 2016). Protons reflected by the magnetic anomalies are responsible for generation of monochromatic ULF waves or ELF waves through cyclotron resonance with MHD waves or whistler mode waves. Mirror-reflected electron beams along the magnetic field connected to the magnetic anomaly are thought to be the source of non-monochromatic whistler mode waves in the frequency range from 0.1 to 10 Hz. Detection of the non-monochromatic whistler waves depends on magnetic connection between the spacecraft and the magnetic anomalies.

Another type of ELF whistler waves were found by Kaguya. The frequency range was broad (1-16 Hz) like the non-monochromatic whistlers generated by field-aligned electrons, while their detection was less sensitive to the magnetic connection as well as the waves generated by reflected protons. They were preferentially observed above the polar region of the moon. The detection site was off the magnetic anomaly. They were found when the incident solar wind density was high.

The generation mechanism of such diffuse whistler mode waves is not yet understood. Dense solar wind flux incident to lunar surface unshielded by the crustal magnetic field is likely to cause scattering of solar wind protons in the form of ions or neutral atoms to be re-ionized. Scattered protons with less collimated velocities might account for the broad frequency range and the occurrence property less sensitive to the magnetic connection to the lunar surface.

References

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Harada, Y., and J. S. Halekas, Chapter 18: Upstream waves and particles at the Moon, in "*Low-Frequency Waves in Space Plasmas*", 2016, pp. 307-322, American Geophysical Union, doi: 10.1002/9781119055006.

Keywords: whistler mode wave, moon, Kaguya, solar wind, ELF, broadband

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Relationship between the inner heliosheath thickness and the pickup ion density

*Ken Tsubouchi[1]

1. University of Electro-Communications

The interaction of the supersonic solar wind with the interstellar medium results in the formation of the shock wave (termination shock; TS) inside the heliosphere, as well as the discontinuous interface between them (heliopause; HP). The location of the TS and HP characterizes the size and shape of the heliosphere, which suggests a feature of the pressure equilibrium with interstellar space. Therefore, it is important to quantitatively associate the thickness of the inner heliosheath (IHS), the region between the TS and HP, with the energy composition there. Recently, both Voyager 1 and 2 (V1, V2) crossed the TS at the heliocentric radial distance of 94 (V1) and 84 (V2) au, and the HP at 122 (V1) and 119 (V2) au, estimating the IHS thickness along the V1 and V2 trajectories 28 (V1) and 35 (V2) au, respectively. This difference is mainly caused by that of solar wind conditions, because each crossing was in a different phase of the solar activity. However, it is insufficient to evaluate the pressure in the IHS by solar wind parameters only. The striking feature of the IHS plasmas is the dominant contribution of pickup ions (PUIs) to the energy density. It is well known that the presence of PUIs greatly modifies the TS property and the consequent energy composition in the downstream. In this talk, we aim to study the dependence of the PUI density on the size of the IHS by simultaneously generating the TS and HP via large-scale hybrid simulations. A simple analytical assessment is also presented. We expect that the results will be useful to deduce the PUI density itself from the observed IHS thickness.

Keywords: pickup ion, heliosheath, termination shock

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM12] Coupling Processes in the Atmosphere-Ionosphere System

convener:Huixin Liu(Earth and Planetary Science Division, Kyushu University SERC, Kyushu University), Yuichi Otsuka(Institute for Space-Earth Environmental Research, Nagoya University), Yue Deng(University of Texas at Arlington), Loren Chang(Institute of Space Science, National Central University)

The Atmosphere-Ionosphere (A-I) system forms the so-called near-Earth space. Recent rapidly expanding use of satellite constellations in Low-Earth Orbit (LEO) drives a high demand for better understanding and accurate forecast of the global A-I system for scientific and operational purposes. This session aims to provide a forum for research advances and frontiers related to these aspects, and we invite presentations on global A-I coupling at all temporal and spatial scales. This includes but is not limited to: A-I coupling via atmospheric waves (tides, gravity waves, planetary waves) and trace gases (CO2, O3, H2O), A-I response to Space Weather events (solar flares, CMEs, CIRs), polar-equatorial or inter-hemispheric coupling via TADs/TIDs/disturbance dynamo/penetration electric field, ionospheric plasma irregularities, ionospheric currents, etc. Observations, theoretical studies, model simulations, data assimilation, instruments development are all highly welcome.

[PEM12-01] Inter-hemispheric Coupling During Sudden Stratospheric Warming Events

Kristina Shizuka Yamase Skarvang[2], *Patrick J Espy[1], Robert E. Hibbins[1], Willem E. van Caspel[1] (1.Norwegian Univ. of Science and Technology, Birkeland Centre for Space Science, 2.Norwegian Univ. of Science and Technology)

[PEM12-02] Dynamical characteristics of the middle atmosphere associated with the Antarctic sudden stratospheric warming in 2019.

★Invited Papers

*Kaoru Sato[1], Yoshihiro Tomikawa[2], Dai Koshin[1] (1.Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, 2.National Institute of Polar Research)

[PEM12-03] WACCMX Simulations of the 2002 and 2019 Southern Hemisphere Sudden Stratospheric Warmings

★Invited Papers

*Nicholas M Pedatella[1] (1.National Center for Atmospheric Research)

[PEM12-04] Characteristics of small-scale gravity waves in the Arctic winter mesosphere

*JING LI[1], TAO LI[2,3], QIAN WU[4], YIHUAN TANG[2], ZHAOPENG WU[1,3], JUN CUI[1] (1.Planetary Environmental and Astrobiological Research Laboratory (PEARL), School of Atmospheric Sciences, Sun Yat-sen University, Zhuhai, Guangdong, China, 2.CAS Key Laboratory of Geospace Environment, School of Earth and Space Sciences, University of Science and Technology of China, Hefei, Anhui, China, 3.CAS Center for Excellence in Comparative Planetology, Hefei, Anhui, China, 4.High Altitude Observatory, National Center for Atmospheric Research, Boulder, CO, USA)

[PEM12-05] Studying atmospheric and ionospheric variabilities in the mesopause and ionospheric F2-region during winter sudden stratospheric warmings of various types

*Irina Medvedeva[1,2], Konstantin Ratovsky[1], Alla Suvorova[3] (1.Institute of Solar-Terrestrial Physics SB RAS, Irkutsk, Russia , 2.Obukhov Institute of Atmospheric Physics RAS, Moscow, Russia , 3.GPSARC National Central University, Taoyuan, Taiwan)

[PEM12-06] Influences of migrating semidiurnal tide variabilities on the low latitude ionosphere

*Jia-Ting Lin[1], Charles Lin[1], Loren Chang[2,3], Hanli Liu[4], Nicholas M Pedatella[4,5] (1.Department of Earth Sciences, National Cheng Kung University, Taiwan, 2.Center for Astronautical Physics and Engineering, National Central University, Taoyuan, Taiwan, 3.Graduate Institute of Space Science, National Central

University, Taoyuan, Taiwan, 4.High Altitude Observatory, National Center for Atmospheric Research, Boulder, CO, USA, 5.COSMIC Program Office, University Corporation for Atmospheric Research, Boulder, CO, USA)

Inter-hemispheric Coupling During Sudden Stratospheric Warming Events

Kristina Shizuka Yamase Skarvang[2], *Patrick J Espy[1], Robert E. Hibbins[1], Willem E. van Caspel[1]

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Long-term data sets of mesospheric winds and temperatures from the Antarctic station at Rothera (68 S, 68 W) and the Northern Hemisphere radar at Trondheim (64 N, 10.5 E) have be used to examine the Southern Hemisphere (SH) response to sudden stratospheric warmings (SSW) in the Northern Hemisphere (NH). Temperatures and winds in the upper mesosphere (80-100 km) in the SH from a Skiymet meteor radar system are compared to those from a similar system in the NH to examine whether the SSW perturb the global circulation or whether the effects are confined to the NH only. The winds and temperatures from both systems are also be compared with re-analysis and satellite data to examine the role of equatorial ozone in the coupling. The analysis first characterized and removed seasonal cycles, and then performed a super-posed epoch centred on SSW events. The results of this comparison, as well as possible mechanisms for the SH signature, will be presented and discussed.

Keywords: Tide, SSW, Inter-hemispheric, Mesosphere

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Dynamical characteristics of the middle atmosphere associated with the Antarctic sudden stratospheric warming in 2019.

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In September 2019, a strong sudden stratospheric warming (SSW) occurred in the Antarctic. The size of the ozone hole, which is greatly affected by the temperature in the lower stratosphere, was as small as in the 1980s, and its maximum area was smaller than that of Antarctica for the first time in 30 years. We report the dynamical characteristics of this SSW.

First, planetary waves with strong heat fluxes entered into the stratosphere after around August 20. This heat flux intrusion was followed by a sudden increase in the zonal mean temperature averaged over 60 S-90 S at 10 hPa (corresponding to an altitude of about 30 km) around August 22. The temperature was maximized around September 16. Simultaneously, the zonal mean zonal wind at 60 S was significantly weakened to 15 m/s at 10 hPa. The zonal mean zonal wind did not become negative, and hence did not meet the criteria for the major SSW. However, as the zonal mean zonal wind averaged over the past 40 years is about 74 m/s there, the decrease in the zonal wind amounts to nearly 60 m/s. If the same zonal wind weakening occurred around October 1, the criteria for the major SSW would have been met.

What is interesting about this event is that barotropic instability had frequently occurred around 10 hPa since mid-September. Barotropic instability is a phenomenon that is sometimes seen in the upper stratosphere and mesosphere, but rarely occurs at 10 hPa. The characteristics are described by using Ertel’ s potential vorticity (PV). The maximum of the zonal mean |PV| (absolute value of PV) was frequently observed in the range of 70 S to 80 S in the middle stratosphere, and often extended down to the 850 K isentropic surface corresponding to 10 hPa. Time evolution of the horizontal structure of the PV in the polar stereo maps was examined. It is seen that the high |PV| of the polar vortex was strongly deformed by the planetary waves and stretched like a string surrounding the polar vortex and toward low latitudes. Then, the string-like high |PV| was split into many vortices which subsequently developed. These features are a typical barotropic instability.

Next we examined the EP flux in the meridional cross section. The upward EP flux from the troposphere did not converge around 60 S, which is the central latitude of the polar night jet, but went toward low latitudes and converged in a pressure level of 30 hPa (~23 km) to 5 hPa (~35 km). It is considered that the EP flux toward low latitudes is accompanied by the barotropic instability. At 10 hPa, 30 S, which is the center of the EP flux convergence area, a strong westward jet exceeding 20 m/s was formed.

As such, this Antarctic SSW event exhibits an interesting time evolution: Due to the barotropic instability that frequently occurred during the SSW event, the planetary waves did not efficiently decelerate the polar night jet and then the stratospheric condition did not reach the major SSW. Instead, a strong westward jet was formed in the mid-latitudes of the middle stratosphere.

Keywords: sudden stratospheric warming, atmospheric waves, vertical coupling

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WACCMX Simulations of the 2002 and 2019 Southern Hemisphere Sudden Stratospheric Warmings

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Sudden stratospheric warmings (SSWs) are characterized by large-scale, rapid, changes in the polar winter middle atmosphere, and also lead to large variability throughout the whole atmosphere, including changes in the mesosphere, thermosphere, and ionosphere. SSWs occur in roughly six out of ten Northern Hemisphere winters, and, due to hemispheric differences in planetary wave activity, are significantly less frequent in the Southern Hemisphere. Though rare, Southern Hemisphere SSWs have occurred recently in 2002 as well as 2019. With these two events, it is possible to investigate similarities and differences between SSW events in the Northern and Southern Hemispheres. Simulations of the 2002 and 2019 Southern Hemisphere SSWs are performed using in the Specified Dynamics version of the Whole Atmosphere Community Climate Model with thermosphere-ionosphere eXtension (SD-WACCMX). The simulations are used to compare and contrast variability in mesospheric tides and the equatorial ionosphere during Southern and Northern Hemisphere SSW events.

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Characteristics of small-scale gravity waves in the Arctic winter mesosphere

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Using the long-term datasets observed with an OH all-sky imager, a Fabry-Perot Interferometer at Resolute Bay observatory, Canada (74.7˚N, 94.9˚W), Microwave Limb Sounder and reanalysis data, we study the characteristics of small-scale gravity waves (GWs) with the horizontal wavelength less than 20 km in the Arctic winter mesosphere during 2014-2016. The observed small-scale GWs may be excited in the mesopause region, such as secondary wave generated by primary wave breaking, or a result of baroclinic instability processed in the stratosphere, and the interaction of planetary waves with the background winds. In addition, almost all of the small-scale GWs occurred in 2015/2016 anomalous winter, when both the strong El Nino-Southern Oscillation (ENSO) and anomalous Quasi-biennial Oscillation (QBO) happened. Further studies are needed to explore the mechanism of GW excitation and propagation.

Keywords: Small-scale gravity waves, Arctic winter mesosphere, OH airglow imager, Background wind, ENSO

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Studying atmospheric and ionospheric variabilities in the mesopause and ionospheric F2-region during winter sudden stratospheric warmings of various types

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We present the results of studying the activity of atmospheric waves at the heights of the mesopause (80-100 km) and ionospheric F2-region during the periods of winter sudden stratospheric warmings (SSW) of various types. The analysis is based on the experimental data on the rotational temperature of the hydroxyl molecule (OH band (6-2) 834.0 nm) obtained from spectrometric measurements at the Geophysical Observatory of the ISTP SB RAS (51.8˚ N, 103.1˚ E, Tory), and on the peak electron density NmF2, from the Irkutsk ionosonde DPS-4 (52.3˚ N, 104.3˚ E) data. The rotational temperature of the hydroxyl molecule corresponds to the temperature of the atmosphere at the mesopause heights. In this study, we used the method for estimating the atmospheric and ionospheric variabilities described in (Medvedeva and Ratovsky, 2015), which allows one to analyze the manifestation of wave activity in a wide range of altitudes of the upper atmosphere. As a characteristic of atmospheric variability, we used standard deviations of the mesopause temperature in the annual and nightly variations, by which one can analyze the manifestation of the various timescale wave process activity in the upper atmosphere (Perminov et al., 2014, Medvedeva and Ratovsky, 2015). As a characteristic of ionospheric variability, we used the variability of the F2 peak electron density (NmF2). The values of atmospheric and ionospheric variability obtained using this technique during the SSWs, are compared with seasonally average values. We revealed significant differences in the manifestation of wave activity at the heights of the mesopause and ionospheric F2-region during the SSWs of various types. Thus, the major SSW in February 2018 led to an increase in the day-to-day atmospheric and ionospheric variability, which can be caused by the intensification of planetary wave activity in the upper atmosphere. The largest effects of the major January 2019 SSW in the upper atmosphere were observed in the behavior of diurnal atmospheric variability due to the effects of tides and internal gravity waves.

Acknowledgments

The reported study was funded by RFBR, Russian-Taiwanese joint research project number 18-55-52006 MHT_a. Experimental data recorded by the equipment of Center for Common Use «Angara» (http://ckp-rf.ru/ckp/3056/) obtained with budgetary funding of Basic Research program II.16 were used.

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Keywords: atmosphere, ionosphere, temperature, peak electron density , mesopause, sudden stratospheric warming

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Influences of migrating semidiurnal tide variabilities on the low latitude ionosphere

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In this study, we investigate the variability of ionosphere and its electrodynamic responses to the changes in amplitude and phase of migrating semidiurnal tide (SW2) associated with sudden stratospheric warming (SSW) using numerical experiments under boreal winter and solar minimum condition. A sensitivity assessment of the Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM) simulations shows that ionospheric variabilities greatly depend on the SW2 condition in the lower boundary. Our results show that the earlier phase shift of SW2 causes the morning-enhanced and afternoon-reduced TECs by modulating equatorial vertical E ×B drift, which agrees with the observation qualitatively but with insufficient magnitude. Instead, the increase in amplitude of SW2 only drives temporally upward E ×B enhancement at local noon; nevertheless, it is suppressed soon by the rise of SW2 tidal dispassion from the westward acceleration of F-region zonal winds. The long sustained and stronger earlier local time of upward drift arises from a combination of the amplitude and phase changes of the SW2, demonstrating the combination of amplified and earlier phase SW2 are required to reproduce ionospheric SSW effects. Additionally, the equilibrium duration in response to the amplitude and phase change of SW2, and the importance of perturbed zonal and meridional tidal wind in generated equatorial vertical E ×B drift are determined.

Keywords: ionospheric variability responses to the migrating semidiurnal tide, sudden stratospheric warming, dynamo modification from the tidal wind

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM12] Coupling Processes in the Atmosphere-Ionosphere System

convener:Huixin Liu(Earth and Planetary Science Division, Kyushu University SERC, Kyushu University), Yuichi Otsuka(Institute for Space-Earth Environmental Research, Nagoya University), Yue Deng(University of Texas at Arlington), Loren Chang(Institute of Space Science, National Central University)

The Atmosphere-Ionosphere (A-I) system forms the so-called near-Earth space. Recent rapidly expanding use of satellite constellations in Low-Earth Orbit (LEO) drives a high demand for better understanding and accurate forecast of the global A-I system for scientific and operational purposes. This session aims to provide a forum for research advances and frontiers related to these aspects, and we invite presentations on global A-I coupling at all temporal and spatial scales. This includes but is not limited to: A-I coupling via atmospheric waves (tides, gravity waves, planetary waves) and trace gases (CO2, O3, H2O), A-I response to Space Weather events (solar flares, CMEs, CIRs), polar-equatorial or inter-hemispheric coupling via TADs/TIDs/disturbance dynamo/penetration electric field, ionospheric plasma irregularities, ionospheric currents, etc. Observations, theoretical studies, model simulations, data assimilation, instruments development are all highly welcome.

[PEM12-07] A model-data comparative study of large-scale ionospheric disturbances during the 17 March 2015 storm

★Invited Papers

*Gang Lu[1], Irina Zakharenkova[2], Iurii Cherniak[2], Tong Dang[3] (1.National Center for Atmospheric Research, 2.COSMIC Program Office, University Corporation for Atmospheric Research, 3.University of Science and Technology of China)

[PEM12-08] Evolution of mid-latitude density irregularities and scintillation during storms

★Invited Papers

*Toshi Nishimura[1], Sebastijan Mrak[1], Josh Semeter[1] (1.Boston University)

[PEM12-09] Growin: Modeling Ionospheric Instability Growth Rates and Giving Away the Code

*Jonathon Smith[1,2] (1.Catholic University of America, 2.NASA Goddard Space Flight Center)

[PEM12-10] Spatial and temporal relation among magnetic ripples, wavy structure of electron density fluctuation and GPS TEC variations

*Toshihiko Iyemori[1], Tadashi Aoyama[1], Yoshihiro Yokoyama[1], Akiyasu Yamada[1] (1.Kyoto University)

[PEM12-11] Temporal and spatial variations of the total electron content enhancement from the mid-latitude to the equator associated with a geomagnetic storm

*Atsuki Shinbori[1], Yuichi Otsuka[1], Sori Takuya[1], Takuya Tsugawa[2], Michi Nishioka[2] (1.Institute for Space-Earth Environment Research (ISEE), Nagoya University, 2.National Institute of Information and Communications Technology)

[PEM12-12] Atmospheric influence on relationship between solar and ionospheric 27-day variations

*Konstantin Ratovsky[1], Maxim Klimenko [2], Vladimir Klimenko[2], Alexei Dmitriev[3], Loren Chang[3] (1.Institute of Solar-Terrestrial Physics SB RAS, 2.West Department of Pushkov IZMIRAN, RAS, 3.National Central University)

A model-data comparative study of large-scale ionospheric disturbances during the 17 March 2015 storm

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This paper presents a detailed model-data comparative study of the 17 March 2015 geomagnetic storm using the high-resolution version of the Thermosphere-Ionosphere-Electrodynamic General Circulation Model (TIEGCM) and the total electron content (TEC) observations from a dense GNSS network. Driven by time-dependent high-latitude ionospheric convection and auroral precipitation inputs, together with an empirically defined subauroral plasma stream (SAPS) field, our simulation reproduce many observed storm-related ionospheric phenomena, including large-scale traveling ionospheric disturbances (TIDs) over Europe, the effects of prompt penetration electric field (PPEF) over South and Central America, and the formation of a storm enhanced density (SED) plume across the continental United States. Our simulation results reaffirm a number of important characteristics concerning the SED plume: (1) enhanced background ionospheric density is a necessary but not sufficient condition, and enhanced ion drift is required to form the SED plume; (2) the SAPS flow channel does not directly transport the plasma from midnight to postnoon via dusk to form the SED plume; instead, the SED plume is formed at the equatorward and westward edge of the SAPS channel; and (3) the SED plume appears to subcorotate with respect to the Earth.

Keywords: Traveling Ionospheric Disturbances, Storm Enhanced Density (SED), SED Plume, prompt penetration electric field (PPEF)

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Evolution of mid-latitude density irregularities and scintillation during storms

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1. Boston University

While high-latitude and equatorial density irregularities and radio signal scintillations have been explored in detail, studies on mid-latitude density irregularities and scintillation are scarce and their properties are less understood. Mid-latitude scintillation is not frequent, but because much more human activities are present at mid-latitudes than at high and equatorial latitudes, radio signal disturbances at mid-latitudes despite their lower occurrences have a large impact on technology such as aircraft navigation using GNSS. Due to the small number of scintillation observations, past ground-based studies of mid-latitude density irregularities and scintillations are limited to case studies in small regions, statistical studies using limited satellite coverage or a small number of receivers, or inference from TEC variations (e.g., ROTI which does not necessarily indicate scintillation). Thus it has been difficult to determine event-specific spatial distribution of scintillation over a continental scale and changes shorter than satellite orbital periods. In the present study, we determine the event-specific 2-d distributions of mid-latitude GNSS signal scintillation and fluctuation, and their relation to large-scale density structures using a network of GNSS receivers in North America. In the 7-8 September 2017 storm event, we found that GNSS signal scintillation is closely associated with the mid-latitude trough equatorward boundaries. As the trough moved equatorward and the plumes and troughs developed, the phase scintillation increased further in the density gradient, while amplitude scintillation increased in the trough and plume. Other regions are covered by the receivers but did not show GNSS signal scintillation/fluctuation, indicating that our technique can specify occurrence regions of scintillation/fluctuation, and scintillation/fluctuation in this event was confined along the steep TEC gradients and trough. Our study indicates that scintillation structures and evolution can be detected can be precisely determined in this technique.

Keywords: TEC, scintillation, mid-latitude, storm

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Growin: Modeling Ionospheric Instability Growth Rates and Giving Away the Code

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The first seasonal and zonal climatology of Rayleigh-Taylor growth rates during solar minimum and solar moderate conditions as a function of local time and altitude has been developed using open source data and software.
The *growin* python module utilizes other Heliophysics python modules to collate and process vertical plasma drift to drive the SAMI2 model and subsequently calculate the flux tube integrated Rayleigh-Taylor growth rate.
The process is repeated for two different types of drift inputs: the Fejer-Scherliess model and measured drifts from C/NOFS.
These growth rates are compared to bubble occurrence frequencies obtained from a dataset of bubbles detected by the C/NOFS satellite.
There is agreement between periods of strong positive instability growth and high frequencies of bubble occurrence in both low and moderate solar activity conditions when using C/NOFS drifts.
Fejer drifts are only in agreement with bubble occurrence frequencies during moderate solar activity conditions.
Bubble occurrence frequencies are often above 25% even when growth rates in the bottomside F region are negative.
The climatological nature of the growth rates discussed here begs further study into the diurnal variability of the growth rate and its drivers.

Keywords: Ionosphere, Irregularities, Thermosphere

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Spatial and temporal relation among magnetic ripples, wavy structure of electron density fluctuation and GPS TEC variations

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1. Kyoto University

Wavy structures of electron density (Ne) and magnetic ripples observed along the orbit of Swarm satellites in low-latitude on the dayside, and GPS-TEC variation under the orbit are analyzed to see their correlation. Their apparent periods are typically 20-30 seconds, 10-20 seconds and a few minutes, respectively. Near the equatorial region, the APEX latitudes of the region where wavy Ne structure appears and the region traced down from magnetic ripples to 120km altitude, i.e., ionospheric current layer, often coincide suggesting acoustic mode waves as a common source of their generation. Assuming the GPS-TEC variation with a period around a few minutes is temporal variation, we try to check the correlation in the location among the three quantities to check the validity of our idea that the acoustic mode waves are the common source of the variations.

Keywords: Magnetic Ripples, Wavy structure in electron density, GPS-TEC variation, Acoustic gravity waves

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Temporal and spatial variations of the total electron content enhancement from the mid-latitude to the equator associated with a geomagnetic storm

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1. Institute for Space-Earth Environment Research (ISEE), Nagoya University, 2. National Institute of Information and Communications Technology

A spatial distribution of the electron density in the ionosphere shows a strong dependence on geographical latitude, longitude, and local time. The structure changes severely from the high-latitude to the equatorial regions during geomagnetic storms. The storm-time prominent ionospheric phenomena are tongue of ionization (TOI), mid-latitude broad storm-enhanced density (SED), SED plume, and intensification of equatorial ionization anomaly (EIA). These phenomena are very dynamic because ionospheric electric fields and particle precipitation from the magnetosphere vary significantly during the development and decay of the geomagnetic storms. The generation mechanism of SED has been thought as local upward electric field drifts [e.g., Liu et al., 2016], westward plasma transportation from the nightside to the dayside by sub-auroral polarization stream (SAPS) [Foster et al., 2007], equatorward neutral winds [Anderson, 1976], and latitudinal expansion of EIA [e.g., Kelley et al., 2004]. However, since such different mechanisms of the formation of SED have been proposed by many researchers, a comprehensive understanding of the cause of SED formation has not yet been done. In this study, we investigate the temporal and spatial variation of the total electron content enhancement related to SED during the geomagnetic storms using Global Navigation Satellite System (GNSS) Total Electron Content (TEC) data with high time and spatial resolutions together with solar wind, interplanetary magnetic field, geomagnetic indices, ionosonde, geomagnetic field, Jicamarca IS radar and SuperDARN radar data to identify the main mechanism responsible for SED. In this analysis, we first calculate the average TEC of 10 geomagnetically quiet days every month, referring to the list of quiet and disturbed days provided by GFZ. Next, we subtract the storm-time TEC from the average TEC and create global maps of the ratio of the TEC difference (rTEC) in geographical and geomagnetic coordinates. As a result, a clear rTEC enhancement related to the mid-latitude broad SED first occurred from noon to afternoon at high latitudes within 1 hour after sudden increase and expansion of the high-latitude convection and prompt penetration of the electric field to the equator associated with the southward excursion of the IMF. Approximately 1-2 hours after the onset of the hmF2 increase in the mid-latitude and low-latitude regions associated with the high-latitude convection enhancement, the rTEC and foF2 values began to increase and the enhanced rTEC region expanded to the low latitudes within 1-2 hours. This signature suggests that the ionospheric plasmas in the F2-region move at a higher altitude due to local electric field drift, where the recombination rate is smaller, and that the electron density increases due to additional production at the lower altitude in the sunlit region. The average upward electric field drift velocity of the ionosphere was a little faster at the mid-latitude than that at the low latitude. This result implies that the electric field intensity tended to increase with an increasing latitude, and that the source of the electric field is located at high latitudes. After the appearance of the mid-latitude broad SED, the SED plume with a latitudinally narrow structure is separated from the mid-latitude broad SED and is formed along the dusk convection cell. The SED plume can extend up to the pre-noon sector (10:00-11:00 MLT) due to the clockwise rotation of the high-latitude convection pattern. The SED plume moves toward the high latitudes from the throat region between the dawn and dusk convection cells and entries the polar cap region as a TOI phenomenon. Later, another rTEC enhancement related to EIA appeared in the equatorial region

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approximately 1 hour after the prompt penetration of the electric field to the equator and extended to higher latitudes within 3-4 hours. The EIA structure merged with the mid-latitude broad SED structure at the low latitude.

Keywords: Total electron content (TEC), Geomagnetic storm, Ionosphere, Ionospheric convection in the polar region, Penetration electric field, Equatorial ionization anomaly (EIA)

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Atmospheric influence on relationship between solar and ionospheric 27-day variations

*Konstantin Ratovsky[1], Maxim Klimenko [2], Vladimir Klimenko[2], Alexei Dmitriev[3], Loren Chang[3]

1. Institute of Solar-Terrestrial Physics SB RAS, 2. West Department of Pushkov IZMIRAN, RAS, 3. National Central University

We believe that the atmospheric influence on relationship between solar and ionospheric variations includes two effects: (1) the delay in the response of thermospheric characteristics relative to the response of the ionization rate to a change in the solar flux, and (2) the presence of a 27-day component in the ionospheric response to atmospheric variations not related to a change in the solar flux. The first effect leads to a delay in the ionospheric 27-day variations relative to the 27-day variations in the solar flux and to different ratios between the amplitudes of the solar and ionospheric components. The second effect reduces the correlation coefficient between the solar and ionospheric components, and also has a significant effect on the delay and amplitude of the ionospheric component. Both effects are studied both theoretically and with measurements. The basis of the theoretical study is the first principles Global Self-consistent Model of the Thermosphere, Ionosphere, and Protonosphere (GSM TIP) developed in West Department of IZMIRAN. The model gives time-dependent global three-dimensional distributions of (1) the neutral upper atmosphere parameters (temperature, composition, and wind velocity vectors) from 80 to 526 km, (2) the ionosphere parameters (density, temperature, and velocity vectors of atomic and molecular ions and electrons) from 80 km up to 15 Earth radii. For all considered periods the GSM TIP was utilized for model runs with taking into account solar activity variations and without taking into account geomagnetic activity variation. Note that our approach ignores possible changes in the lower atmosphere due to an increase in solar activity. The basis of the observational study is a statistical analysis of 27-day variations in the peak electron density, total electron content, global electron content and solar index F10.7. We assume that atmospheric variations unrelated to changes in solar flux have a strong effect on the peak electron density and a much smaller effect on the global electron content. For this reason, the response in global electron content is expected to better agree with the model calculations compared to the response in the peak electron density. A statistical analysis of both characteristics allows us to verify this assumption.

Acknowledgments
The reported study was funded by RFBR, Russian-Taiwanese joint research project number 18-55-52006 MHT_a. Experimental data recorded by the equipment of Center for Common Use «Angara» (http://ckp-rf.ru/ckp/3056/) obtained with budgetary funding of Basic Research program II.12 were used.

Keywords: atmosphere, solar and ionospheric 27-day variations

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM12] Coupling Processes in the Atmosphere-Ionosphere System

convener:Huixin Liu(Earth and Planetary Science Division, Kyushu University SERC, Kyushu University), Yuichi Otsuka(Institute for Space-Earth Environmental Research, Nagoya University), Yue Deng(University of Texas at Arlington), Loren Chang(Institute of Space Science, National Central University)

The Atmosphere-Ionosphere (A-I) system forms the so-called near-Earth space. Recent rapidly expanding use of satellite constellations in Low-Earth Orbit (LEO) drives a high demand for better understanding and accurate forecast of the global A-I system for scientific and operational purposes. This session aims to provide a forum for research advances and frontiers related to these aspects, and we invite presentations on global A-I coupling at all temporal and spatial scales. This includes but is not limited to: A-I coupling via atmospheric waves (tides, gravity waves, planetary waves) and trace gases (CO2, O3, H2O), A-I response to Space Weather events (solar flares, CMEs, CIRs), polar-equatorial or inter-hemispheric coupling via TADs/TIDs/disturbance dynamo/penetration electric field, ionospheric plasma irregularities, ionospheric currents, etc. Observations, theoretical studies, model simulations, data assimilation, instruments development are all highly welcome.

[PEM12-13] Observations of Atmospheric Waves in the Thermosphere from New Earth-Orbiting Spacecraft

★Invited Papers

*Scott England[1] (1.Virginia Tech)

[PEM12-14] Observations of the Thermosphere-Ionosphere System by the Global-scale Observations of the Limb and Disk (GOLD) Mission

★Invited Papers

*Richard Eastes[1] (1.Laboratory for Atmospheric and Space Physics/University of Colorado)

[PEM12-15] Initial result on aurora and airglow observations with the all sky 630nm imager on Shirase

*Takeshi Sakanoi[1], Naoshi Yagi[1], Yuta Hozumi[2], Takuo T. Tsuda[2], Takeshi Aoki[2], Akinori Saito[3], Takahiro Naoi[5], Takanori Nishiyama[4], Mitsumu K. Ejiri[4] (1.Planetary Plasma and Atmospheric Research Center, Graduate School of Science, Tohoku University, 2.Graduate School of Informatics and Engineering, The University of Electro-Communications, 3.Graduate School of Science, Kyoto University, 4.National Institute of Polar Research, 5.National Institute of Information and Communications Technology)

[PEM12-16] **Comparison between migrating atmospheric tides in TIMED/SABER observations and free running WACCM-X simulations**

*Yi Chung Chiu[1], Loren Chang[1], Cornelius Csar Jude Salinas[1], Qian Liying [2] (1.Graduate Institute of Space Science and Engineering, National Central University, Taiwan, 2.High Altitude Observatory, National Center for Atmospheric Research, Boulder, Colorado, USA)

[PEM12-17] Interannual Variation of Diurnal Tide Components in Tropical Lower Thermospheric Temperatures

*Cornelius Csar Jude Salinas[1], Huixin Liu[2], Loren Chang[1], Jia Yue[3], James Russell[4], Martin G Mlynczak[5] (1.National Central University, 2.Kyushu University, 3.NASA Goddard Space Flight Center, 4.Hampton University, 5.NASA Langley Research Center)

[PEM12-18] Dynamical response in the upper atmosphere: GAIA simulation with doubled CO2

*Huixin Liu[1], Chihiro Tao[2], H. Jin[2] (1.Earth and Planetary Science Division, Kyushu University SERC, Kyushu University, 2.NICT)

Observations of Atmospheric Waves in the Thermosphere from New Earth-Orbiting Spacecraft

*Scott England[1]

1. Virginia Tech

Atmospheric waves play an important role in coupling different regions of the atmosphere. Clear evidence of wave coupling from the troposphere to the thermosphere and from the thermosphere to the ionosphere have been seen. Prior observations had revealed significant perturbations to the ionosphere that result from atmosphere waves in the lower thermosphere region, where coupling to the ionosphere via the E-region dynamo can play a significant role. However, observations of atmospheric waves at altitudes above the lower thermosphere are comparatively rare and much about the nature of waves and their impacts at these higher altitudes is not known. Not only the dynamo coupling between the neutral thermosphere and ionosphere is expected to change between the lower and middle thermosphere, but also the nature of the waves themselves as diffusive separation and ion drag become increasingly important. New results of atmospheric waves at altitudes above the lower thermosphere from observations with ICON and GOLD will be presented.

Keywords: Thermosphere, Atmospheric Waves, Ionosphere

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Observations of the Thermosphere-Ionosphere System by the Global-scale Observations of the Limb and Disk (GOLD) Mission

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Observations by the Global-scale Observations of the Limb and Disk (GOLD) mission provide fundamental information for understanding the Thermosphere-Ionosphere system. Data from GOLD’s two-channel, ultraviolet spectrograph include images taken from geostationary orbit at a 30-minute cadence. The dayside images cover the full disk of Earth. For the first time these data provide simultaneous, synoptic imaging of the composition and temperature near 160 km. The images, and GOLD’s limb observations, quantify the global-scale response of the thermosphere to external and internal forcing as it evolves spatially and temporally. Intriguing observations, some of which are indicate the presence of coupling of the thermosphere-ionosphere system to the mesosphere, have now been conducted during geomagnetically quiet and storm times as well as during a solar eclipse. These observations are providing significant tests of current models, an essential step to advances in global-scale modeling of the thermosphere and ionosphere system. Examples of these observations, as well as their potential for advancing models of the thermosphere-ionosphere system, will be presented.

Keywords: thermosphere, ionosphere, coupling, forcing

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Initial result on aurora and airglow observations with the all sky 630nm imager on Shirase

*Takeshi Sakanoi[1], Naoshi Yagi[1], Yuta Hozumi[2], Takuo T. Tsuda[2], Takeshi Aoki[2], Akinori Saito[3], Takahiro Naoi[5], Takanori Nishiyama[4], Mitsumu K. Ejiri[4]

1. Planetary Plasma and Atmospheric Research Center, Graduate School of Science, Tohoku University, 2. Graduate School of Informatics and Engineering, The University of Electro-Communications, 3. Graduate School of Science, Kyoto University, 4. National Institute of Polar Research, 5. National Institute of Information and Communications Technology

To cover the auroral and airglow observation gap in the Southern Ocean, we developed an all-sky imager (Shirase ASI) with a 3-axis attitude stabilized gimbal installed on the icebreaker Shirase. The route of Shirase from February to March is preferable to observe aurora in the aurora region at the south of Australia. This region is also important to understand the height and zonal variations of mesospheric dynamics. All-sky image data taken in the observation gap provide us unique opportunity to examine the auroral and airglow phenomena, and contribute to network observation in collaboration with ground-based imagers. The advantage of Shirase ASI is to observe faint auroral and airglow emissions with a long exposure time more than 10s under the conditions where the ship is swaying. In addition to auroral observation, Shirase ASi can observe airglow variations caused by plasma bubbles and MSTID when Shirase is located at the mid- and low-latitudes.
On the development of Shirase ASI, we selected the low-noise cooled CMOS (ZWO ASI183MM Pro) as a detector. We developed compact and small optical system which consists of a bandpass filter (Andover interference filter, center wavelength 630 nm, FWHM 4.4 nm), and objective fisheye lens (Fujinon FE185C086HA, focal length 2.7 mm, F value 1.8). Optical system was mounted on a 3-axis attitude stabilized gimbal (DJI Ronin-S). The optical system with the gimbal was installed in the water-proof observation box on the 06 deck of Shirase. During observation time, the data is temporarily recorded in the mini-PC (LIVA Q2) in the observation box, and data is transferred to NAS via the laptop PC in the observation room of Shirase during the next day. The laptop PC obtains the current location from GPS signal, and calculates the appropriate start and end timings of observation every day. The exposure time and interval are 19 s and 20 s, respectively, and the data is integrated in later analysis for up to 120 s depending on the intensity of target. All of observation data will be collected in April when Shirase returns to Japan, but in order to confirm the status of instruments and observation data, about 10 thumbnail images and housekeeping data, such as the temperatures and humidity in the observation box, are sent to Japan via e-mail. The observation box on the deck is temperature controlled using an automatic oil heater, and circulation of cooled air from the air cooler in the observation room connecting with insulated hoses.
We got sensitivity calibration data of Shirase ASI using the integrated sphere in NIPR on June 26 and 27, 2019. We confirmed that ASI has the dynamic range of intensity from 34 R to 3000 R with a resolution of 0.73 R/bit when the camera operates with a gain of 400 and an exposure time of 120 s. We obtained 630 nm airglow images with ASI at the Zao observatory of Tohoku University (geographic latitude and longitude: 38.1 deg. N, 140.5 deg. E) on June 13, 2019. From the test observation data integrated for 120 s, we obtained the variation of 630.0 nm airglow with an amplitude of 43 R caused by MSTID travelling from north-east to south-west. On September 3, 2019, the whole system of Shirase ASI was installed on the Shirase 06 deck and in the observation room 1. From the data obtained during the test cruise on October 11, 2019, we examined the performance of gimbal that attenuate the sway of ship. We estimated that typical sway range of Shirase to be 8 deg, and that of field-of-view of ASI to be 0.5 deg. 0.5 deg of the sway corresponds to 2km of horizonal distance in the 630nm emission layer at a 250 km altitude, which

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satisfies the scientific requirement of spatial resolution of airglow variations in the F-region.
We confirmed that Shirase ASI has been operated correctly from the departure of Japan on November 12, 2019. We will perform detailed data analysis after returning of Shirase to Japan in April 2020. In this talk, I will report the initial results of data analysis.

Keywords: aurora, airglow, Shirase, Antarctica, Initial result

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Comparison between migrating atmospheric tides in TIMED/SABER observations and free running WACCM-X simulations

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The Whole Atmosphere Community Climate model –eXtended (WACCM-X) is a comprehensive numerical model with a range from the Earth’ s surface to the upper thermosphere (~ 500 km) and also includes the ionosphere. Excited in the troposphere and stratosphere, atmospheric tides are the dominant dynamical feature in the mesosphere and lower thermosphere and play an important role in vertical coupling. In this study, we used the least squares method to extract diurnal and semidiurnal migrating tides from free running WACCM-X temperatures in the mesosphere and lower thermosphere region (MLT). The results are compared to observations from TIMED/SABER. Differences in tidal structure and variation during solar maximum and minimum in March and June are examined, to better understand the variation of migrating tides resolved in free running WACCM-X, and its implications for future studies utilizing this model.

Keywords: WACCM-X, TIMED/SABER, Atmospheric Tides

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Interannual Variation of Diurnal Tide Components in Tropical Lower Thermospheric Temperatures

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1. National Central University, 2. Kyushu University, 3. NASA Goddard Space Flight Center, 4. Hampton University, 5. NASA Langley Research Center

This work takes advantage of almost 16 years of temperature observations by the SABER instrument onboard the TIMED satellite to analyze the interannual variation of the migrating diurnal tide and two non-migrating diurnal tidal components in tropical lower thermospheric temperatures. The two non-migrating diurnal tides are the DE2 and DE3 tides. These are analyzed because they are known to significantly affect the upper atmosphere. A wavelet analysis on the de-seasonalized time-series of the amplitudes of these tides between latitudes 20S and 20N and located at around 105 km show that they have very clear 2 to 4 year oscillations that are consistent with the the Quasi-biennial Oscillation (QBO) as well as the El Nino Southern Oscillation (ENSO). An 11-year oscillation is also found although this oscillation is beyond the cone-of-influence in the spectra. A closer look at the spectra though reveals that the presence of these 2 year oscillations aren’ t consistent throughout the data coverage. Specifically, the 2 year oscillations in DW1 disappears after 2012 while the 2 year oscillations in DE3 weakens between 2012 and 2014. Thus, this work pushes further our understanding of tidal interannual variability by explaining these specific details in the wavelet spectra of these tides through numerical experiments conducted using the Ground-to-topside model of the Atmosphere and Ionosphere for Aeronomy (GAIA). GAIA will be run with and without the QBO, ENSO and 11-year solar cycle to determine how much of these interannual phenomena contribute to these diurnal tide interannual variations.

Keywords: Atmospheric Tides, Lower Thermosphere

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Dynamical response in the upper atmosphere: GAIA simulation with doubled CO2

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It is known that increasing CO2 in the atmosphere will produce global cooling in the thermosphere, in contrast to global warming in the troposphere. However, how will thermosphere dynamics and wave activity change remain unclear. In this study, we explore these aspects via a doubled-CO_2 numerical experiment using the whole atmosphere model GAIA. Model simulations were done for solar minimum under geomagnetic quiet conditions, with the CO2 mixing ratio set at 345 ppm and 690 ppm, respectively. The results reveal three major features in the doubled-CO_2 impacts. 1. The thermosphere cools about 10K more around solstices than equinoxes, more at the summer pole than the winter pole. 2. The meridional circulation strongly accelerates by 5--15 m/s. 3. The tidal activity experiences dramatic changes, with a 40--60% reduction in the semi-diurnal tides (SW2) throughout the thermosphere, but an 30-50% enhancement in diurnal tides (DW1) below 200 km altitude. The non-migrating tide DE3 changes only about 3K. These changes in meridional circulation and tides are robust features in all seasons, and can profoundly affect the spatial and local time distribution of the ionospheric responses via composition and electrodynamics.

Keywords: green house gas, global cooling, thermosphere circulation, thermosphere dynamics

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM12] Coupling Processes in the Atmosphere-Ionosphere System

convener:Huixin Liu(Earth and Planetary Science Division, Kyushu University SERC, Kyushu University), Yuichi Otsuka(Institute for Space-Earth Environmental Research, Nagoya University), Yue Deng(University of Texas at Arlington), Loren Chang(Institute of Space Science, National Central University)

The Atmosphere-Ionosphere (A-I) system forms the so-called near-Earth space. Recent rapidly expanding use of satellite constellations in Low-Earth Orbit (LEO) drives a high demand for better understanding and accurate forecast of the global A-I system for scientific and operational purposes. This session aims to provide a forum for research advances and frontiers related to these aspects, and we invite presentations on global A-I coupling at all temporal and spatial scales. This includes but is not limited to: A-I coupling via atmospheric waves (tides, gravity waves, planetary waves) and trace gases (CO2, O3, H2O), A-I response to Space Weather events (solar flares, CMEs, CIRs), polar-equatorial or inter-hemispheric coupling via TADs/TIDs/disturbance dynamo/penetration electric field, ionospheric plasma irregularities, ionospheric currents, etc. Observations, theoretical studies, model simulations, data assimilation, instruments development are all highly welcome.

[PEM12-19] Energy Flux and Conductance from Meso-Scale Auroral Features

★Invited Papers

*Christine Gabrielse[1], Toshi Nishimura[2], Margaret Chen[1], James Hecht[1], Larry Lyons[3], Yue Deng[4] (1.The Aerospace Corporation, 2.Boston University, 3.UCLA, 4.University of Texas, Arlington)

[PEM12-20] Study of latitudinal and longitudinal differences of mesospheric and ionospheric waves based on 3-dimentional FFT analysis of long-term multi-point airglow images

★Invited Papers

*Kazuo Shiokawa[1], Yuichi Otsuka[1], Takuji Nakamura[2] (1.Institute for Space-Earth Environmental Research, Nagoya University, 2.National Institute of Polar Research)

[PEM12-22] Global distribution of the mesoscale disturbances at 95km altitude detected by a space-borne airglow observation

*Akinori Saito[1], Ryota Okada[1], Takeshi Sakanoi[2], Yuta Hozumi[3] (1.Department of Geophysics, Graduate School of Science, Kyoto University, 2.Planetary Plasma and Atmospheric Research Center, Graduate School of Science, Tohoku University, 3.University of Electro-Communications)

[PEM12-23] Recurrent high-speed solar wind co-rotating interaction region imprint on the ionosphere and atmosphere: GPS TEC variations and atmospheric gravity waves

*Paul Prikryl[1,2], James M. Weygand[3], Reza Ghoddousi-Fard[4], Lidia Nikitina[2], Bharat S. R. Kunduri[5] (1.Physics Department University of New Brunswick, Canada , 2.Geomagnetic Laboratory Natural Resources Canada, 3.Earth Planetary and Space Sciences, University of California, USA, 4.Canadian Geodetic Survey Natural Resources Canada , 5.Bradley Dept. of Electrical and Computer Engineering, Virginia Tech, USA)

[PEM12-24] Observation of secondary gravity waves over the Southern Andes during an intense mountain wave event.

*Masaru Kogure[1], Jia Yue[2,3], Takuji Nakamura[1,4], Lars Hoffmann[5], Sharon Vadas[6], Yoshihiro Tomikawa[1,4], Mitsumu K. Ejiri[1,4], Diego Janches[2,3] (1.National Institute of Polar Research, 2.NASA Goddard Space Flight Center, 3.Catholic University of America, 4.SOKENDAI (The Graduate University for Advanced Studies), 5.Forschungszentrum Jülich, 6.NorthWest Research Associates)

Energy Flux and Conductance from Meso-Scale Auroral Features

*Christine Gabrielse[1], Toshi Nishimura[2], Margaret Chen[1], James Hecht[1], Larry Lyons[3], Yue Deng[4]

1. The Aerospace Corporation, 2. Boston University, 3. UCLA, 4. University of Texas, Arlington

Earth’s Atmosphere-Ionosphere system is inseparably coupled, with both regions driven from above and below by various terrestrial and space weather phenomena. Global models have done well at capturing large-scale effects, but currently do not capture the meso-scale (~10s-500 km) phenomena which often are locally more intense. As computing power improves, and modeling meso-scales now becomes possible, it is vital to provide data-informed inputs of the relevant drivers. In this presentation, we focus on the energy flux deposited into the ionosphere from the magnetosphere by precipitating particles that result in the aurora, specifically at meso-scales, and the resulting conductance. Thanks to NASA’s THEMIS mission, an array of all-sky-imagers (ASIs) across Canada monitors the majority of the nightside auroral oval at a 3 second cadence, providing a global view at temporal & spatial resolutions required to study the aurora on meso-scales. Thus, we present 2-D maps over time of the energy flux, energy, and conductance that result from the aurora during solar storms and substorms, including those features at meso-scales. Our results can be utilized by the broad community, for example, as inputs to atmospheric models or as the resulting conductance from precipitation inferred by magnetospheric models or missions like THEMIS, Van Allen Probes, or Arase.

Keywords: conductance, aurora, mesoscale, energy, precipitation

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Study of latitudinal and longitudinal differences of mesospheric and ionospheric waves based on 3-dimentional FFT analysis of long-term multi-point airglow images

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1. Institute for Space-Earth Environmental Research, Nagoya University, 2. National Institute of Polar Research

In this presentation, we review recent results obtained by the 3-dimentional Fast Fourier Transform (FFT) analysis of multi-point airglow images reported by Takeo et al. (2017) and Tsuchiya et al. (2018; 2019; 2020). We used the airglow images taken by the Optical Mesosphere Thermosphere Imagers (OMTIs) at Shigaraki (SGK) (35°N, 136°E, 1999-2017) and Rikubetsu (RIK) (44°N, 144°E, 1999-2017), Japan, Athabasca (ATH), Canada, (55°N, 247°E, 2005-2017), and Magadan (MGD), Russia (60°N, 151°E, 2008-2017). First we estimated phase-velocity spectra of mesospheric gravity waves in 557.7-nm airglow images and medium-scale traveling ionospheric disturbances (MSTIDs) in 630.0-nm airglow images. For all the stations, mesospheric gravity waves in 557.7-nm airglow images tend to propagate poleward in summer and equatorward in winter (except for MGD). The summer-time poleward waves may be caused by duct propagation of gravity waves from tropospheric convection source. Wind filtering effect by mesospheric jet is clearly seen over Japan (SGK and RIK), while it becomes less evident at high latitudes in ATH and MGD. For MSTIDs in 630.0-nm airglow images, southwestward-propagating waves are dominant at SGK, RIK, and ATH (except for summer), while they are not evident at MGD. Clear anti-correlation of MSTID power (amplitudes) and 11-year solar activity can be found at SGK, RIK, and ATH. We also show wavenumber spectra of gravity waves and MSTIDs at these stations. Weak positive correlations were obtained between the daily wave power of gravity waves in 557.7-nm images and MSTIDs in 630.0-nm images, suggesting that the MSTIDs in the thermosphere may be partially generated by the gravity waves from the mesopause region.

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Keywords: airglow, atmospheric gravity wave, traveling ionospheric disturbance

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Global distribution of the mesoscale disturbances at 95km altitude detected by a space-borne airglow observation

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1. Department of Geophysics, Graduate School of Science, Kyoto University, 2. Planetary Plasma and Atmospheric Research Center, Graduate School of Science, Tohoku University, 3. University of Electro-Communications

Global distribution of the mesoscale disturbances at 95 km altitude was investigated with the 762nm airglow observed by International Space Station-Ionosphere, Mesosphere, upper Atmosphere and Plasmasphere mapping (ISS-IMAP) mission. The horizontal structures of the mesospheric disturbances have been widely investigated with ground-based all-sky imagers. It is reported that the horizontal wavelength of the mesospheric structures has maximum between 10 km and 30km. The structures whose wavelength is longer than 100 km are, however, difficult to be detected by the ground-based imagers because of their narrow field-of-view. The mesoscale structures on the topside of the mesosphere with a few hundred kilometers of horizontal scale are yet to be investigated. Visible and near Infrared Spectral Imager (VISI) of ISS-IMAP mission observed the mesospheric airglow structures with the airglow from the molecular oxygen in 762nm wavelength. The size of VISI’s field-of-view is 600km in the direction perpendicular to the ISS trajectory, and longer than 10,000km along the trajectory. The mesoscale structures at 95km altitude was investigated with the 762nm airglow data of VISI. By the comparison between the plasma bubble activities measured by the ground-based GNSS receivers, and the mesoscale structure activities in the mesosphere measured by ISS-IMAP/VISI, the relation between the plasma bubble and mesospheric disturbance is discussed. The classical “seeding” theory of the plasma bubble by the atmospheric gravity waves that vertically propagate from the lower atmosphere to the upper atmosphere was evaluated with the space-borne global observation.

Keywords: Ionosphere, Mesosphere, Airglow, Plasma bubble, Atmospheric Gravity Wave

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Recurrent high-speed solar wind co-rotating interaction region imprint on the ionosphere and atmosphere: GPS TEC variations and atmospheric gravity waves

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1. Physics Department University of New Brunswick, Canada , 2. Geomagnetic Laboratory Natural Resources Canada, 3. Earth Planetary and Space Sciences, University of California, USA, 4. Canadian Geodetic Survey Natural Resources Canada , 5. Bradley Dept. of Electrical and Computer Engineering, Virginia Tech, USA

High-speed streams (HSS) from coronal holes dominate solar wind structure in the absence of coronal mass ejections during solar minimum and the descending branch of solar cycle. Prominent and long-lasting coronal holes produce intense co-rotating interaction regions (CIR) on the leading edge of high-speed plasma streams that cause recurrent ionospheric disturbances and geomagnetic storms. Through solar wind coupling to the magnetosphere-ionosphere-atmosphere (MIA) system they affect the ionosphere and neutral atmosphere at high latitudes, and, at mid to low latitudes, by the transmission of the electric fields [1] and propagation of atmospheric gravity waves from the high-latitude lower thermosphere [2].

The high-latitude ionospheric structure, caused by precipitation of energetic particles, strong ionospheric currents and convection, results in changes of the GPS total electron content (TEC) and rapid variations of GPS signal amplitude and phase, called scintillation [3]. The GPS phase scintillation is observed in the ionospheric cusp, polar cap and auroral zone, and is particularly intense during geomagnetic storms, substorms and auroral breakups. Phase scintillation index is computed for a sampling rate of 50 Hz by specialized GPS scintillation receivers from the Canadian High Arctic Ionospheric Network (CHAIN). A proxy index of phase variation is obtained from dual frequency measurements of geodetic-quality GPS receivers sampling at 1 Hz, which include globally distributed receivers of the RT-IGS network that are monitored by the Canadian Geodetic Survey in near-real-time [4]. Temporal and spatial changes of TEC and phase variations following the arrivals of HSS/CIRs [5] are investigated in the context of ionospheric convection and equivalent ionospheric currents derived from the ground magnetometer network using the spherical elementary current system method [6,7].

The Joule heating and Lorentz forcing in the high-latitude lower thermosphere have long been recognized as sources of internal atmospheric gravity waves (AGWs) [2] that propagate both upward and downward, thus providing vertical coupling between atmospheric layers. In the ionosphere, they are observed as traveling ionospheric disturbances (TIDs) using various techniques, e.g., de-trended GPS TEC maps [8].

In this paper we examine the influence on the Earth’s ionosphere and atmosphere of a long-lasting HSS/CIRs from recurrent coronal holes at the end of solar cycles 23 and 24. The solar wind MIA coupling, as represented by the coupling function [9], was strongly increased during the arrivals of these HSS/CIRs.

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Keywords: Polar and auroral ionosphere, High-speed solar wind stream, Solar wind-magnetosphere-ionosphere-atmosphere coupling, Atmospheric gravity wave, Extratropical and tropical cyclones

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Observation of secondary gravity waves over the Southern Andes during an intense mountain wave event.

*Masaru Kogure[1], Jia Yue[2,3], Takuji Nakamura[1,4], Lars Hoffmann[5], Sharon Vadas[6], Yoshihiro Tomikawa[1,4], Mitsumu K. Ejiri[1,4], Diego Janches[2,3]

1. National Institute of Polar Research, 2. NASA Goddard Space Flight Center, 3. Catholic University of America, 4. SOKENDAI (The Graduate University for Advanced Studies), 5. Forschungszentrum Jülich, 6. NorthWest Research Associates

Gravity waves (GWs) are an important atmospheric phenomenon with horizontal scales ranging from several kilometers to several thousand kilometers. GWs propagate vertically from their sources in the troposphere to upper altitudes, and they deposit their momentum into the background flow when they break. This deposition of momentum influences the global atmospheric circulation and temperature structure of the atmosphere [Lindzen, 1981; Holton, 1983].

The Southern Andes are well known as one of the mountain wave hot spots [e.g., Ern et al., 2004; Alexander et al., 2008; Hoffmann et al., 2013]. Recently, Vadas and Becker [2019] demonstrated with numerical modeling that the breaking of mountain waves over the Andes can create secondary GWs at about 50-80 km of altitude, yielding concentric ring structures. Vadas and Becker [2019] also pointed out that secondary (and higher-order) GWs could create medium- and large-scale ionospheric disturbances. Some observational studies support this hypothesis [Vargas et al., 2016; de Wit et al., 2017; Liu et al., 2019], but the observational evidence is still limited and indirect, and the characteristics of the secondary GWs (e.g., occurrence rate, horizontal distribution, and wave parameters) are not well understood. The purpose of this study is to look for signatures of secondary GW generation in observations from a space-based instrument (VIIRS/Suomi-NPP) and compare their characteristics in the real atmosphere with model simulations.

This study focuses on a mountain wave event with significant amplitudes (>3 K) and ~500 km horizontal wavelengths over the Southern Andes, observed on 24 and 25 July 2017 with AIRS/Aqua satellite data [Hoffman et al., 2017]. The AIRS/Aqua satellite instrument can measure GWs with >30 km horizontal wavelengths in a range of ~20-50 km of altitude. In the MERRA-2 reanalysis wind data, a mesoscale vortex-like pattern appeared to the west of the Andes, and the wind flowed over the Andes. Thus, the GWs observed by AIRS/Aqua were probably mountain waves. VIIRS/Suomi-NPP (can resolve GWs with > several km horizontal wavelengths at ~85 km) did not detect mountain waves but instead observed concentric ring-like GWs with a few hundred km wavelengths at 4.5 UT on the same night (25 July 2017) over the Southern Andes and its east side (leeward).

In this presentation, we will show the observational results and discuss the relationship between the mountain waves observed by the AIRS/Aqua satellite and the concentric GWs observed by VIIRS/Suomi-NPP. In particular, we will focus on what altitude the observed mountain waves broke and why the observed concentric ring-like GWs extended leeward.

Keywords: Gravity wave, The middle atmosphere, The Andes

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM12] Coupling Processes in the Atmosphere-Ionosphere System

convener:Huixin Liu(Earth and Planetary Science Division, Kyushu University SERC, Kyushu University), Yuichi Otsuka(Institute for Space-Earth Environmental Research, Nagoya University), Yue Deng(University of Texas at Arlington), Loren Chang(Institute of Space Science, National Central University)

The Atmosphere-Ionosphere (A-I) system forms the so-called near-Earth space. Recent rapidly expanding use of satellite constellations in Low-Earth Orbit (LEO) drives a high demand for better understanding and accurate forecast of the global A-I system for scientific and operational purposes. This session aims to provide a forum for research advances and frontiers related to these aspects, and we invite presentations on global A-I coupling at all temporal and spatial scales. This includes but is not limited to: A-I coupling via atmospheric waves (tides, gravity waves, planetary waves) and trace gases (CO2, O3, H2O), A-I response to Space Weather events (solar flares, CMEs, CIRs), polar-equatorial or inter-hemispheric coupling via TADs/TIDs/disturbance dynamo/penetration electric field, ionospheric plasma irregularities, ionospheric currents, etc. Observations, theoretical studies, model simulations, data assimilation, instruments development are all highly welcome.

[PEM12-25] **Importance of Realistic Auroral Precipitation, Electrical Field Variability, and Model Resolution in Resolving the Storm-Time Neutral Temperature and Density**

★Invited Papers

*Xian Lu[1], Haonan Wu[1], Gang Lu[2], Xinzhao Chu[3,4], Wenbin Wang[2], Delores Delores[2,4], Yukitoshi Nishimura[5] (1.Department of Physics and Astronomy, Clemson University, Clemson, SC, USA, 2.High Altitude Observatory, National Center for Atmospheric Research, Boulder, CO, USA, 3.Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, CO, USA, 4.Department of Aerospace Engineering Sciences, University of Colorado, Boulder, CO, USA, 5.College of Electrical and Computer Engineering, Boston University, Boston, MA, USA)

[PEM12-26] Driver and Response Characteristics for Improved Physics-Based Simulation of the Thermosphere

★Invited Papers

*Eric K Sutton[1], Marcin Pilinski[2], Greg Lucas[2], Jeffrey P Thayer[1], Thomas E Berger[1] (1.Space Weather Technology, Research & Education Center, University of Colorado at Boulder, 2.Laboratory for Atmospheric and Space Physics, University of Colorado at Boulder)

[PEM12-27] Longitudinal Variation and Peak Time of Equatorial Electrojet Current from Ground and Satellite Measurements

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[PEM12-28] Thermospheric wind acceleration in the ionospheric trough for Kp = 0+

*Shin-ichiro Oyama[1,2,3], Anita Aikio[2], Heikki Vanhamaki[2], Atsuki Shinbori[1], Mike Rietveld[5], Yasunobu Ogawa[3], Mirjam Kellinsalmi[4], Tero Raita[2], Kazuo Shiokawa[1], Ilkka Virtanen[2], Lei Cai[6], Abiyot Workayehu[2], Marcus Pedersen[2], Kirsti Kauristie[4], Boris Kozelov[7], Andrei Demekhov[7] (1.Institute for Space-Earth Environmental Research, Nagoya University, 2.Space Physics and Astronomy Research Unit, University of Oulu, Finland, 3.National Institute of Polar Research, Japan, 4.Finnish Meteorological Institute, Finland, 5.EISCAT, Norway, 6.KTH Royal Institute of Technology, Sweden, 7.Polar Geophysical Institute, Russia)

[PEM12-29] Day-to-day variation of pre-reversal enhancement in the equatorial ionosphere based on GAIA model

Priyanka Ghosh[1], *Yuichi Otsuka[1], Sivakandan Mani[1], Hiroyuki Shinagawa[2] (1.Institute for Space-Earth Environmental Research, Nagoya University, 2.National Institute of Information and Communications

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[PEM12-30] Enhanced Electric Field Before Large Earthquakes

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Importance of Realistic Auroral Precipitation, Electrical Field Variability, and Model Resolution in Resolving the Storm-Time Neutral Temperature and Density

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Dramatic Neutral Temperature enhancement and an Inversion Layer (NTIL) have been detected by the Fe Boltzmann lidar at McMurdo, Antarctica during a geomagnetic storm. None of empirical or default configurations of physical models capture these features. We use the Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIEGCM) with high-latitude drivers constrained by data to examine the mechanisms of NTIL. The auroral precipitation maps from DMSP/SSUSI are incorporated in the TIEGCM, which increase Pedersen conductivity significantly in the auroral region. Sub-grid electric field variabilities are implemented with regard to the spatial distribution of auroral activities. Thereby, the observed large temperature enhancement and NTIL are reproduced. The default model runs underestimate the neutral densities by 40% compared with GRACE measurements, which are resolved by incorporating observed auroral maps and sub-grid electric field variabilities. The mechanism to generate temperature inversion in the lower thermosphere is : strong local Joule heating due to the enhanced auroral precipitation and sub-grid electric field variability induces large upward vertical wind which leads to strong cooling around 200 km. Strong heating around 150 km, while cooling dominating above it, generates the inversion layer. The two different model resolutions are run for this event, and the contributions from the fine-scale auroral precipitation and electric field to the storm-time neutral atmosphere are examined.

Keywords: geomagnetic storm, auroral energetic particles, neutral ion coupling, electric field variability, DMSP/SSUSI, TIEGCM

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Driver and Response Characteristics for Improved Physics-Based Simulation of the Thermosphere

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The neutral density of the thermosphere directly impacts satellites that reside within or traverse Low-Earth Orbit (LEO) over a wide range of timescales. At shorter time scales—minutes to days—variations in density impede the operational imperative to track satellites and objects and to avoid collisions. At longer time scales—a solar cycle and beyond—variations in density control the size and distribution of the LEO population of objects. As the number of SmallSat missions and the resulting debris objects population increase at unprecedented rates, monitoring and modeling the LEO environment become ever more important. The challenges of this are compounded by the relatively few direct data sources currently available with which to monitor the thermosphere over these pertinent timescales. In this talk, we will discuss efforts to use precision orbit determination (POD) from GNSS-equipped SmallSats to fill in the sparsely observed thermosphere. We will also provide an update on efforts to create a civilian thermosphere monitoring system, blending available data sources with a physical model of the coupled thermosphere-ionosphere system in the context of a data assimilative framework.

Keywords: thermosphere, density, data assimilation, GNSS, Precision Orbit Determination

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Longitudinal Variation and Peak Time of Equatorial Electrojet Current from Ground and Satellite Measurements

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In this study, we presented the variability of equatorial electrojet (EEJ) current examined using data measured by ground stations and satellite magnetometers during quiet days in different solar activity levels. Two main focus here are the EEJ’ s longitudinal profile and its peak time. We have evaluated both ground and satellite data using linear regression method before categorized them into different solar activity levels: low, moderate and high. A good agreement of EEJ longitudinal profile between both measurements appear during low solar activity with a high correlation coefficient is observed in the Southeast Asian sector. Apart from that, our analysis demonstrated that the seasonal dependence of EEJ’ s peak time reported by previous studies were only reflected at certain longitude sectors.

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Thermospheric wind acceleration in the ionospheric trough for Kp = 0+

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Ionospheric trough is a low plasma-density area occasionally appeared at subauroral latitudes, typically seen for period of geomagnetic disturbances. On 20 February 2018, a zonally elongated ionospheric trough was developed from Fennoscandia to North America. Of notable interest was the geomagnetic activity, which was considerably quiet level as represented by Kp index of 0+ for the time interval interested in this study. The ionospheric trough was located at 70-71 deg N and the main auroral oval stayed at 74-76 deg N in the Fennoscandia sector. A minor but obvious auroral enhancement occurred at about 18:30 UT (~21 MLT) near Svalbard archipelago. We call this “pseudo-breakup” in this study. Coinciding with the pseudo-breakup, westward turning of the ionospheric ion velocity from +200 m/s to -200 m/s was detected with the dynasonde at Tromsø, Norway (69.6 deg N), that is, in the ionospheric trough or slightly its equatorward side. At the same time, a collocated Fabry-Perot interferometer (FPI) also detected westward acceleration of the wind starting from +100 m/s (positive eastward) but without change its direction. While some previous publications mentioned the westward acceleration in the vicinity of the substorm growth-phase arc, there are few reports to clearly present the experimental evidence in the ionospheric trough. Causality to produce the westward acceleration of the FPI wind was probably ion drag despite of moderately low plasma density in the ionospheric trough. The relative speed between ions and neutral particles would result in frictional heating, which might lift denser or molecular neutral particles to the upper ionosphere and induce decrease in the ionospheric density through dissociative recombination of the molecular ions.

Keywords: Thermosphere, Ionosphere, trough, Fabry Perot interferometer

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Day-to-day variation of pre-reversal enhancement in the equatorial ionosphere based on GAIA model

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Plasma bubble is a localized plasma density depletion occurring at magnetic equator through the Rayleigh-Taylor instability. Eastward electric field plays an important role for the Rayleigh-Taylor instability, so that the plasma bubbles tend to occur more frequently when Pre-Reversal Enhancement (PRE) of the eastward electric field is intense. However, mechanisms for day-to-day variation of the PRE is not still unknown. Using Ground-to-Topside Model of Atmosphere and Ionosphere for Aeronomy (GAIA), we have aimed to find parameters which control day-to-day variation of PRE. With respect to the day-to-day variation, cross-correlation coefficients of PRE with zonal electric current density, electron density, and neutral winds between the E and F regions are investigated. We have found that the cross-correlation coefficient between PRE and eastward current density in the E and F regions are approximately 0.5 and 0.8, respectively. We have also found that the cross-correlation coefficient between PRE and eastward electric current density is largest at 17 LT (pre-sunset) than at other local time. This result suggests that the equatorial electro-jet at pre-sunsent is closely related to development of PRE. This result is consistent with previous observation of equatorial electro-jet by Uemoto et al. (2010).

Keywords: equatorial ionosphere, plasma bubble, GAIA

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Enhanced Electric Field Before Large Earthquakes

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Electric field seems to be a main driver which disturbs ionosphere prior to large earthquake. The problem is where and how the electric field is generated. We have proposed that electric field is originally dynamo field which appears ionosphere E and F region. It enhances around the epicenter region. That is, during daytime the eastward electric field is enhanced, while during nigh time, westward electric field is enhanced. This idea explains all ionosphere anomalies which we have found from the past studies (Oyama et al., 2008; Oyama et al., 2011 ;Oyama et al., 2019). Next question is the mechanism of enhanced dynamo E field. Most probably, Pedersen conductivity of E/F region reduced. The electric potential which exists between dawn and dusk is divided by the conductivity of the earthquake-disturbed region, resulting in the stronger E field in the disturbed region. Further question is the mechanism of reduced conductivity. The conductivity is reduced by irregularity of neutral particle density and by increase of neutral density. These two are generated by the breaking of gravity and/or acoustic waves.

Keywords: Ionosphere, Earthquake, Electric field, Waves

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM12] Coupling Processes in the Atmosphere-Ionosphere System

convener:Huixin Liu(Earth and Planetary Science Division, Kyushu University SERC, Kyushu University), Yuichi Otsuka(Institute for Space-Earth Environmental Research, Nagoya University), Yue Deng(University of Texas at Arlington), Loren Chang(Institute of Space Science, National Central University)

The Atmosphere-Ionosphere (A-I) system forms the so-called near-Earth space. Recent rapidly expanding use of satellite constellations in Low-Earth Orbit (LEO) drives a high demand for better understanding and accurate forecast of the global A-I system for scientific and operational purposes. This session aims to provide a forum for research advances and frontiers related to these aspects, and we invite presentations on global A-I coupling at all temporal and spatial scales. This includes but is not limited to: A-I coupling via atmospheric waves (tides, gravity waves, planetary waves) and trace gases (CO2, O3, H2O), A-I response to Space Weather events (solar flares, CMEs, CIRs), polar-equatorial or inter-hemispheric coupling via TADs/TIDs/disturbance dynamo/penetration electric field, ionospheric plasma irregularities, ionospheric currents, etc. Observations, theoretical studies, model simulations, data assimilation, instruments development are all highly welcome.

[PEM12-31] Chemical releases from the sounding rockets - old but new technique to observe thermosphere and ionosphere

*Yoshihiro Kakinami[1], Shigeto Watanabe[1], Masa-yuki Yamamoto[2], Takumi Abe[3], Hiroto Habu[3], Taro Watanabe[2], Mark Conde[4], Miguel Larsen[5] (1.Hokkaido Information University, 2.Kochi University of Technology, 3.ISAS/JAXA, 4.University of Alaska Fairbanks, 5.Clemson University)

[PEM12-32] IDEASSat: A 3U CubeSat Mission for Ionospheric Science and Expanded in-Situ Observations

*Loren Chang[1], Chi-Kuang Chao[1], Yi Duann[1], Yi-Chung Chiu[1], Rong Tsai-Lin[1], Tzu-Ya Tai[1], Wei-Hao Luo[1], Chi-Ting Liao[1], Hsin-Tzu Liu[1], Amal Chandran[2], Cheng-Ling Kuo[1], Jann-Yenq Liu[1] (1.Department of Space Science and Engineering, National Central University, 2.Satellite Research Centre, Nanyang Technological University, Singapore)

[PEM12-33] Development of new receiver for HF Doppler sounding utilized by Software-Defined Radio device

*Hiroyuki Nakata[1], Yuhei Oki[2], Kenro Nozaki[3], Keisuke Hosokawa[3], Ichiro Tomizawa[3], Ryo Matsushima[3], Kumiko K. Hashimoto[4], Toshiaki Takano[1], Hiroyo Ohya[1] (1.Graduate School of Engineering, Chiba University, 2. Department of Electrical and Electronics Engineering, Faculty of Engineering, Chiba University, 3.The University of Electro-Communications, 4.Kibi International University)

[PEM12-34] GPS radio occultation measurement for SMILES-2

*Makoto Suzuki[1], Philippe Baron[2], Satoshi Ochiai[2], Naohiro Manago[3], Josaphat Tetuko Sri Sumantyo[3], JANN-YENQ Liu[4], Akinori Saito[5], Huixin Liu[6], Masato Shiotani[7] (1.Institute for Space and Astronautical Sciences, Japan Aerospace Exploration Agency, 2.National Institute of Information and Communications Technology, 3.Center for Environmental Remote Sensing, Chiba University, 4.Center for Astronautical Space and Engineering, National Central University , 5.Kyoto University, 6.Dept. of Earth and Planetary Science Faculty of Science Kyushu University, 7.RISH, Kyoto University)

[PEM12-35] SCIntillation and IONosphere – eXtended (SCION-X) – A Small Satellite for Ionospheric and Atmospheric Science

*Pin-An Lin[1], Kai-Lun Cheng[1], Tsai-Ju Yu[1], Ruo-Yu Wang[1], Yueh-Chun Hsieh[1], Glenn Franco Gacal[1], Hsin-I Tu[1], Sittinat Denduonghatai[1], Guan-Po Ciou[1], Loren C. Chang[1], Jann-Yenq Liu[1], Cheng-Ling Kuo[1], Tang-Huang Lin[2], Amal Chandran[3] (1.Graduate Institute of Space Science and Engineering, National Central University, Taoyuan City, Taiwan, 2.Center for Space and Remote Sensing Research, National Central

University, Taoyuan City, Taiwan, 3.Satellite Research Centre, Nanyang Technological University, Nanyang Avenue, Singapore)

[PEM12-36] The development and validation of a photochemical model for atomic oxygen ion retrieval from ground-based airglow observations

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Chemical releases from the sounding rockets - old but new technique to observe thermosphere and ionosphere

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Chemical releases from the sounding rockets for observing dynamics and properties of lower thermosphere and ionosphere have been conducted since 1950’s. Vapors of sodium (Na), lithium (Li), barium (Ba), and strontium (Sr), and tri-methyl aluminum (TMA) are released as a tracer of neutral wind and ion drift velocity. Ionized Ba (Ba^+) is used as a tracer of ion drift because Ba is immediately ionized by solar EUV after the release while the others are used as tracers of neutral wind. The chemical release experiments using Na, Li, Ba, and Sr require solar or lunar illumination to visualize the chemical clouds while TMA does not require them because of chemiluminescence. The chemical release experiments had contributed to understand dynamics of thermosphere and ionosphere but the number of experiments decreased due to limitation of optical observation etc. However, since the performance of CCD has been improved in the past decade and one can detect dark resonance scattered light, the chemical release experiment has been draw renewed attention from scientists again. Lithium ejection system was newly developed in Japan and the chemical release experiment of Li was conducted in Uchinoura, Japan in 2007 after a long interval. The experiment achieved success to release Li and vertical profile of neutral wind velocity together with diffusion velocity were obtained in the dusk. Similar experiments were successfully conducted in the dawn in Uchinoura, Japan in 2011, in the dusk in Marshall Islands in 2013, and in the daytime in Wallops, US in 2013. The results showed strong wind shears exist around 100 km altitude. We estimated altitude profile of neutral density from the diffusion velocity. The Li cloud was detected under the condition of moonlit in Uchinoura, Japan in 2013. These experiments show that the wind profile is observable in all local time. The ejection systems of Barium and Strontium were newly developed in US. The chemical release of Ba and Sr was conducted in Andoya, Norway in 2014 and neutral and ion drift velocities were simultaneously observed. Further, another experiment using Ba, Sr, and TMA was executed in 2019 and Ba and Sr experiment was also executed in Norway in 2019. In this paper, we summarize the results of chemical release experiments in recent decade and present new experiment planed in Japan.

Keywords: sounding rocket, chemical release, lithium, Li, barium, Ba, strontium, Sr, tri-methyl aluminum, TMA

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IDEASSat: A 3U CubeSat Mission for Ionospheric Science and Expanded in-Situ Observations

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The Ionospheric Dynamics Exploration and Attitude Subsystem Satellite (IDEASSat / INSPIRESat-2) is a three-unit (U) CubeSat developed with the objective of providing in-situ measurements of the Earth's ionosphere in order to quantify both global scale ionospheric variability and small scale irregularities. The science payload is the Compact Ionospheric Probe (CIP) - an all in one in-situ plasma sensor developed at Taiwan National Central University (NCU), which is the miniaturized version of the larger Advanced Ionospheric Probe (AIP) that is carried and operational aboard the 450 kg FORMOSAT-5 spacecraft. The spacecraft has been developed by NCU in partnership with the International Satellite Program in Research and Education (INSPIRE) consortium, and is funded by the Taiwan National Space Organization (NSPO), Ministry of Science and Technology, and Ministry of Education as part of the first national effort to encourage small satellite development at Taiwan universities. IDEASSat will work in conjunction with FORMOSAT-5, as well as the INSPIRESat-1 and ARCADE/INSPIRESat-4 small satellites to provide ionospheric observations spanning different altitudes and local times. IDEASSat will be launched in late 2020. In this report, we describe the IDEASSat mission and spacecraft design, the potential for combined multi-satellite observations, as well as unique lessons learned as part of the development process.

Keywords: Ionosphere, Scintillation, CubeSat

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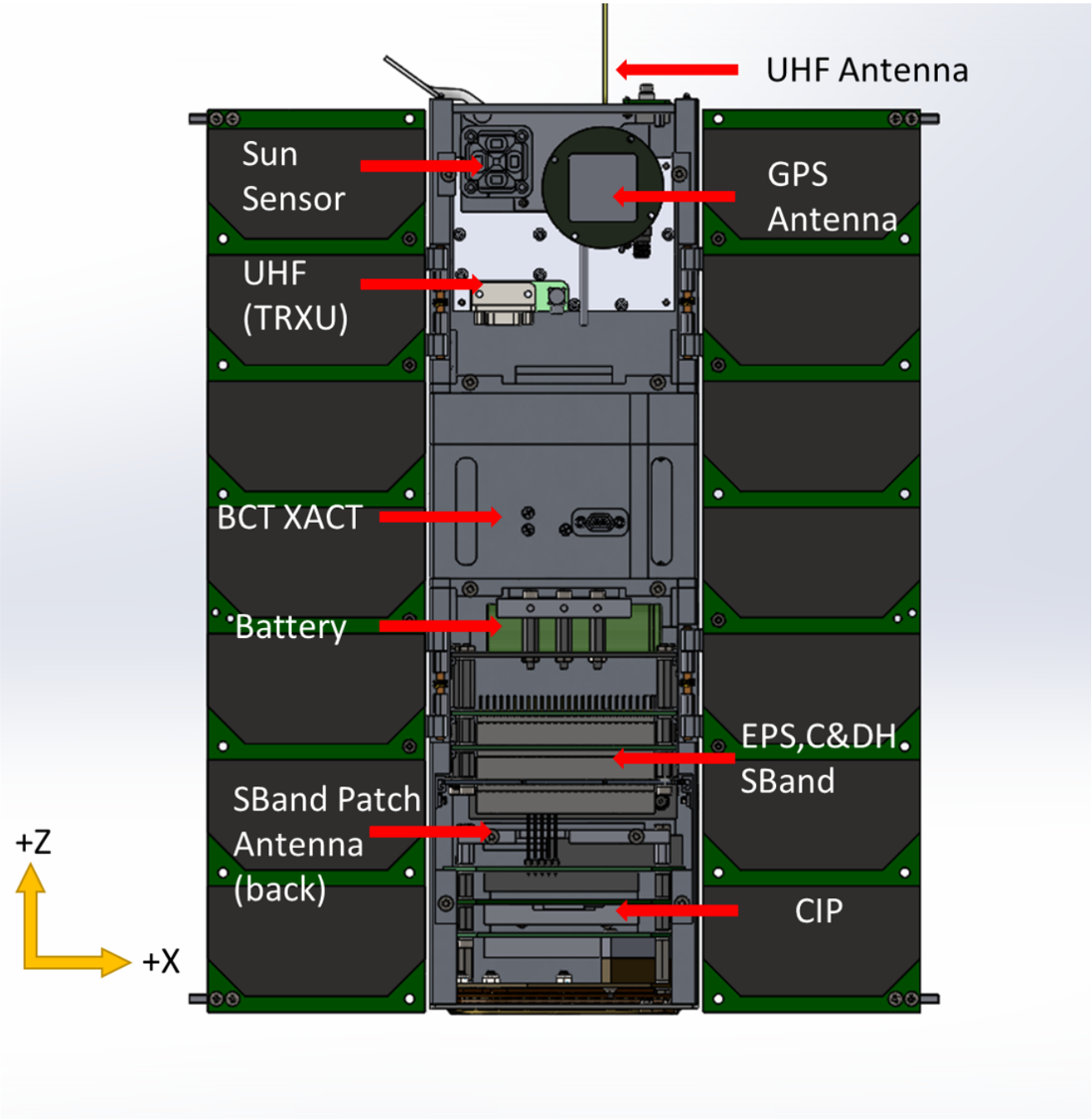

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Development of new receiver for HF Doppler sounding utilized by Software-Defined Radio device

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To examine the dynamics of the ionosphere, the observation of both steady and disturbed states of the ionosphere is important. Various observation systems have been utilized to observe the behaviors of the ionosphere itself and the ionospheric disturbances. One of the useful observation systems is HF Doppler sounding. When the reflection point of the radio wave moves vertically, the frequency of the radio wave shifts due to the Doppler effect. From this Doppler frequency, we are able to estimate the vertical motions of the ionospheric plasma. To develop and maintain the transmitter and the receiver of Doppler sounding system, the knowledge of the analog circuit has been inevitable. Recently, on the other hand, Software-Defined Radio (SDR) device, which equips digital electronics for signal processing, is developed and make it possible to develop the equipments for HF Doppler sounding system easily by utilizing the software processing. This means that the receivers for HF Doppler sounding system are developed without the knowledge of the analog circuits. Therefore, we have developed the new HF receiver using SDR device instead of the traditional receiver. In this study, we adopted USRP N210 as a new SDR device. In HFD sounding system, the transmitter for 5.006 MHz and 8.006 MHz is located at Chofu Campus of the University of Electro-Communications and that for 6.055 MHz and 9.595 MHz (now off the air) is Radio NIKKEI transmitter located at Nagara. The previous receiver can observe radio waves at four different frequencies with 100 Hz sampling. New SDR receiver is also enable to observe the four different radio waves with 160 Hz sampling. Test observation of the new SDR receiver were performed in Awaji with the previous receiver. We compared the observational results of Doppler frequencies between both receivers.

The Doppler frequencies of the sky wave observed by SDR receiver and the previous analog receiver are coincided each other. Therefore, it is found that the new receiver can be utilized for the actual observation. New SDR receivers will be installed at Onna, Sarobetsu, and existing stations.

Keywords: HF Doppler sounding, Receiver Development, Software Defined Radio, USRP

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GPS radio occultation measurement for SMILES-2

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SMILES-2 (Shiotani et al IGARSS 2019, Ochiai et al IGARSS 2019) is a proposal submitted to JAXA/ISAS small satellite program (Feb. 2020), which is now under selection to go to Pre-Phase A1b and, if selected, it launch will be latter half of 2020s. SMILES-2 will have 3 instruments; (1) submm and THz limb sounder, (2) GPS Radio Occultation (RO) for temperature and density, and (3) Langmuir probe for in situ Electron density and temperature. This paper discuss the combined measurement of submm-THz and GPS RO.

Two submm bands are (i) 619.1-627.1, 649.05-657.05 GHz double side bands (DSB) with 638.075 GHz Local oscillator (LO), and (ii) 750.0-756.0, 771.0-777.0 GHz DSB with 763.5 GHz LO, both with 1.0 MHz sampling interval. The 638 GHz band is a band width extended one from ISS/JEM/SMILES frequency coverage, and the 763.5 GHz band is designated to measure O2 and H2O well suited for temperature and wind speed retrieval. Terahertz (THz) band is aiming to measure O-atom (O-atom density, temperature, and wind speed), and OH. Suzuki et al have shown sensitivity for chemical species (Suzuki et al IGARSS 2019), and Baron et al have shown sensitivity for temperature and wind speed (Baron et al, AMT 2020).

GPS RO is established measurement technique of temperature-density-altitude profile (0-40 km) and electron density profile (upper atmosphere; 90 km - Satellite altitude). If SMILES-2 spacecraft has two RO antenna forward and backward, we can expect 5-6 times/day coincidence (i.e. <100 km in azimuth direction at tangent points) of submm-THz and GPS-RO measurements. The THz observation of SMILES-2 (2.0 THz for O-atom) can provide dataset of temperature, O-atom density, wind speed of neutral atmosphere (<150 km), so we can investigate the interaction from electron density at the coincident condition.

GPS RO meteorological dataset (0-40 km) is also crucial for improving spectroscopic parameters (gamma-air and n-air), since those spectroscopic parameter will have 5%-20% uncertainty without careful laboratory measurements . It will affect to all retrieval of chemical species with same magnitude (5%-20%). So, we propose to make spectroscopic studies based upon SMILES-2 dataset (submm-THz L1B data with GPS RO temperature profile). The GPS RO dataset is the only dataset which has comparable temperature precision of SMILES-2, and the accuracy (systematic difference from true value) is much better than the SMILES-2 dataset.
GPS RO instrument can be developed easily based upon JAXA GPSR system standard for most JAXA earth orbiting satellites, and it was a plan in the 2018 SMILES-2 proposal. We have chosen the one from Taiwan Central University because of its strong scientific ad engineering heritage from COSMIC-1/2 programs.

Keywords: submm, limb souding, GPS radio occultation, electron density profile, temperature profile

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SCIntillation and IONosphere –eXtended (SCION-X) –A Small Satellite for Ionospheric and Atmospheric Science

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With the advent of the new era of space science and technology and the effects of climate change, SCION-X, a small satellite under development by National Central University in Taiwan has the ability to provide more accurate observations for atmospheric measurements and air quality from the lower atmosphere, as well as ionospheric plasma density for space weather monitoring and forecasts. SCION-X will carry three science payloads. One of the payloads for SCION-X mission is a GNSS Radio Occultation Receiver (GROR), which uses measurements of GPS L1 and L2 pseudorange, phase, and carrier to noise ratio (Cb/No) to derive the vertical profiles of ionospheric electron density and S4 amplitude scintillation index. These observations will be further complemented by the Compact Ionospheric Probe (CIP), which is an in-situ plasma sensor with high Technological Readiness Level (TRL) and high sampling rates to measure ionospheric parameters and irregularity structure at sub-kilometer scales. These observations will help to correct and predict the positioning errors and satellite communications disruptions caused by ionospheric anomalies such as the generation and propagation of plasma bubbles. In addition to ionospheric studies, GROR can also provide observations of the water vapor and temperature distribution in the troposphere. Assimilation of the tropospheric observations into weather forecast models will be beneficial for global climate research and improve the accuracy of tropical cyclone forecasts. The third payload is Hyper-SCAN, which is a newly developed hyperspectral imager. By analyzing the spectrum between 380 - 1020 nm and comparing with in-situ PM2.5 aerosol measurements on the ground, a first calibration test of Hyper-SCAN will be performed to serve as a reference for the study of PM2.5 pollution distribution and its sources.

Keywords: ionosphere irregularity, weather forecast, radio occultation, air pollution (PM2.5)

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The development and validation of a photochemical model for atomic oxygen ion retrieval from ground-based airglow observations

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Three photochemical inversion models are derived to retrieve atomic oxygen ion density ($[O^+]$) from 630.0 nm intensity emitted by $O(^1D)$ excited state, to understand the relation between 630.0 nm airglow emission and $[O^+]$. Three experiments are performed in this study. The first experiment validated our inversion models with Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM) results, with the derived $[O^+]$ showing high correlation with the TIE-GCM model truth. Sensitivity testing results show that molecular oxygen density ($[O_2]$) used in the inversion process is most effective in determining the trends of calculated $[O^+]$. The second and third experiments are applied with ground-based spectrometer 630.0 nm data from Geophysical Observatory of the Russian Academy of Sciences Siberian Branch near Irkutsk, Russia (51.8˚N, 103.1˚E) in 2016, but with unobserved background inputs from TIE-GCM and empirical models, respectively. A new height profile based on emission layer thickness and *hmF2* derived 630 nm airglow intensity peak altitude for Gaussian distribution (GD) is applied for converting Rayleighs into Volume Emission Rate (VER) (*Adachi et al.,* 2009), and is consistent with the TIE-GCM calculated airglow peak altitude. Future work will replace GD with Chapman distribution which should be closer to reality. With the new inversion models and preliminary height profile, estimations of $[O^+]$ using empirical models and airglow observation are possible and may be extended to estimate $[O_2]$ if combined with electron density measurements.

Keywords: Airglow, Atomic Oxygen Ions, Photochemical models, TIEGCM, Irkutsk

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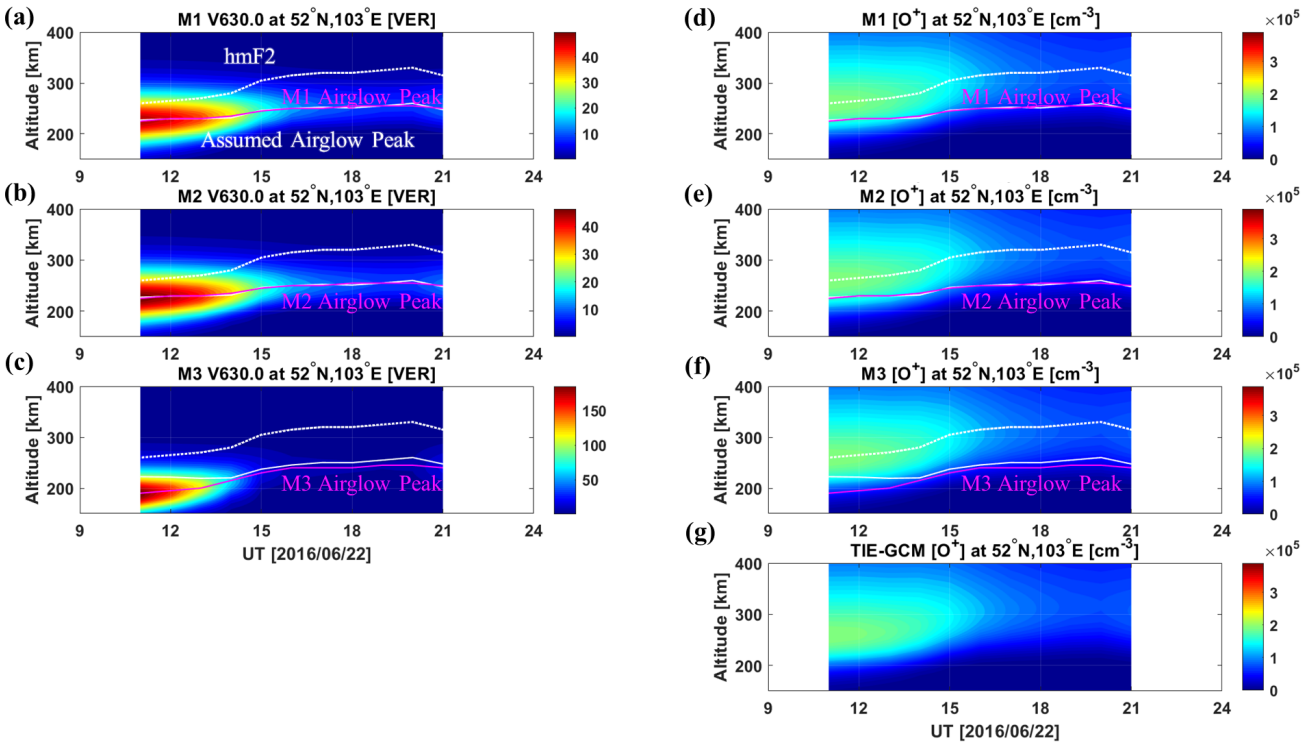

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM13] Dynamics of Magnetosphere and Ionosphere

convener:Aoi Nakamizo(Applied Electromagnetic Research Institute, National Institute of Information and Communications Technology), Mitsunori Ozaki(Faculty of Electrical and Computer Engineering, Institute of Science and Engineering, Kanazawa University), Akiko Fujimoto(Kyushu Institute of Technology), Yuka Sato(Nippon Institute of Technology)

This session provides an opportunity to present recent results from satellite and ground-based observations and theoretical and simulation studies on the magnetosphere, ionosphere, and their coupling processes. We invite talks and posters discussing various phenomena related to the magnetosphere-ionosphere system: solar wind-magnetosphere interaction, magnetosphere-ionosphere convection, field-aligned current, magnetic storms/substorms, neutral-plasma interaction, ionospheric ion inflow and outflow, aurora phenomena, and so forth. Discussions on planetary and satellite ionospheres and magnetospheres, future missions and instrument developments are also welcome.

[PEM13-01] Effect of solar wind high-speed streams on the high-latitude ionosphere

★Invited Papers

*Anita Aikio[1], Nada Ellahouny[1], Ilkka Virtanen[1], Heikki Vanhamäki[1], Marcus Pedersen[1], Johannes Norberg[2], Kirsti Kauristie[2], Maxime Grandin[3], Alexander Kozlovsky[4], Tero Raita[4], Aurelie Marchaudon[5], Pierre-Louis Blelly[5], Shin-ichiro Oyama[6] (1.Space Physics and Astronomy Research Unit, University of Oulu, Finland, 2.Finnish Meteorological Institute, Helsinki, Finland, 3.CoE in Sustainable Space, University of Helsinki, Finland, 4.Sodankylä Geophysical Observatory, Finland, 5.IRAP, University of Toulouse, France, 6.ISEE, Nagoya University, Japan)

[PEM13-02] The relationship between F-region disappearance in the polar cap region and field-aligned currents at geosynchronous orbit during the 11 May 2019 magnetic storm

*Hyuck Jin Kwon[1], Khan-Hyuk Kim[1], Geonhwa Jee[2,3], Jongho Seon[1], Jeong-Han Kim[2], Changsup Lee[2], Young-Bae Ham[2,3], Terence Bullett[4,5], Uli Auster[6], Werner Magnes[7], Stefan Kraft[8] (1.Kyung Hee Univ., 2.Korea Polar Research Institute, 3.University of Science and Technology, 4.University of Colorado, 5.NOAA, 6.TUBS, 7.OeAW, 8.ESA)

[PEM13-03] High ion temperature events at F region altitudes in the cusp: Spatial relations to the moving electron precipitation regions

*Satoshi Taguchi[1], Yunosuke Nagafusa[1], Yasunobu Ogawa[2], Keisuke Hosokawa[3], Tomokazu Oigawa[1], Morio Tanaka[1], Hiroyuki Shinagawa[4] (1.Department of Geophysics, Graduate School of Science, Kyoto University, 2.National Institute of Polar Research, 3.Department of Communication Engineering and Informatics, University of Electro-Commnunications, 4.National Institute of Information and Communication Technology)

[PEM13-04] Ionization of the mesosphere during substorm growth phase

*Kiyoka Murase[1], Ryuho Kataoka[2], Takanori Nishiyama[2], Koji Nishimura[2], Taishi Hashimoto[2], Yoshimasa Tanaka[2], Akira Kadokura[2], Yoshihiro Tomikawa[2], Masaki Tsutsumi[2], Kaoru Sato[3], Satoshi Kasahara[3], Takefumi Mitani[4], Shoichiro Yokota[9], Tomoaki Hori[7], Kunihiro Keika[3], Nana Higashio[5], Takeshi Takashima[4], Yoshiya Kasahara[6], Shoya Matsuda[4], Masafumi Shoji[7], Ayako Matsuoka[4], Iku Shinohara[4], Yoshizumi Miyoshi[7], Tatsuhiko Sato[8] (1.The Graduate University for Advanced Studies, 2.National Institute of Polar Research, 3.University of Tokyo, 4.Japan Aerospace Exploration Agency, Institute of Space and Astronautical Science, 5.Japan Aerospace Exploration Agency, 6.Kanazawa University, 7.Nagoya University, 8.Japan Atomic Energy Agency, 9.Osaka University)

[PEM13-05] Characteristics of ion upflows from the low-altitude ionosphere observed by EISCAT

*Masayoshi Takada[1], Kanako Seki[1], Yasunobu Ogawa[2], Kunihiro Keika[1], Satoshi Kasahara[1], Shoichiro Yokota[3], Tomoaki Hori[4], Kazushi Asamura[5], Yoshizumi Miyoshi[4], Iku Shinohara[5] (1.Tokyo University, 2.National Institute of Polar Research, Japan, 3.Graduate School of Science, Osaka University, 4.Institute for Space-Earth Environmental Research, Nagoya University, 5.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency)

[PEM13-06] The Formation of Substorm Aurora in the Solar Wind-Magnetosphere- Ionosphere Coupling System

*Yan Song[1], Robert L Lysak[1] (1.University of Minnesota)

Effect of solar wind high-speed streams on the high-latitude ionosphere

*Anita Aikio[1], Nada Ellahouny[1], Ilkka Virtanen[1], Heikki Vanhamäki[1], Marcus Pedersen[1], Johannes Norberg[2], Kirsti Kauristie[2], Maxime Grandin[3], Alexander Kozlovsky[4], Tero Raita[4], Aurelie Marchaudon[5], Pierre-Louis Blelly[5], Shin-ichiro Oyama[6]

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The Sun and the solar wind are sources of space weather disturbances in the geospace environment. During the declining phases of solar cycles, the solar wind high-speed streams (HSSs) are a dominant phenomenon, even though they appear at all phases of the solar cycle. HSSs originate from the coronal holes on the Sun and during their travel in the interplanetary space, HSSs interact with the slow solar wind, generating co-rotating interaction regions (CIRs). The effect of HSS/CIRs on the terrestrial ionosphere is a complicated and poorly understood process, which involves flow of mass and energy from the Sun, interaction with the Earth’ s magnetosphere, and final entry of energy into the ionosphere in different forms including particle precipitation and Poynting flux producing Joule heating.

In this talk, we will focus on the effects of HSS/CIRs on the high-latitude ionosphere. We will give a brief overview of the observed features and modeling effects in earlier studies and then we will focus on one specific event taking place in March 2016, for which we have an extensive set of measurements. The event was caused by two interacting HSS/CIR structures, which produced a moderate geomagnetic storm, which lasted for eight days. In specific, we have EISCAT Tromso and Svalbard (ESR) incoherent scatter radar measurements for this event, giving information of development of plasma parameters during several days of the storm. The radars were performing CP3 antenna scan patterns covering latitudes from the north of the radar site to the south. TomoScand ionospheric tomography provided electron densities from latitudes extending to the south of EISCAT Tromso radar field-of-view. IMAGE magnetometer network gave information of the substorms taking place locally; globally the AE index repeatedly exceeded 1000 nT. In specific, we are interested in the effects of this storm on the high-latitude F-region electron density behavior (long-duration decreases and increases in different MLT sectors) and the physical processes producing the observed changes, including ionosphere-thermosphere coupling.

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The relationship between F-region disappearance in the polar cap region and field-aligned currents at geosynchronous orbit during the 11 May 2019 magnetic storm

*Hyuck Jin Kwon[1], Khan-Hyuk Kim[1], Geonhwa Jee[2,3], Jongho Seon[1], Jeong-Han Kim[2], Changsup Lee[2], Young-Bae Ham[2,3], Terence Bullett[4,5], Uli Auster[6], Werner Magnes[7], Stefan Kraft[8]

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The 2nd Antarctic station of Korea, Jang Bogo Station (JBS, AACGM latitude: 79.87˚S) has been operating ‘Vertical Incidence Pulsed Ionospheric Radar (VIPIR)’ to monitor the variations of the ionosphere since 2015. During the main phase of the 11 May 2019 geomagnetic storm, we confirmed the absence of F-region for ~12 hours from ~10:00 UT to ~22:00 UT in night time from the VIPIR observations. During the interval of the F-region disappearance, Geo-KOMPSAT-2A (GK-2A), located west of JBS with ~2-hr local time separation, observed strong westward geomagnetic field perturbations at geosynchronous orbit. These field perturbations at GK-2A can be attributed to the field-aligned currents (FAC) flowing out of the ionosphere in the Southern Hemisphere below the satellite in the pre-midnight sector and into the ionosphere in the Northern Hemisphere above the satellite in the post-midnight sector. We examined the relationship between NmF2 at JBS and the amplitude of westward perturbation at GK-2A and found that NmF2 decreases as the amplitude of westward perturbation increases (i.e., as the intensity of FAC increases). This indicates that the F-region plasma density decrease at the polar cap region is associated with FAC during the main phase of the geomagnetic storm. Since the plasma density decrease is related to the O/N2 decrease, we suggest that the heating of the polar atmosphere is driven by FAC, causing the Joule heating in the auroral zone.

Keywords: Polar ionosphere, F-region disappearance, Field-Aligned Currents

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High ion temperature events at F region altitudes in the cusp: Spatial relations to the moving electron precipitation regions

*Satoshi Taguchi[1], Yunosuke Nagafusa[1], Yasunobu Ogawa[2], Keisuke Hosokawa[3], Tomokazu Oigawa[1], Morio Tanaka[1], Hiroyuki Shinagawa[4]

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High ion temperatures at F region altitudes reflect how fast the ions convect through the slower moving neutral gas. Previous studies have shown that the high ion temperature regions exist in the vicinity of the mesoscale moving cusp aurora. For the large-scale motion of the electron precipitation region in the cusp, it is understood that fast ion flow often occurs nearly simultaneously with the intensification of the electron precipitation, but the detailed spatial relations between the fast ion flow and the large-scale motion of the electron precipitation region require clarification. In this study, we examined auroral image data obtained by an all-sky imager at Longyearbyen, Svalbard and data from field-aligned fixed EISCAT Svalbard Radar (ESR). From data obtained during six winter seasons (December 2012 to January 2018) we first identified approximately 84 hours as the period of the simultaneous observation in the daytime sector. Examination of the ESR ion temperature at F region altitudes during those periods of time has shown that the ion temperatures up to 2000 K are often observed, whereas the ion temperatures exceeding 2000 K are very limited. We present two cases from those high ion temperature events. Aurora image data show that one event is the repetitive poleward motions of the cusp auroras which were observed in the large-area of the imager's field-of-view, while another is the equatorward shift of the large-scale cusp aurora belt responding to the southward turning of the IMF. Although the maximum ion temperatures for both cases are similar, their rise and decay features during approximately 10 min are different. We show the detailed features of the ion temperature variations and their spatial relations to the motion of the electron precipitation regions, and discuss the ion-neutral interaction for the cases in which the large-scale electron precipitation regions move in the cusp.

Keywords: Plasma flow, cusp, ion temperature, electron precipitation, aurora

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Ionization of the mesosphere during substorm growth phase

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We report two mesospheric ionization events, both occurred during a substorm growth phase. The ionization reached at 68 km altitude at 2305 UT on 25 May 2017, and at 0000 UT on 25 July 2018, as identified by the PANSY radar at Syowa Station. Theoretically, the deep ionization events can be caused by the thinning of the magnetotail because of the small curvature radius of magnetic field lines at equator, which is comparable to the gyro radius of energetic electrons. Fortunately, the footprints of the Arase satellite passed nearby the Syowa Station during these two events, and we cannot find associated plasma waves to scatter energetic electrons, as expected from the curvature theory. In this study, we quantitatively evaluate the mesospheric ionization profiles by comparing the intensity of cosmic noise absorption as observed by the imaging riometer at Syowa Station, and the simulated one using the PHITS code with the input data of energetic electron flux as observed by the Arase satellite.

Keywords: atmospheric ionization, energetic electron precipitation, substorm growth phase

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Characteristics of ion upflows from the low-altitude ionosphere observed by EISCAT

*Masayoshi Takada[1], Kanako Seki[1], Yasunobu Ogawa[2], Kunihiro Keika[1], Satoshi Kasahara[1], Shoichiro Yokota[3], Tomoaki Hori[4], Kazushi Asamura[5], Yoshizumi Miyoshi[4], Iku Shinohara[5]

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Molecular ions ($O_2^+/NO^+/N_2^+$) in the magnetosphere have been observed during the magnetic storms [e.g., Klecker et al., 1986]. Recent Arase observations in the ring current revealed that the existence of the molecular ions is a common phenomenon during geomagnetically disturbed period under Dst < -30 nT [Seki et al., 2019]. These molecular ions are considered to originate from the low-altitude ionosphere (altitude < 300 km). In order to escape to the magnetosphere, they thus need to have been transported upward from low-altitude ionosphere below 300 km altitude by some heating processes such as ion frictional heating, electron turbulent heating and small-scale plasma instability. However, what mechanism causes such an ion upflow from the low-altitude ionosphere is not known, because it is difficult to transport molecular ions against dissociative recombination [Peterson et al., 1994]. In this study, we aim at observational investigation of the ion upflow mechanisms based on simultaneous observations by the EISCAT radar and the Arase (ERG) satellite.

Three ion upflow events from the low-altitude ionosphere during geomagnetically disturbed periods (Dst < -30 nT) are analyzed in detail using the EISCAT uhf radar data. These ion upflows have similar features: the upward velocity along the field aligned direction with ion temperature enhancement at 200-400 km altitudes and electron temperature enhancement at 100-120 km altitudes. It indicates that the ion frictional heating caused by strong electric field formed these ion upflows from the low-altitude ionosphere. On the other hand, we found ion upflow events from the low-altitude ionosphere which showed different features from the above three events. Geomagnetic conditions are less active (Dst ~ 0 nT, AE ~ 200 nT) in these latter events. The ion upflows occurred with no significant ion heating but with electron density and temperature enhancement. It suggests that electron heating caused by soft electron precipitation created the second type of the ion upflows from the low-altitude ionosphere.

Keywords: Ion upflow, Molecular ion, Ionospheric heating, EISCAT radar, Arase (ERG) satellite

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The Formation of Substorm Aurora in the Solar Wind-Magnetosphere-Ionosphere Coupling System

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1. University of Minnesota

Magnetospheric substorms have often been referred to as auroral substorms. Understanding the formation of substorm auroras, the evolution of their morphological structures, and the explosive nature of the aurora displays during the expansion phase is a key unsolved question in substorm study.

A necessary condition for the development of substorms is the accumulation of free magnetic energy in the magnetotail. Thus the question how this energy can be released and converted into accelerated particle energy causing the explosive enhancement of the aurora needs to be answered. We pointed out that a decrease in momentum transfer from the solar wind into the magnetosphere due to, for example, an IMF northward turning, will start a preconditioning stage, and cause force imbalance, producing a net earthward body force acting on the magnetotail. This huge earthward force can cause a large scale movement of the tail towards a more dipole-like configuration, producing disturbances in the tail, such as bursty bulk flows and dipolarization fronts.

We suggest that electrostatic fields are the most efficient and powerful means for auroral particle acceleration during substorm. We will elucidate the generation of parallel electrostatic fields by Alfvenic interaction in the inhomogenous Solar Wind-Magnetosphere-Ionosphere coupling system. The generation of parallel electrostatic fields in the auroral acceleration region and the resulting formation of low-density cavities is a positive feedback process. The continuous large energy supply from Poynting flux during the expansion phase can support long-lasting strong parallel electrostatic fields and create explosive auroral displays.

Keywords: Auroral substorm, Auroral particle acceleration , Generation of electric fields

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM13] Dynamics of Magnetosphere and Ionosphere

convener:Aoi Nakamizo(Applied Electromagnetic Research Institute, National Institute of Information and Communications Technology), Mitsunori Ozaki(Faculty of Electrical and Computer Engineering, Institute of Science and Engineering, Kanazawa University), Akiko Fujimoto(Kyushu Institute of Technology), Yuka Sato(Nippon Institute of Technology)

This session provides an opportunity to present recent results from satellite and ground-based observations and theoretical and simulation studies on the magnetosphere, ionosphere, and their coupling processes. We invite talks and posters discussing various phenomena related to the magnetosphere-ionosphere system: solar wind-magnetosphere interaction, magnetosphere-ionosphere convection, field-aligned current, magnetic storms/substorms, neutral-plasma interaction, ionospheric ion inflow and outflow, aurora phenomena, and so forth. Discussions on planetary and satellite ionospheres and magnetospheres, future missions and instrument developments are also welcome.

[PEM13-07] The Known and Unknown of Equatorial Plasma Bubbles

★Invited Papers

*Shasha Zou[1], Ercha Aa[1,2] (1.University of Michigan Ann Arbor, 2.MIT Haystack Observatory)

[PEM13-08] **Causality for formation of electromagnetic channel from Polar to Equatorial Ionosphere**

*Akimasa Yoshikawa[1], Aoi Nakamizo[2], Shinichi Ohtani[3] (1.Department of Earth and Planetary Sciences, Kyushu University, 2.National Institute of Information and Commiunications Technology , 3.APL/JHU)

[PEM13-09] **Automatic scaling of echo traces on ionogram for elucidation of a global current system**

*Moe Hayashi[1], Akimasa Yoshikawa[4], Akiko Fujimoto[3], Shinichi Ohtani[2] (1.Kyushu University, 2.The Johns Hopkins University Applied Physics Laboratory, 3.Kyushu Institute of Technology, 4.Department of Earth and Planetary Sciencse, Kyushu University)

[PEM13-10] Ion-neutral collision frequencies for calculating ionospheric conductivity

*Akimasa Ieda[1] (1.Institute for Space-Earth Environmental Research, Nagoya University)

[PEM13-11] Properties of Auroral Electron Backscatter

*John P Dombeck[1], Joshua Magnus[1], Robert Lysak[1], Cynthia Cattell[1] (1.University of Minnesota)

The Known and Unknown of Equatorial Plasma Bubbles

*Shasha Zou[1], Ercha Aa[1,2]

1. University of Michigan Ann Arbor, 2. MIT Haystack Observatory

In the equatorial and low latitude ionosphere, the equatorial ionization anomaly (EIA) is the most striking large-scale phenomenon. Embedded within EIA are smaller-scale low-density structures, i.e., the equatorial plasma bubbles (EPBs). EPBs are known to host ionospheric irregularities that can cause severe satellite signal scintillations and even signal loss of lock, thereby affecting communication and navigation. However, our understanding of the day-to-day and longitudinal variability of EIA and EPBs is still illusive. During geomagnetic disturbances, energy and momentum from the solar wind and the magnetosphere largely deposit in the high-latitude region, while their impact can propagate to the mid-latitude to equatorial regions in multiple ways to affect EPB dynamics, including prompt penetrating electric field (PPEF), disturbance winds and the associated dynamo electric field (DDEF), and traveling atmosphere disturbances and their ionosphere manifestations (TADs/TIDs). In recent years, the rapidly developing ground-based GNSS receiver network has enabled regional to continental scale measurements of the ionosphere and has revealed rich dynamic structures in those regions during storm time, such as much widened or asymmetric EIA crest and super equatorial plasma bubbles reaching relatively high latitudes. In this talk, we will discuss our recent findings about the knowns and unknowns of EPB dynamics, such as the dynamic evolution of the super bubble event during the Sep. 7, 2017 storm.

Keywords: Equatorial Plasma Bubble, Penetration Electric Field, Magnetosphere-Ionosphere Coupling, Geomagnetic Storm

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Causality for formation of electromagnetic channel from Polar to Equatorial Ionosphere

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Formation of global ionospheric current system and it’ s associated plasma dynamics are frequently discussed under the electrostatic approximation of plasma electrodynamics. Since the Poynting flux never across the equipotential line, it is impossible to provide electromagnetic energy from source region to loading region across the magnetic field line. And hence, to discuss causality for evolution of ionospheric current system, we need to take into account an electromagnetic process of coupled system. To resolve this problem, we propose electromagnetic coupling model from polar to equatorial ionosphere. In this model, ionospheric current produces Ampere force and generates motion of plasma. The motion of plasma and associated mechanical process excite electromotive force and resultant electric field. Curl of electric field causes magnetic field disturbances and evolution of ionospheric current. Therefore, causality for evolution of electromagnetic energy and plasmas acceleration for expanding of ionospheric current system has occurred at the wave front region and/or conductivity gradient region. In this talk, we will discuss about what type of plasma motion induces electric field in the ionosphere, and how and whrere they produce magnetic field disturbances (hence the Ampere force) for acceleration of plasma as wave propagation process. Furthermore, we also discuss what kind of mechanical and electromagnetic process have occurred at the conductivity gradient region, which become very important for establishment of geometrical structure of ionospheric current system.

Keywords: Magnetosphere-ionosphere Coupling, electromagnetic coupling, plasma dynamics, Polar-Equator coupling

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Automatic scaling of echo traces on ionogram for elucidation of a global current system

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Space weather occurs in a magnetosphere-ionosphere-atmosphere and solar-wind coupled system. In ionosphere, ionospheric current produces Ampere force and generates plasma motions. The motions of plasma and associated mechanical process excite electromotive force and resultant electric field. Curl of electric field causes magnetic field disturbances and evolution of ionospheric current. Therefore, it is very important to investigate an electoromagnetic and dynamic process of ionospheric plasma for comprehensive understanding (i.e., causality and global aspects) of space weather phenomena.

Ionogram, observing data of ionosphere, gives important information of plasma behavior in the ionosphere such as ionospheric electron density and of which altitude variation. So ionogram is very useful for analyzing motion of plasma in variety of space weather phenomena. Ionospheric observations start 1920s, but the technique for automatic scaling of echo traces on ionogram hasn't been established yet because of the complexly of data and considerable variations.

For the above reasons, in this study, we develop a new algorithm for automatically scaling ionospheric echoes applying image analysis. Our method has five steps: 1. Data extraction in proportion to intensity of reflection. 2. Sampling echo traces density of data. 3. Removing scattered noise. 4. Acquisition of fo (frequency of each layers) and h (height of each layers). Using this method, we successfully get echo traces, fo (frequency of each layers) and h (hight of each layers). It enables speedy and objective process for a large amount of ionogram data, and it helps to clarify a variety of space weather phenomena.

Applying above new technique, we try to understand how polar to equatorial (P-E) coupled channel is formed during substorm processes. As for the onset process of substorm, Imajo et al., (2015) suggest formation of global Cowling channel [Yoshikawa et al.,,2012] from polar to middle and low latitude dayside ionosphere. On the other hand, detail of P-E coupled process during expansion phase to recovery phase of substorm and connection between dayside and nightside ionosphere have not been become clear.

In this talk, we will introduce our new technique of automatic scaling of echo traces on ionogram and will show preliminary results of combining analysis for substrom process by using ionospheric data (ionogram) and magnetospheric data (SuperMAG, MAGDAS).

Keywords: Ionogram, P-E combination

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Ion-neutral collision frequencies for calculating ionospheric conductivity

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Molecular oxygen collides with its first positive ion in the earth’ s ionosphere. The collision frequency of this particle pair is used to calculate the electric conductivity of the ionosphere. However, for this parental pair there are two collision types, resonant and nonresonant, and the selection of the collision type has differed among previous studies in calculation of conductivity.

In the present study, we clarify that the nonresonant collision is physically essential for this pair because the relevant temperatures are low. That is, the peak of the ionospheric conductivity occurs at altitudes between 100 and 130 km, where the temperatures of ions and neutral particles are usually lower than 600 K, and for these temperatures nonresonant collisions are dominant. The collision frequency would be underestimated by 30% if the resonant collision was assumed at an altitude of 110 km (where the temperature is 240 K).

The impact of this difference on the conductivity is estimated to be small (3%), primarily because molecular nitrogen is much more abundant than molecular oxygen. Although we have confirmed that the nonresonant collision is essential, we also include the resonant type, primarily in case of possible elevated temperature events.

A set of ion-neutral collision frequency coefficients for calculating the conductivity is summarized, including other particle pairs, in the Appendices. Small corrections to the traditional coefficients are made.

Ieda (2019), JGR, doi:10.1029/2019JA027128

Keywords: ionospheric conductivity, collision frequency, charge exchange, oxygen, ionosphere, atmosphere

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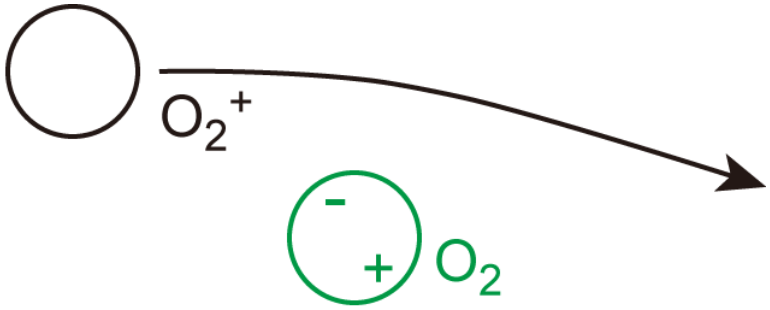
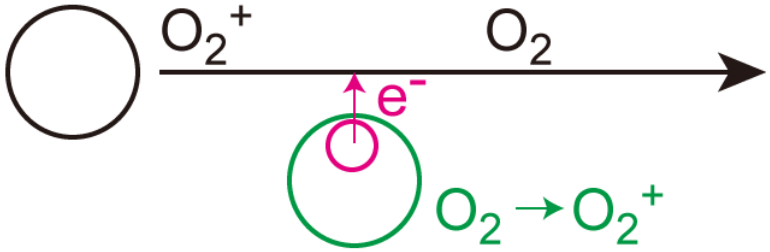
(a)

Non-resonant type
- Polarization
- Low particle speed



(b)

Resonant type
- Charge-exchange
- High particle speed



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Properties of Auroral Electron Backscatter

*John P Dombeck[1], Joshua Magnus[1], Robert Lysak[1], Cynthia Cattell[1]

1. University of Minnesota

Electron precipitation is an important and significant magnetosphere-ionosphere (M-I) coupling component. Understanding the net, rather than just downward, energy and number flux contribution and where that energy is deposited for different precipitation types and conditions is an important part of the SW-M-I-T system. We present the results of a number of related studies on backscatter properties that reduce the energy and number flux input to the ionosphere from electron precipitation and provide electron outflow. These include a straight-forward empirical backscatter model for primary and secondary backscatter based on ~13 years of FAST 2d distribution data that is accurate to within a few percent, a quasi-static acceleration net precipitation model including trapping of backscatter, and the results of an empirical study of backscatter reprecipitation effects in the conjugate hemisphere.

Keywords: Backscatter, Electron Precipitation, Aurora, Magnetosphere-Ionosphere Coupling

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM13] Dynamics of Magnetosphere and Ionosphere

convener:Aoi Nakamizo(Applied Electromagnetic Research Institute, National Institute of Information and Communications Technology), Mitsunori Ozaki(Faculty of Electrical and Computer Engineering, Institute of Science and Engineering, Kanazawa University), Akiko Fujimoto(Kyushu Institute of Technology), Yuka Sato(Nippon Institute of Technology)

This session provides an opportunity to present recent results from satellite and ground-based observations and theoretical and simulation studies on the magnetosphere, ionosphere, and their coupling processes. We invite talks and posters discussing various phenomena related to the magnetosphere-ionosphere system: solar wind-magnetosphere interaction, magnetosphere-ionosphere convection, field-aligned current, magnetic storms/substorms, neutral-plasma interaction, ionospheric ion inflow and outflow, aurora phenomena, and so forth. Discussions on planetary and satellite ionospheres and magnetospheres, future missions and instrument developments are also welcome.

[PEM13-13] What is the role of repeatable meso-scale processes in the Magnetosphere-Ionosphere system?

★Invited Papers

*Jesper W Gjerloev[1], Shinichi Ohtani[1] (1.Johns Hopkins University Applied Physics Laboratory)

[PEM13-14] 3D current system of auroral vortices in the discrete arc estimated by auroral tomography and local KRM methods

*Yoshimasa Tanaka[1,2,3], Yasunobu Ogawa[1,3], Akira Kadokura[1,2,3], Takanori Nishiyama[1,3], Akimasa Yoshikawa[4], Bjorn Gustavsson[5], Kirsti Kauristie[6], Carl-fredrik Enell[7], Urban Brandstrom[8], Tima Sergienko[8], Alexander Kozlovsky[9], Tero Raita[9], Heikki Vanhamaki[10] (1.National Institute of Polar Research, 2.Polar Environment Data Science Center, 3.The Graduate University for Advanced Studies, 4.Department of Earth and Planetary Sciences, Kyushu University, 5.The Arctic University of Norway, 6.Finnish Meteorological Institute, 7.EISCAT Scientific Association, 8.Swedish Institute of Space Physics, 9.Sodankyla Geophysical Observatory, 10.University of Oulu)

[PEM13-15] Simulation on 3D structure of auroral electrojet

*Yuto Yano[1], Yusuke Ebihara[1] (1.Research Institute for Sustainable Humanosphere, Kyoto University)

[PEM13-16] Statistical characteristics of the duskside mesoscale field-aligned currents without accompanying the large-scale Region 1 current

*Yoshihiro Yokoyama[1], Satoshi Taguchi[1], Toshihiko Iyemori[2], Keisuke Hosokawa[3] (1.Department of Geophysics, Graduate School of Science, Kyoto University, 2.Kyoto University, 3. Department of Communication Engineering and Informatics, University of Electro-Communications)

[PEM13-17] Ionospheric plasma sheet isolation during northward interplanetary magnetic field periods reproduced by numerical magnetohydrodynamic modeling

*Masakazu Watanabe[1,2], Takashi Tanaka[2], Shigeru Fujita[3] (1.Graduate School of Science, Kyushu University, 2.International Center for Space Weather Science and Education, Kyushu University, 3.Meteorological College)

[PEM13-18] Impact of foreshock transients on the Earth's nightside magnetosphere and ionosphere

*Chih-Ping Wang[1], Xueyi Wang[2], Terry Z. Liu[3], Yu Lin[2], Sixue Xu[1] (1.University of California Los Angeles, 2.Auburn University, 3.University of Alaska, Fairbanks)

What is the role of repeatable meso-scale processes in the Magnetosphere-Ionosphere system?

*Jesper W Gjerloev[1], Shinichi Ohtani[1]

1. Johns Hopkins University Applied Physics Laboratory

Profound mysteries exist about how the Earth’ s magnetosphere and ionosphere (M-I) interact and generate the dynamic and structured auroras. Scattered throughout the auroras are recurrent auroral forms (tens to hundreds of km) but their role in the M-I system remains unknown. Such features are likely manifestations of energy and momentum transport within the M-I system. Shortcomings in our understanding of these recurrent forms are largely due to observational challenges arising from their complex structure and dynamic variability. These characteristics present a difficult observational challenge which require multipoint, multivariate measurements with appropriate spacing in time and space.

Keywords: dynamic M-I system, meso-scale processes, multi-point measurements

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3D current system of auroral vortices in the discrete arc estimated by auroral tomography and local KRM methods

*Yoshimasa Tanaka[1,2,3], Yasunobu Ogawa[1,3], Akira Kadokura[1,2,3], Takanori Nishiyama[1,3], Akimasa Yoshikawa[4], Bjorn Gustavsson[5], Kirsti Kauristie[6], Carl-fredrik Enell[7], Urban Brandstrom[8], Tima Sergienko[8], Alexander Kozlovsky[9], Tero Raita[9], Heikki Vanhamaki[10]

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In the magnetosphere-ionosphere coupling, three-dimensional (3D) current system on the ionosphere is essential to understand how electromagnetic energy and momentum are transported between the magnetosphere and ionosphere. However, it is generally difficult to derive the 3D current system of the auroral phenomena from the observation. One of the methods to obtain the 3D current system on the ionosphere is so-called Kamide-Richmond-Matsushita (KRM) method. This method calculates the 3D current system from the ionospheric equivalent current and the ionospheric conductivity; the former is derived from the ground-based magnetometer network data and the latter is often given by the empirical model.
In this study, we estimate the 3D current system of auroral vortices in the discrete arc, which were observed with the multiple imagers with a wavelength of 427.8 nm in Northern Europe at 22:15-22:20 UT on March 14, 2015, by using the local KRM method (Vanhamaki et al., 2006). The advantage of this study is to obtain the ionospheric conductivity from the imager network observation. We applied the auroral computed tomography method to the multiple monochromatic images and obtained 3D distribution of the volume emission rate of 427.8 nm every 10 second during 22:15-22:20 UT. By using the theoretical model and the empirical atmosphere model, we converted the volume emission rate to the electron density in the ionosphere. As a result, we obtained the height-integrated conductivity in the horizontal area of 150 km x 300 km. The ionospheric equivalent current was derived every 10 second from the IMAGE chain magnetometer data. Finally, we estimated 3D current system around the discrete arcs by using the local KRM method. The results showed that pairs of upward and downward field-aligned current (FAC) drifted eastward along the arc together with the auroral vortices. It was found that the distribution of the upward and downward FACs was distorted, which was caused by the divergent ionospheric Hall current due to the non-uniform ionospheric conductivity.

Keywords: aurora tomography, 3D structure of aurora, 3D current system, magnetosphere ionosphere coupling, auroral vortex structure

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Simulation on 3D structure of auroral electrojet

*Yuto Yano[1], Yusuke Ebihara[1]

1. Research Institute for Sustainable Humanosphere, Kyoto University

We developed a simplified Hall-MHD simulation to understand the magnetosphere-ionosphere coupling in the polar region during the auroral substorm. The governing equations were derived from the law of conservation of momentum of ions and electrons, the equation of continuity of plasma, the law of Ohm, the law of Ampere, and the law of Faraday. The Hall effect is included because it retains the Hall term in the governing equations. The advection in the governing equations were solved by using the Lax-Wendroff scheme and the Superbee limiter function. We imposed a flow shear on the topside boundary to excite Alfven wave. First, we ran the simulation under the condition that the ionospheric plasma density is uniform in the horizontal space. The Alfven wave propagates downward, and reflected at altitude being lower than the peak of the Pedersen conductivity. It was confirmed that the FACs were closed by the Pedersen current in the lower ionosphere. Secondary, we introduced a high-density channel. The secondary electric field is confirmed to appear due to blockage of the Hall current (polarization), which intensifies the ionospheric current. The direction of ionospheric current depends on altitude. The current is intensified at specified altitudes. This is similar to the auroral electrojet.

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Statistical characteristics of the duskside mesoscale field-aligned currents without accompanying the large-scale Region 1 current

*Yoshihiro Yokoyama[1], Satoshi Taguchi[1], Toshihiko Iyemori[2], Keisuke Hosokawa[3]

1. Department of Geophysics, Graduate School of Science, Kyoto University, 2. Kyoto University, 3. Department of Communication Engineering and Informatics, University of Electro-Communications

During prolonged quiet times the large-scale Region 1 current nearly diminishes except for its near-noon part, and irregular magnetic perturbations exist at latitudes where the Region 1 current disappeared. Our recent event study has shown that the irregular magnetic perturbations on the duskside are a result of highly structured quasi-static field-aligned currents whose typical latitudinal size is 20–30 km, and that those mesoscale currents in the duskside auroral oval are the phenomena that are pertinent to the magnetosphere for a northward IMF condition, not a simple remnant of the typical Region 1. In the present study, in order to clarify detailed characteristics of the mesoscale field-aligned currents without accompanying the large-scale Region 1 we examined large amounts of data obtained by Swarm satellites during three years, i.e., from January 2014 to December 2016. How the occurrence of those mesoscale field-aligned currents is controlled by solar illumination of the ionosphere and upstream solar wind parameters other than the northward component of IMF is presented.

Keywords: mess scale field-aligned current, northward IMF condition, Swarm satellite

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Ionospheric plasma sheet isolation during northward interplanetary magnetic field periods reproduced by numerical magnetohydrodynamic modeling

*Masakazu Watanabe[1,2], Takashi Tanaka[2], Shigeru Fujita[3]

1. Graduate School of Science, Kyushu University, 2. International Center for Space Weather Science and Education, Kyushu University, 3. Meteorological College

During periods of northward interplanetary magnetic field (IMF), for the case of IMF $B_y<0$, the dawnside plasma sheet expands poleward in the northern ionosphere, while in the southern ionosphere the duskside plasma sheet expands poleward. At the same time, auroral arcs aligned to the auroral oval are often observed at dawnside high latitudes in the northern hemisphere and at duskside high latitudes in the southern hemisphere. The above-mentioned dawn-dusk relation reverses for the case of IMF $B_y>0$. Although the oval-aligned arcs at high latitudes may simply be an intensification of the poleward boundary of the plasma sheet, an alternative explanation is the plasma sheet “fragments” that have been detached from the main body of the plasma sheet. For the latter case, an open magnetic flux is intruding into the closed flux region on the flankside in the ionosphere, implying an unknown topological structure in the magnetosphere that differs from the basic 2-null, 2-separator topology. We call this ionospheric configuration “plasma sheet isolation.” The purpose of this study is to investigate such plasma sheet isolation by numerical magnetohydrodynamic modeling. Using the REPPU (Reproduce Plasma Universe) code, we unintentionally found a plasma sheet isolation event for the following solar wind and IMF conditions. We first made a steady state magnetosphere with a total IMF intensity of B=6 nT and a clock angle of $\theta=45^\circ$ ($B_y<0$). The solar wind parameters were N=10/cc (density), V=370 km/s (speed), and T=100,000 K (temperature). We then changed the IMF abruptly to B=13 nT and $\theta=70^\circ$ without changing the B_y sign. The figure below shows the polar caps about 70 min after the IMF change. The gray area represents the open magnetic flux region, while the white area shows the closed magnetic flux region. The thin solid lines indicate the contours of electric potentials every 1 kV. Plasma sheet isolation is seen on the dawnside in the northern hemisphere and on the duskside in the southern hemisphere. The plasma sheet isolation started about 50 min after the IMF change and lasted about 40 min. The plasma sheet fragments on the two hemispheres are magnetically conjugate. In the magnetotail, the closed lines threading these fragments are stuck by IMF lines, exhibiting a tangling of field lines. We discuss the origin of such a topological structure in terms of magnetic reconnection. The plasma sheet isolation is a consequence of Dungey-type “crossover reconnection” in the tail plasma sheet that is prohibited in the basic 2-null, 2-separator structure.

Keywords: Plasma sheet isolation, Magnetohydrodynamics, Magnetic field topology

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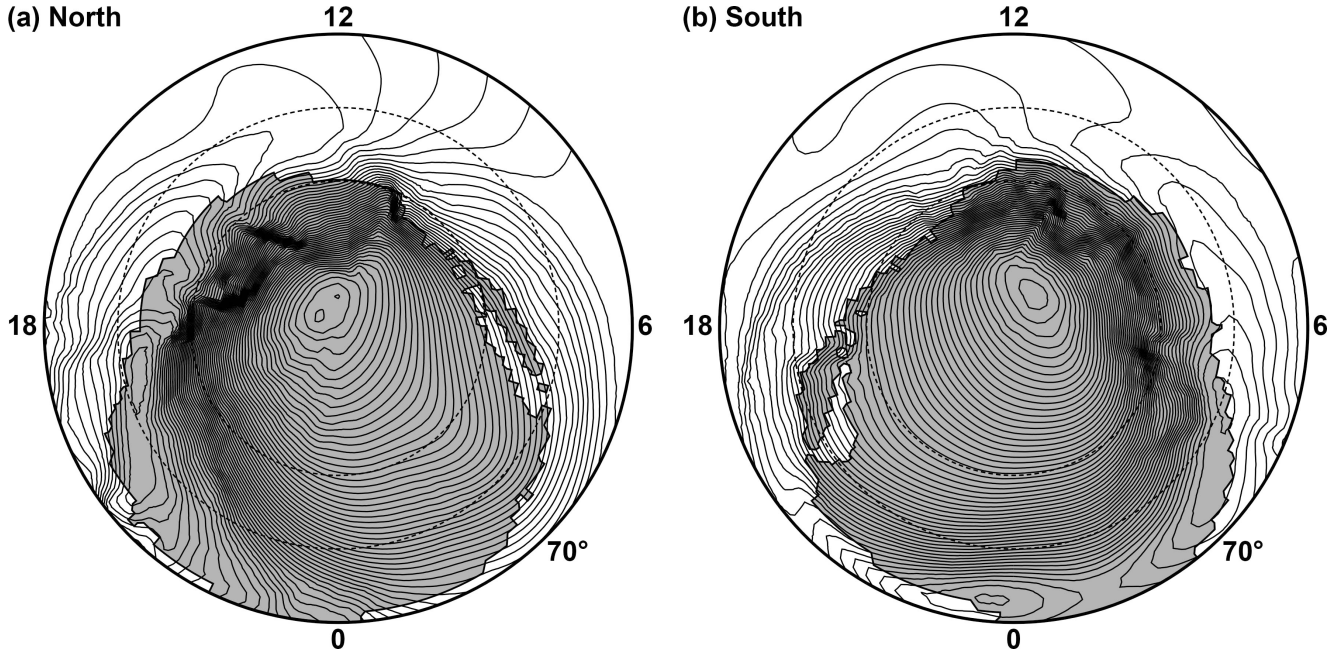

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Impact of foreshock transients on the Earth’s nightside magnetosphere and ionosphere

*Chih-Ping Wang[1], Xueyi Wang[2], Terry Z. Liu[3], Yu Lin[2], Sixue Xu[1]

1. University of California Los Angeles, 2. Auburn University, 3. University of Alaska, Fairbanks

The density and flow perturbations associated foreshock transients can result in dynamic pressure changes in the magnetosheath, thus distorting the magnetopause and driving disturbances within the magnetosphere and ionosphere. In this paper, we present three events from multiple spacecraft observations to show that transient foreshock perturbations associated with an IMF directional discontinuity can persist as they propagate to the mid-tail magnetosheath ($X < -40\ R_E$) together with the discontinuity and disturb the nightside magnetopause. We show observations that these transients can enhance compressional magnetic field waves within the nightside magnetosphere, drive Pc-5 magnetic field perturbations on the ground traveling from the dayside toward nightside, and generate localized ionospheric flow vortex on the nightside. We also present results from a 3D global hybrid simulation of an rotational IMF discontinuity using the ANGIE3D (AuburN Global hybrId codE in 3-D) code. The simulation shows that transient plasma and field perturbations are formed in front of the foreshock with characteristics consistent with a foreshock bubble (FB). The FB subsequently propagates into the magnetosheath, and as it propagates tailward to the mid-tail together with the discontinuity it continuously causes localized and transient distortion of the flank magnetopause, as well as field-aligned currents into the ionosphere. Therefore, our observations and simulations demonstrate that foreshock transients can have a global impact on the nightside magnetosphere and ionosphere.

Keywords: foreshock transient, multi-spacecraft observation, magnetotail, nightside magnetosphere and ionosphere, 3D global hybrid simulation, ULF waves

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM13] Dynamics of Magnetosphere and Ionosphere

convener:Aoi Nakamizo(Applied Electromagnetic Research Institute, National Institute of Information and Communications Technology), Mitsunori Ozaki(Faculty of Electrical and Computer Engineering, Institute of Science and Engineering, Kanazawa University), Akiko Fujimoto(Kyushu Institute of Technology), Yuka Sato(Nippon Institute of Technology)

This session provides an opportunity to present recent results from satellite and ground-based observations and theoretical and simulation studies on the magnetosphere, ionosphere, and their coupling processes. We invite talks and posters discussing various phenomena related to the magnetosphere-ionosphere system: solar wind-magnetosphere interaction, magnetosphere-ionosphere convection, field-aligned current, magnetic storms/substorms, neutral-plasma interaction, ionospheric ion inflow and outflow, aurora phenomena, and so forth. Discussions on planetary and satellite ionospheres and magnetospheres, future missions and instrument developments are also welcome.

[PEM13-19] The main observational properties of throat aurora and their implicaitons on dayside S-M-I coupling

*Han Desheng[1] (1.School of Ocean and Earth Science, Tongji University)

[PEM13-20] A Possible Formation Scenario of the Transpolar Arcs with the Nightside End Distortions: Role of Field-Aligned Currents

*Motoharu Nowada[1], Qiu-Gang Zong[2], Benoît Hubert[3], Quan-Qi Shi[1], Yong-Fu Wang[2], Jun Yang[1], Adrian Grocott[4], Alexander William Degeling[1], An-Min Tian[1], Xu-Zhi Zhou[2], Chao Yue[2] (1.Shandong Provincial Key Laboratory of Optical Astronomy and Solar-Terrestrial Environment, Institute of Space Sciences, Shandong University, Weihai, 2.Institute of Space Physics and Applied Technology, School of Earth and Space Sciences, Peking University, 3.Space science, Technologies and Astrophysics Research (STAR) Institute, Université de Liège, Belgium, 4.Space and Planetary Physics Group, Department of Physics, Lancaster University, Lancaster, United Kingdom)

[PEM13-21] **Fade of transpolar arc and its relation to the intensification of the nightside oval**

*Takahiro Obara[1] (1.Planetary Plasma and Atmospheric Research Center,Tohoku University)

[PEM13-22] Feedback instability theory extended to the magnetosphere-ionosphere coupling with field-aligned inhomogeneity

*Tomo-Hiko Watanabe[1], Junya Hiwatari[1], Shinya Maeyama[1] (1.Graduate School of Science, Nagoya University)

[PEM13-23] Antarctic large area network observation of auroral phenomena using unmanned system: Current status of project as of early 2020

*Akira Kadokura[1], Yasunobu Ogawa[1], Yoshimasa Tanaka[1], Hisao Yamagishi[1], Masaki Okada[1], Ryuho Kataoka[1], Herbert Akihito Uchida[2], Yuichi Otsuka[3], Motoba Tetsuo[4], Natsuo Sato[1] (1.National Institute of Polar Research, 2.SOKENDAI, 3.Nagoya University, 4.Johns Hopkins University, Applied Physics Laboratory)

[PEM13-24] **Short review for recent studies of pulsating aurora in Japan during Arase era**

★Invited Papers

*Keisuke Hosokawa[1], Yoshizumi Miyoshi[2], Mitsunori Ozaki[3], Shin-ichiro Oyama[2], Yasunobu Ogawa[4], Satoshi Kurita[2], Yoshiya Kasahara[3], Yasumasa Kasaba[5], Satoshi Yagitani[3], Shoya Matsuda[7], Fuminori Tsuchiya[5], Atsushi Kumamoto[5], Ryuho Kataoka[4], Kazuo Shiokawa[2], Hiroshi Miyaoka[4], Yoshimasa Tanaka[4], Satonori Nozawa[2], Mariko Teramoto[6], Takeshi Takashima[7], Iku Shinohara[7], Ryoichi Fujii[8] (1.Univ. of Electro-Communications, 2.ISEE, Nagoya Univ., 3.Kanazawa Univ., 4.National Institute of Polar

Research, 5.Tohoku Univ., 6.Kyushu Institute of Technology, 7.ISAS/JAXA, 8.Research Organization of Information and Systems)

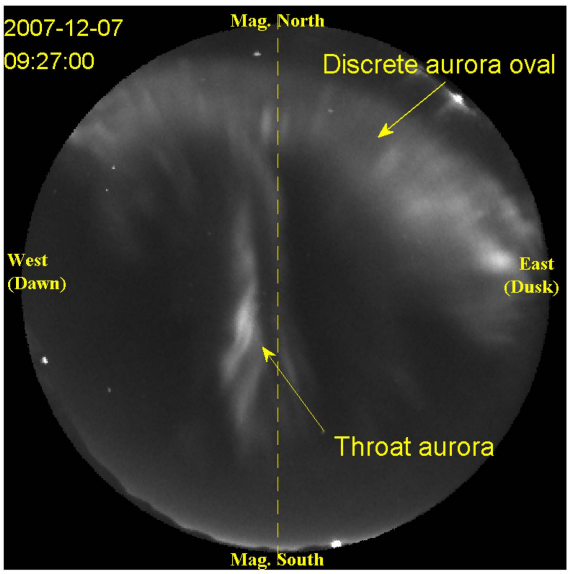
The main observational properties of throat aurora and their implicaitons on dayside S-M-I coupling

*Han Desheng[1]

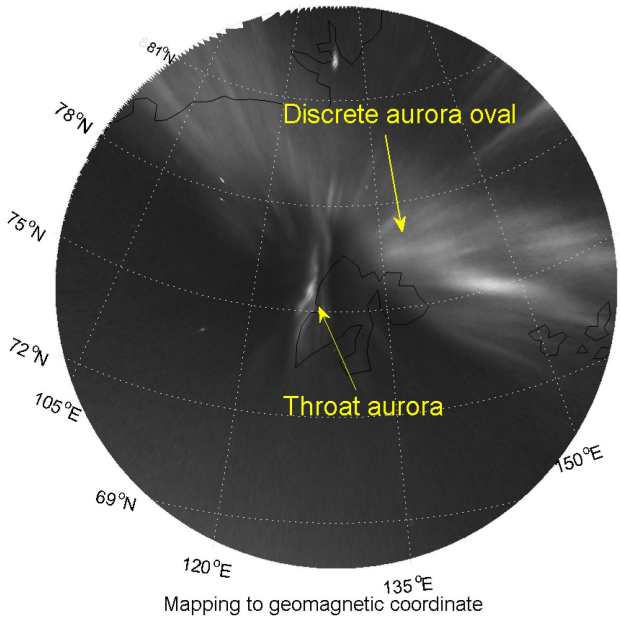
1. School of Ocean and Earth Science, Tongji University

Throat aurora is a particular auroral form observed around the dayside ionospheric convection throat region and was defined during an extensive study on dayside diffuse aurora. Throat auroras typically exhibit as north-south aligned discrete auroral forms extending from the equatorward edge of the east-west-aligned auroral oval toward low latitude. The main observational properties of throat aurora have been revealed as follows. 1) The occurrence rate of throat aurora is rather high. 2) Throat auroras are caused by precipitation of particles from the magnetosheath and have been suggested to be the ionospheric signature of magnetopause indentations. 3) The occurrence rate of throat aurora is dependent on both magnetospheric internal factors, such as diffuse aurora and magnetospheric convection, and external factor, i.e., the IMF cone angle. 4) Throat aurora are associated with clear magnetopause reconnection signatures. Based on these observational results, a conceptual model for throat aurora is proposed, which suggests that a polarization electric field in the ionosphere may play the key role for producing throat aurora by affecting the magnetopause reconnection.

Keywords: Throat aurora, Cusp, solar wind-magnetosphere coupling



Orignal auroral image in red line



Mapping to geomagnetic coordinate

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A Possible Formation Scenario of the Transpolar Arcs with the Nightside End Distortions: Role of Field-Aligned Currents

*Motoharu Nowada[1], Qiu-Gang Zong[2], Benoît Hubert[3], Quan-Qi Shi[1], Yong-Fu Wang[2], Jun Yang[1], Adrian Grocott[4], Alexander William Degeling[1], An-Min Tian[1], Xu-Zhi Zhou[2], Chao Yue[2]

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Since we discovered the newly morphological transpolar arc (TPA), whose nightside end got distorted toward pre- or post-midnight, identified as “nightside distorted TPAs”, their fundamental characteristics have been revealed based on investigations of the space-borne auroral imager data and corresponding solar wind conditions. Nightside distorted TPAs had two types; “J”- and “L”-shaped TPAs, and their locations of appearance (dawn or duskside of the polar cap) were governed by the polarity of the B_y component of the Interplanetary Magnetic Field (IMF). Furthermore, we found that the nightside distorted TPAs have antisymmetric morphologies in the Northern and Southern hemispheres, also depending on the IMF-B_y orientation.
In this presentation, we show that that the electric currents flowing aligned to the magnetic field lines which connect between the magnetotail and the ionosphere, that is, Field-aligned currents (FACs) play an essential role in the formations of the “J”- and “L”-shaped TPAs. They are induced by significant plasma flow velocity difference (plasma flow shear) between the fast plasma flows associated with nightside magnetic reconnection and slower background plasma flows in the magnetotail. The current vortex structures with the counterclockwise rotation are also clearly seen in the ionospheric current vectors derived from fluctuations of the geomagnetic field measured at the ground observatories beneath and in close proximity of the growth regions of the nightside distorted TPA. This result suggests that the FACs were flowing out of the ionosphere toward the magnetotail (upward FACs) near the TPA.
Furthermore, based on the geomagnetic field variations and the SuperDARN HF radar data, we obtained evidence in which the locations of magnetotail magnetic reconnection, which persisted even during northward IMF-B_z intervals, that is, the TPA durations, retreated further down tail as the TPA grew to the dayside. Taking into account these observational results, we finally show a model to illustrate the nightside distorted TPA (particularly, “L”-shaped TPA) formation.

Keywords: Nightside distorted transpolar arc: “J”- and “L”-shaped TPAs , Solar wind-magnetotail-ionosphere coupling, Magnetospheric diagnosis , Magnetotail magnetic reconnection, Plasma flow shear, Field-aligned currents

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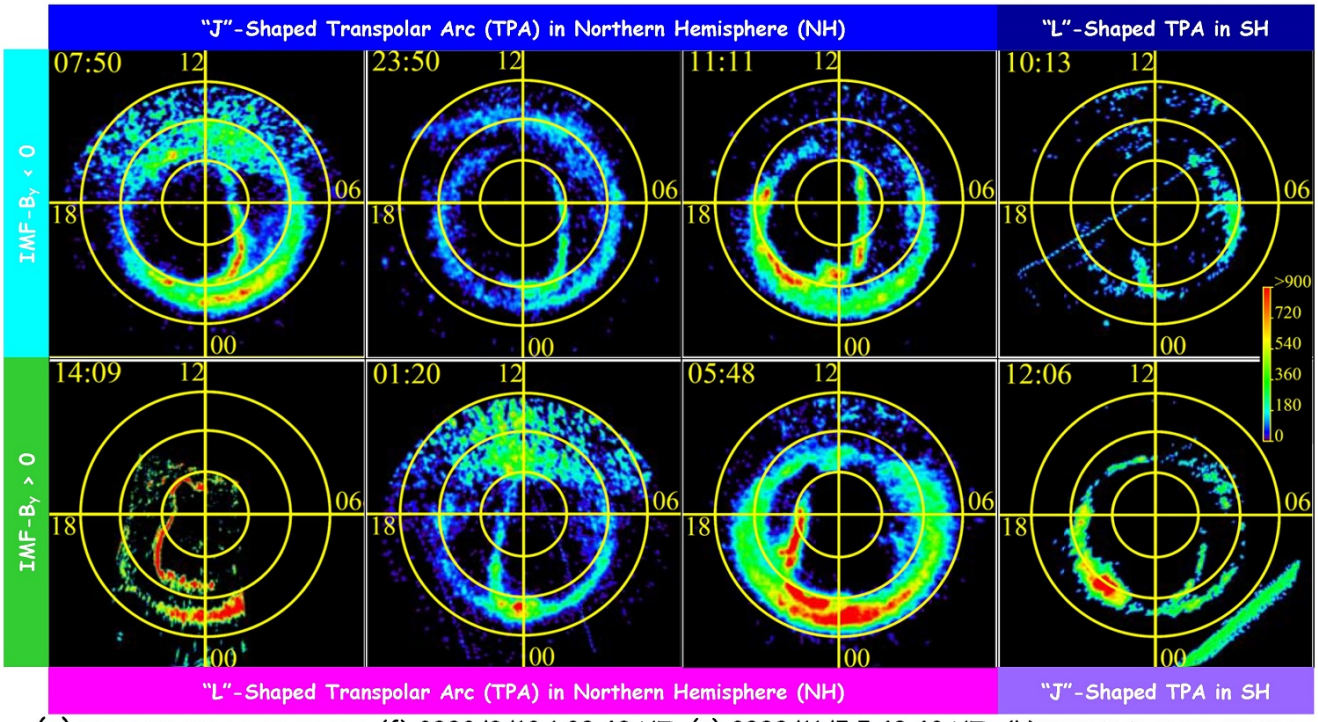

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Fade of transpolar arc and its relation to the intensification of the nightside oval

*Takahiro Obara[1]

1. Planetary Plasma and Atmospheric Research Center,Tohoku University

We have identified that night side oval intensification took place when the transpolar arc was fading. This is due to the switch of IMF Bz polarity from north to south. We have confirmed in the past that theta aurora appears in the polar cap region, corresponding to the IMF By polarity change (Type I) or long lasting strong IMF By (Type II) during northward IMF conditions. In the Type I case, the transpolar arc was detached from the morning (evening) side oval and moves dusk ward (dawn ward), corresponding to the IMF By polarity change from negative to positive (positive to negative). Movement of the transpolar arc is caused by the large supply of newly formed open field lines to the polar cap region, due to the change of the null point location. For the change of IMF By from negative to positive (positive to negative), accumulation of the magnetic flux occurs within the newly formed polar cap region in the dawn side (dusk side). When the IMF switched to the south, accumulation continues in the same side of the polar cap. Enhanced convention stores the energy and the stored energy at last releases, resulting in the intensification of the night side auroral oval. Location of the intensification with respect to the transpolar arc seems to depend on the IMF By polarity; i.e. dusk side for negative IMF By and dawn side for positive IMF By in the northern polar cap. For the Type II case, accumulation of open flux in the polar cap would enhance due to the switch of IMF Bz to the south, resulting in the intensification of the night side oval.

Keywords: Transpolar arc, IMF polarity change, Intensification of night side aurora

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Feedback instability theory extended to the magnetosphere-ionosphere coupling with field-aligned inhomogeneity

*Tomo-Hiko Watanabe[1], Junya Hiwatari[1], Shinya Maeyama[1]

1. Graduate School of Science, Nagoya University

The feedback instability theory for Alfvenic coupling of the magnetosphere and the ionosphere has been extended by introducing inhomogeneous profiles of the ionospheric collision frequency and the magnetospheric Alfven speed. The eigenvalue analysis clarifies the stabilizing mechanism of high frequency components of the ionospheric Alfven resonator (IAR) mode for the strongly inhomogeneous collision frequency profile in the ionosphere. The stabilization is brought by an effective internal resistivity due to the ionospheric inhomogeneity, not by a shear of the ionospheric current. Low frequency components of the field line resonance (FLR) mode remain unstable even when the high frequency components are stabilized. The theoretical results demonstrate a robustness of the feedback instability mechanism providing spontaneous growth of the auroral arc structure in the magnetosphere-ionosphere coupling.

Keywords: feedback instability, Alfven wave, magnetosphere-ionosphere coupling

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Antarctic large area network observation of auroral phenomena using unmanned system: Current status of project as of early 2020

*Akira Kadokura[1], Yasunobu Ogawa[1], Yoshimasa Tanaka[1], Hisao Yamagishi[1], Masaki Okada[1], Ryuho Kataoka[1], Herbert Akihito Uchida[2], Yuichi Otsuka[3], Motoba Tetsuo[4], Natsuo Sato[1]

1. National Institute of Polar Research, 2. SOKENDAI, 3. Nagoya University, 4. Johns Hopkins University, Applied Physics Laboratory

Space and upper atmospheric sciences group in the National Institute of Polar Research (NIPR) is now planning to construct an observation network for auroral phenomena along the coast of the Dronning Maud Land in the Antarctica including Japanese Syowa Station, and has developed a Unmanned Auroral Observation system (UAO), which is equipped with a 3-axis fluxgate magnetometer, all-sky auroral imager, GNSS/TEC receiver, and a data communication system using the Inmarsat satellite data link with a low power consumption. The first UAO (UAO-1) had been installed at Amundsen Bay area, which is located about 500 km eastward from Syowa Station, in February, 2017 in the summer operation of the 58th Japanese Antarctic Research Expedition (JARE-58). The second UAO (UAO-2) had been installed at Belgium Princess Elisabeth Antarctica (PEA) Station in January, 2020. Electric power of the UAO-1 is supplied by a hybrid natural energy electric generation system which consists of three sets of 192W wind generators and 8 sets of 62W solar panels, while that of the UAO-2 is supplied from the AC power source of the PEA Station which is generated by a power generation system of the station using nine big wind generators and solar panels. For the UAO, observed magnetometer data (1 sec resolution), GNSS BINEX data (30 sec resolution), daily Keogram and sample image data of the auroral imager, and House Keeping data (temperatures and power voltages) (1 min resolution) are transmitted at every 1 hour via the satellite link system to a server in Japan by FTP, and auroral image data of 1 sec resolution are stored in a memory card of the video encoder in the system. Sample interval and pixel resolution of the transmitted auroral image data are 1 hour (5 minutes) and 640x480 (160x120) for the UAO-1 (UAO-2), respectively. UAO-2 has the other USB memory in the system which can store auroral still image of 1 sec resolution with 640x480 pixel resolution and GNSS BINEX data of 1 sec resolution. PEA Station is maintained during summer season, and becomes an unmanned station during winter season, while the electric power to all the instruments at the station is supplied continuously all through the season. In January, 2020, we had also installed an auroral imager system at Indian Maitri Station, which consists of four sets of all-sky imager using Watec cameras: 1) Panchromatic (color) ; 2) Panchromatic (black&white); 3) filtered at 560nm (FWHM:10nm); 4) filtered at 632nm (FWHM:10nm), respectively. Maitri is a year-round station. The auroral imager system is run autonomously. We ask expedition members at Maitri to send daily summary files via E-mail to us. In our presentation, we will talk about current status of the project including the installation both at PEA and Maitri stations in this January, and preliminary results of the observations at both stations.

Keywords: aurora, network observation, substorm

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Short review for recent studies of pulsating aurora in Japan during Arase era

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Pulsating aurora (PsA) is one of the major types of aurora often seen in the lower latitude part of the auroral region in the morning side. PsA is known to have two distinct periodicities. One is the main pulsation whose period ranges from a few to a few tens of seconds. The other is so-called internal modulation which is ~3 Hz luminosity modulation during the ON phase of main pulsation. Previous studies indicated that ~50% of PsA are accompanied by the internal modulation (i.e., internal modulation is often seen, but not always observed during PsA). Recent coordinated ground/satellite observations of PsA suggested that these two periodicities are closely associated with the intensity modulation of whistler mode chorus waves in the morning side magnetosphere. In particular, the association between the main pulsation and bursts of chorus was confirmed for example by Nishimura et al. (2010) and more recently by Kasahara et al. (2018). However, it has still been under debate which characteristics of chorus waves control the existence/absence of internal modulation. This review talk will be focused on several results from recent coordinated ground/satellite observations of PsA (e.g., Ozaki et al., 2019; Hosokawa et al., 2020) since the launch of the Arase satellite. Especially, we will introduce conjugate high-time resolution measurements of fine-scale temporal variations of chorus waves in space and PsA seen from the ground.In addition, we will talk about recent ground-based radar observations of PsA showing the simultaneous precipitation of sub-relativistic electrons during PsA, which will be one of the primary scientific objectives of EISCAT_3D currently being prepared in Scandinavia.

Keywords: Aurora, Magnetosphere, Chorus waves

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM13] Dynamics of Magnetosphere and Ionosphere

convener:Aoi Nakamizo(Applied Electromagnetic Research Institute, National Institute of Information and Communications Technology), Mitsunori Ozaki(Faculty of Electrical and Computer Engineering, Institute of Science and Engineering, Kanazawa University), Akiko Fujimoto(Kyushu Institute of Technology), Yuka Sato(Nippon Institute of Technology)

This session provides an opportunity to present recent results from satellite and ground-based observations and theoretical and simulation studies on the magnetosphere, ionosphere, and their coupling processes. We invite talks and posters discussing various phenomena related to the magnetosphere-ionosphere system: solar wind-magnetosphere interaction, magnetosphere-ionosphere convection, field-aligned current, magnetic storms/substorms, neutral-plasma interaction, ionospheric ion inflow and outflow, aurora phenomena, and so forth. Discussions on planetary and satellite ionospheres and magnetospheres, future missions and instrument developments are also welcome.

[PEM13-25] Utilizing the Heliophysics/Geospace System Observatory to Understand Particle Injections: Their Scale Sizes and Propagation Directions

*Christine Gabrielse[1], Emma Spanswick[2], Anton Artemyev[3], Toshi Nishimura[4], Andrei Runov[3], Larry Lyons[3], Vassilis Angelopoulos[3], Drew L. Turner[5], Geoffrey D. Reeves[6], Eric Donovan[2] (1.The Aerospace Corporation, 2.Univ. of Calgary, 3.UCLA, 4.Boston University, 5.John Hopkins Applied Physics Lab., 6.LANL)

[PEM13-26] **Flux decrease of outer radiation belt electrons associated with solar wind pressure pulse: A Code coupling simulation of GEMSIS-RB and GEMSIS-GM**

*Ito Hiroki[1], Yoshizumi Miyoshi[1], Shinji Saito[2], Yosuke Matsumoto[3], Takanobu Amano[4] (1.Institute for Space-Earth Environmental Research, Nagoya University, 2.National Institute of Information and Communications Technology, 3.Gradual School of Science, Chiba University, 4.Department of Earth and Planetary Science, University of Tokyo)

[PEM13-27] Seasonal Variation in Mass and Electron Densities of the Plasmasphere in the New Zealand Meridian

*Yuki Obana[1], Akiko Fujimoto[2], Satoko Saita[3], János Lichtenberger[4,5], Tanja Petersen[6] (1.Department of Engineering Science, Faculty of Engineering, Osaka Electro-Communication University, 2.Graduate School of Computer Science and Systems Engineering, Kyushu Institute of Technology, 3.National Institute of Technology, Kitakyushu College, 4.Eötvös Loránd University, 5.Research Center for Astronomy and Earth Sciences, 6.GNS Science)

[PEM13-28] Differences in Near-Earth Magnetotail Evolution Between Pseudosubstorms and Substorms

*Yukinaga Miyashita[1], Kento Fukui[2], Shinobu Machida[2], Yoshizumi Miyoshi[2], Akimasa Ieda[2], Toshi Nishimura[3], Vassilis Angelopoulos[4] (1.Korea Astronomy and Space Science Institute, 2.Institute for Space-Earth Environmental Research, Nagoya University, 3.Boston University, 4.University of California, Los Angeles)

[PEM13-29] Geomagnetic field and energetic particle oscillations observed at geosynchronous orbit during the growth and expansion phases of a substorm

*Khan-Hyuk Kim[1], Hyuck-Jin Kwon[1], Jongho Seon[1], Uli Auster[2], Werner Magnes[3], Stefan Kraft[4] (1.School of Space Research, Kyung Hee University, Korea, 2.IGeP, TUBS, Mendelssohnstrasse, Braunschweig, Germany, 3.Space Research Institute, OeAW, Graz, Austria, 4.ESOC-ESA, Robert-Bosch-Strasse, Darmstadt, Germany)

[PEM13-30] Longitudinal propagation of thin auroral arcs

Fei Zhang[1], *Jian Yang[1], Wenrui Wang[1,2] (1.Southern University of Science and Technology, 2. Sun Yat-sen University)

Utilizing the Heliophysics/Geospace System Observatory to Understand Particle Injections: Their Scale Sizes and Propagation Directions

*Christine Gabrielse[1], Emma Spanswick[2], Anton Artemyev[3], Toshi Nishimura[4], Andrei Runov[3], Larry Lyons[3], Vassilis Angelopoulos[3], Drew L. Turner[5], Geoffrey D. Reeves[6], Eric Donovan[2]

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The injection region's formation, scale size, and propagation direction have been debated throughout the years, with new questions arising with increased plasma sheet observations. How do temporally and spatially small-scale injections relate to the larger injections historically observed at geosynchronous orbit? How to account for opposing propagation directions--earthward, tailward, and azimuthal--observed by different studies? To address these questions, we used a combination of multisatellite and ground-based observations to knit together a cohesive story explaining injection formation, propagation, and differing spatial scales and timescales. We used a case study to put statistics into context. First, fast earthward flows with embedded small-scale dipolarizing flux bundles transport both magnetic flux and energetic particles earthward, resulting in minutes-long injection signatures. Next, a large-scale injection propagates azimuthally and poleward/tailward, observed in situ as enhanced flux and on the ground in the riometer signal. The large-scale dipolarization propagates in a similar direction and speed as the large-scale electron injection. We suggest small-scale injections result from earthward-propagating, small-scale dipolarizing flux bundles, which rapidly contribute to the large-scale dipolarization. We suggest the large-scale dipolarization is the source of the large-sale electron injection region, such that as dipolarization expands, so does the injection. The >90 keV ion flux increased and decreased with the plasma flow, which died at the satellites as global dipolarization engulfed them. We suggest the ion injection region at these energies in the plasma sheet is better organized by the plasma flow.

Keywords: injections, ionosphere, aurora, particle transport, substorms, multi-point observations

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Flux decrease of outer radiation belt electrons associated with solar wind pressure pulse: A Code coupling simulation of GEMSIS-RB and GEMSIS-GM

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Relativistic electron flux of the outer radiation belt dynamically changes in response to solar wind variations. Enhancement of dynamic pressure causes the flux drop-out of the outer belt electrons, and magnetopause shadowing (MPS) has been proposed to cause rapid loss of relativistic electrons (e.g.,Kim et al.,2008). In general, it has been expected that MPS is a cross-field transportation due to convection and/or the dayside compression of the magnetosphere. However, the gyro-radius of relativistic electrons of the outer belt seems to be too small compared with the spatial scale of gradient of the dayside magnetopause, so that it is difficult for electrons to escape across the magnetopause(e.g., Kim and Lee, 2014). In this study, we investigate another escaping process of relativistic electrons into the interplanetary space. We conduct a code-coupling simulation of a test-particle simulation code (GEMSIS-RB: Saito et al., 2010) and a global MHD magnetosphere simulation code (GEMSIS-GM: Matsumoto et al., 2010). We calculate trajectories of a number of electrons of guiding-center of electrons in electromagnetic fields calculated from GEMSIS-GM. In the simulation, electrons are initially distributed from Re = 6 to 11 with initial energies from 1 MeV to 10 MeV. Initial pitch angles of electrons are distributed from 50 degrees and 90 degrees. In this simulation, the solar wind dynamic pressure and the magnetopause stand-off distance change in the different phase of variation ; [i] The stand-off distance of the magnetopause is 12 RE with the initial dynamic pressure of 1.0 nPa, By_IMF of 0.005 nT, Bz_IMF = 3.0 nT. [ii] The solar wind dynamic pressure increases to 2.5 nPa, and the magnetopause moves to 9 RE. In this period, the pitch angle scattering of electrons with L value larger than 9.0 occurs by Drift Shell Bifurcation (DSB). [iii] The dynamic pressure decreases, and the inflation of the magnetopause takes place. The stand-off distance of the magnetopause moves back to 10 RE. In this period, the pitch angle of electrons with L value larger than 9.25 are scattered by DSB. During phase [ii], the high-latitude magnetic reconnections occur at dawn-side. Several electrons scattered by DSB change their mirror points to the high latitude where electrons can escape into the interplanetary magnetic field along the field line. During the periods, the high-latitude reconnections occur at the high-latitude in the dusk side. As a result, some of trapped electrons escape into the interplanetary space along open magnetic field, which cause the loss of trapped electrons in the lower L-shells at least L = 8.75. In our study, it is also found that outward transport tends to occur at high energy, because electrons with fast drift velocity observes dawn to dusk electric field for relatively long period, and resultant outward movement takes place. Moreover, the higher the dynamic pressure, the lower the L value closer to the earth. The study reveals a part of erectrons of the outer radiation belt escape into the interplanetary space along the field line, which are different process from the MPS.

Keywords: radiation belt, simulation

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Seasonal Variation in Mass and Electron Densities of the Plasmasphere in the New Zealand Meridian

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The equatorial mass and electron densities of the plasmasphere are respectively obtained from field line resonance (FLR) frequency and dispersion of whistler wave frequency. They have been effective tools for monitoring the plasmasphere from ground-based measurements.

At the two geomagnetic stations Middlemarch (L=2.8, belonging to CRUX magnetometer array http://www1.osakac.ac.jp/crux/) and Eyrewell (EYR, L=2.5, belonging to INTERMAGNET http://www.intermagnet.org/) in New Zealand, 1 sec observation of geomagnetic field started in 2011, and data have been accumulated for over 9 years. These observation points are approximately 300 km (dL=0.3) apart in the north-south direction, and this is an ideal location to detect field line resonances from cross-phase and power ratio.

In order to detect FLR frequencies, we applied an automatic algorithm, well-known 't-statistic method' introduced by Berube et al., 2003, to this data set and derive equatorial plasma mass densities. As a result, the plasma density in quiet time (maximum of Kp index in the previous 4 days < 4) showed the seasonal variation with minima in December, and its amplitude is larger in the solar maximum. According to the previous studies (e.g., Park et al., 1978), the electron density in the West American meridian showed opposite seasonal variation with minima in June) and similar dependence of solar activity (amplitude of the seasonal variation is larger in the solar maximum).

The Automated Whistler Detectorand Analyser (AWDA) system automatically detects whistler traces from VLF signals recorded at Dunedin (L=2.8) in New Zealand and provides equatorial electron densities.

By combining the electron and plasma mass densities, the corresponding average ion mass can be estimated by the reasonable assumptions that the plasma is quasi-neutral and the electron mass is negligible compared to the ion mass.

In the presentation, we will introduce the first results of comparison of these densities obtained from New Zealand stations during 2011-2019 which includes both solar maximum and minimum.

Keywords: plasmasphere, inner magnetosphere, ionosphere, Magnetosphere-Ionosphere coupling

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Differences in Near-Earth Magnetotail Evolution Between Pseudosubstorms and Substorms

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Pseudosubstorms (pseudobreakups) are similar to substorms during the early stage of auroral development but differ in the later stage. That is, pseudosubstorms are not accompanied by poleward expansion, while substorms are. To understand what causes this difference, we statistically studied temporal and spatial development of the near-Earth magnetotail at X=-7 to -11 Re around pseudosubstorm and substorm onsets, based on THEMIS data. We find that near-Earth reconnection occurs before onset for both pseudosubstorms and substorms, but the earthward flow generated by reconnection is slower for pseudosubstorms than for substorms. Dipolarization, together with magnetic field fluctuations, occurs at X=-8 Re for both cases, but it is weaker at other distances for pseudosubstorms than for substorms. This result suggests that the current disruption related to dipolarization does not expand tailward and hence auroral poleward expansion does not occur for pseudosubstorms. Furthermore, the total pressure is larger at X=-8 to -11 Re for several minutes before onset for substorms than for pseudosubstorms. The total pressure gradient increases more largely after onset for substorms than for pseudosubstorms. We suggest that these differences are important factors for determining whether ballooning instability causing current disruption grows in a wide area, that is, whether the initial action develops into a substorm or subsides as a pseudosubstorm.

Keywords: substorm, pseudosubstorm, pseudobreakup, magnetotail, ballooning instability, THEMIS

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Geomagnetic field and energetic particle oscillations observed at geosynchronous orbit during the growth and expansion phases of a substorm

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Magnetic field and energetic electron data (E > 175 keV) acquired by GEO-KOMPSAT-2A (GK-2A) geosynchronous spacecraft in the pre-midnight sector have been used to study quasi-periodic magnetic field and particle oscillations during the substorm growth and expansion phases on 6 March 2019. Three types of oscillations are found in the magnetic field and electron flux: (1) ~300-s and (2) ~120-s oscillations during the decrease of the energetic particle flux prior to the expansion phase (i.e., during the substorm growth) and (3) ~60-s oscillations during the substorm expansion. The ~300-s electron flux oscillations have a quadrature relationship with the magnetic field oscillations in the azimuthal component at geosynchronous orbit, indicating the properties of a standing Alfven wave, and are nearly identical to the waveform of the geomagnetic field measured at low latitude (L = ~1.3) ground station. The ~120-s electron flux oscillations were observed just before the substorm onset. They are out of phase with the magnetic field perturbation in the radial component, which is dominant in the pre-midnight sector. There are no ground perturbations corresponding to the ~120-s electron flux oscillations. At the substorm onset, the ~60-s electron flux oscillations were excited, and the first four cycle of the flux oscillations show an in-phase signature of Pi2 oscillations identified at low-latitude ground station. In this study, we discuss how and where the electron flux oscillations are generated during the substorm growth and expansion phases.

Keywords: Substorm, Geosynchronous orbit, Alfven wave

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Longitudinal propagation of thin auroral arcs

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Substorm onset is initiated along an east-west aligned thin arc. The formation and dynamics of these thin arcs are important for understanding substorms. However, the arcs can be complicated and their associated process in the magnetosphere is still unclear. Our previous Rice Convection Model simulation has showed that when it is traveling through the middle plasma sheet, a flux tube bubble is elongated along the Sun-Earth direction, causing an auroral streamer; while when it arrives at the magnetic transition region and expands azimuthally, it will give rise to an east-west thin arc . In order to verify our prediction, we analyzed a number of events using THEMIS All-Sky-Imager data,.We find that the longitudinal propagation speed of the leading edge of the arcs is between 0.5 and 3.5 km/s, which is consistent with our simulation results.

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM14] Frontiers in solar physics

convener:Shinsuke Imada(Institute for Space-Earth Environmental Research, Nagoya University), Alphonse Sterling(NASA/MSFC), Takaaki Yokoyama(School of Science, University of Tokyo), Toshifumi Shimizu(Institute of Space and Astronautical Science, JAXA)

Over recent decades, Sun-observing satellite missions have told us much about the dynamic solar atmosphere. These satellites can observe magnetic activity in the solar corona at wavelengths inaccessible from ground-based telescopes, such as X-rays and EUV. Additionally, the seeing-free conditions of space allow for consistent, high-spatial resolution at visible wavelengths; e.g. the HInode satellite can observe solar surface magnetic field elements down to ~0.2 arcsec. From observations such as these, we have identified three important points regarding what is required form future space-based solar missions to solve fundamental solar problems, such as how the corona is heated and what drives solar eruptions: (1) seamless observation over all temperature regimes of the solar atmosphere, from the chromosphere to the corona, at the same time; (2) high spatial and temporal resolution to resolve elemental structures of the solar atmosphere, and to track their evolution; and (3) plasma diagnostic capability to quantify the dynamics of elementary process taking place in the solar atmosphere. To meet these requirements, recently the solar physics community in Japan proposed the Solar-C_EUVST mission, which will be launched in the mid-2020s. Furthermore, additional top-rate solar observatories, such as the Parker Solar Probe (PSP), Solar Orbiter, and the Daniel K. Inouye Solar Telescope (DKIST), will be operating in the years leading up to Solar-C_EUVST. In this session we will discuss what solar physics observational and numerical-simulation studies are required prior to the mid-2020s, to prepare most efficiently for the new observational era. We welcome contributions dealing with remote-sensing space-based observations (e.g. from Hinode and SDO), in-situ observations from near- and deep-space (e.g., PSP, Pioneer), ground-based observations, and numerical studies.

[PEM14-01] Alfvenic fluctuations in the near-Sun solar wind: Measurements from Parker Solar Probe

★Invited Papers

*Stuart D Bale[1] (1.University of California Berkeley)

[PEM14-02] Contribution of the BepiColombo mission to inner heliospheric science

★Invited Papers

*Go Murakami[1], Yoshizumi Miyoshi[2], Kazumasa Iwai[2], Daikou Shiota[3], Takeshi Imamura[4], Iku Shinohara[1], Shinsuke Imada[2], Toshifumi Shimizu[1] (1.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 2.Institute for Space-Earth Environmental Research, Nagoya University, 3.National Institute of Information and Communications Technology, 4.Graduate School of Frontier Sciences, The University of Tokyo)

[PEM14-03] Instrumental design of the Solar-C_EUVST telescope

*Yoshinori Suematsu[1], Toshifumi Shimizu[2], Hirohisa Hara[1], Tomoko Kawate[2], Yukio Katsukawa[1], Kiyoshi Ichimoto[3], Shinsuke Imada[4] (1.NAOJ National Astronomical Observatory of Japan, 2.ISAS/JAXA, 3.Kyoto University, 4.Nagoya University)

[PEM14-04] Analysis of Small-scale Flares using Genetic Algorithm

*Toshiki Kawai[1], Shinsuke Imada[1] (1.Institute for Space-Earth Environmental Research, Nagoya University)

[PEM14-05] Magnetic Flux Cancellation and Associated Plasma Heating in the Upper Solar Atmosphere

*Sung-Hong Park[1], KD Leka[1,2], Kanya Kusano[1] (1.Institute for Space-Earth Environmental Research of Nagoya University, 2.NorthWest Research Associates)

[PEM14-06] Nonlinear force-free modeling of the flare-productive magnetic fields observed in the solar active region 12673

*Daiki Yamasaki[1], Satoshi Inoue[2], Shin'ichi Nagata[3], Kiyoshi Ichimoto[3] (1.Department of Astronomy, Kyoto University, 2.Institute for Space-Earth Environmental Research, Nagoya University, 3.Astronomical Observatory, Kyoto University)

Alfvenic fluctuations in the near-Sun solar wind: Measurements from Parker Solar Probe

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1. University of California Berkeley

The PSP/FIELDS instrument has measured a rich variety of phenomena over PSP Encounters 1-3, including Alfvenic fluctuations and turbulence, dust, plasma instabilities and solar and Jovian radio emissions. The PSP spacecraft had its 4th solar encounter at < 28 Rs in late January, 2020. Here we report a summary of first results from the PSP/FIELDS instrument focusing on new results beyond those observed in Encounter 1-3 and describing measurements of Alfvenic 'switchbacks'.

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Contribution of the BepiColombo mission to inner heliospheric science

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BepiColombo is the ESA-JAXA joint mission to explore Mercury with two spacecraft: "Mio" (Mercury Magnetospheric Orbiter: MMO) and "Bepi" (Mercury Planetary Orbiter: MPO). The two spacecraft were successfully launched by Ariane-5 launch vehicle from Kourou in French Guiana on 20 October 2018. Mio is fully dedicated to investigating Mercury’s environment with a complete package of plasma instruments (particles, electric fields, and magnetic fields), a spectral imager of sodium exosphere, and a dust monitor. The trajectory of the BepiColombo spacecraft ranges from 1.2 AU to 0.3 AU including Earth, Venus, and Mercury flybys. During the cruise to Mercury, in addition to two spacecraft MMO Sunshield and Interface Structure (MOSIF) and Mercury Transfer Module (MTM) are all integrated together. Though the observation capabilities of some instruments onboard Mio and MPO are constrained due to the stacked configuration during the interplanetary cruise phase, BepiColombo can still contribute to inner-heliospheric science. For example, continuous monitoring of interplanetary magnetic fields and solar energetic particles can be achieved during the cruise phase. In the solar conjunction periods, the radio science instrument will perform the solar corona measurements by a radio occultation method. In addition to BepiColombo, NASA’s Parker Solar Probe and ESA’s Solar Orbiter are exploring the inner heliosphere at the same time. JAXA’s Venus orbiter Akatsuki also has capabilities of radio occultations. These multi spacecraft explorations collaborated with ground-based observations and numerical simulations will play a key role to investigate the inner heliospher. Here we present the overview and observation plans of BepiColombo for the interplanetary cruise phase and the proposals for collaborated studies with other spacecraft, ground-based observations, and simulations.

Keywords: Inner heliosphere, BepiColombo, Planetary exploration

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Instrumental design of the Solar-C_EUVST telescope

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The Solar-C_EUVST: the EUV High-Throughput Spectroscopic Telescope, is a revolutionary spectrometer that is designed to provide high-quality and high cadence spectroscopic data covering a wide temperature range of the chromosphere to flaring corona. To achieve high spatial and temporal resolution than ever, the optics of Solar-C_EUVST is designed to have only two imaging systems; a 28-cm aperture off-axis parabolic primary mirror and a two-split toroidal grating both which have high reflective coatings in EUV-UV range (17-21 nm, 47-125 nm), without a blocking filter for visible light before the primary mirror. For this reason, about 53 W of sunlight is absorbed by the multilayer coating of a solar absorbance 0.6 put on the primary mirror. The primary mirror has bipod pads support using an adhesive, and movable mechanisms such as tip-tilt and image scanning and refocusing are placed just under the primary mirror, in which a high temperature needs to be avoided. We successfully designed the thermal model of EUVST telescope in which the temperature of the primary mirror bonding part and the mechanisms is well lower than 60 degC and the thermal deformation of the primary mirror is small. The instrumental design of EUVST telescope to achieve high spatial resolution is presented.

Keywords: Solar corona, Solar chromosphere, EUV imaging spectrograph

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Analysis of Small-scale Flares using Genetic Algorithm

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Coronal heating is one of the long-standing problems in solar physics. So far, two primary mechanisms have been proposed to explain how the corona is heated, namely small-scale magnetic reconnection and wave dissipation. To estimate the contribution of small-scale magnetic reconnections, so called nano-flares, to heat the corona is crucial to solve the coronal heating problem. To reach this goal, we develop a new method to analyse small-scale flares based on the combination of a numerical simulation and a machine learning technique. firstly, we obtain the light curves of the coronal loops from SDO/AIA multi-wavelength observation. Secondly, we carry out thousands of one-dimensional hydrodynamic simulations which calculate the time evolutions of coronal loops heated by flares which have various heating rates, durations, and occurrence times. Thirdly, we observe the simulated coronal loops by some SDO/AIA channels in a pseudo-manner. Then, we randomly make some “genes” which have the information of the combination of some pseudo-observed light curves. Comparing observed and linear superposition of pseudo-observed light curves, the genes are optimized based on the genetic algorithm which is one of the machine learning techniques. Repeating the optimization, finally, we estimate the occurrence frequency distribution of flares as a function of energy. As a result, we reveal that the coronal loops are heated by smaller flares dominantly in a specific energy range.

Keywords: machine learning, flare

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Magnetic Flux Cancellation and Associated Plasma Heating in the Upper Solar Atmosphere

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Magnetic flux cancellation in the solar photosphere has been studied to understand a detailed, complicated process of magnetic reconnection, in particular with respect to various types of reconnection signatures in the upper solar atmosphere such as current sheet-like structures, jet-like features and nonthermal particle acceleration. Recently, a theoretical model of magnetic reconnection has been proposed, in which the reconnection process is driven by converging magnetic patches of opposite polarities on the photospheric surface and their flux cancellation. This model allows us to analytically estimate the amount of magnetic energy released as heat at a reconnecting current sheet. Here we present a small-scale flux cancellation event observed by Hinode, IRIS and SDO. During flux cancellation, two opposite-polarity magnetic patches are identified and traced by an automated feature tracking technique. Determining their flux, converging speed and overlying field strength as a function of time, we first estimate the temporal variation of the total rate of energy release as heat through reconnection. This estimated heating rate is then compared with the multi-wavelength IRIS and SDO/AIA observations to quantitatively examine how valid the proposed reconnection model is in the context of the release of magnetic energy.

Keywords: Magnetic Reconnection, Magnetic Flux Cancellation, Plasma Heating

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Nonlinear force-free modeling of the flare-productive magnetic fields observed in the solar active region 12673

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The solar active region (AR) 12673 was one of the most flare-productive AR through the solar cycle 24. This AR produced not only multiple M-class flares but also several X-class flares. Among them, the X9.3 flare observed on September 6th 2017 was the largest solar flare in the solar cycle 24. The purpose of this study is to comprehensively understand the flare-productive magnetic fields and flare activities observed in the AR12673. In this study, based on the nonlinear force-free field (NLFFF) extrapolation, we investigated a temporal evolution of the three-dimensional (3D) magnetic field producing the several M-class flares, which occurred around 2 days prior to the X9.3 flare. Furthermore, we analyzed 3D magnetic field structure few minutes before the M5.5 flare, which was accompanied with coronal mass ejection (CME), and discussed the flare onset mechanism. The NLFFFs were extrapolated from the time series data of the photospheric vector magnetic field, which cover before and after the M5.5 flare, from Helioseismic and Magnetic Imager (HMI) on board the Solar Dynamics Observatory (SDO). As a result, we found the followings; (1) Three magnetic flux ropes (MFRs) evolved from September 4th, one of which produced the X9.3 flare on September 6th. One of the MFRs had a positive helicity which had a different sign from other two MFRs. Since, the temporal evolution of the magnetic flux occupied by the positive helicity captures one of the GOES X-ray flux well, we suggest that the positive helicity injection is related to the occurrence of the M-class flares including the M5.5 flare. (2) We investigated the 3D magnetic field structure before the M5.5 flare. We found a null point in the magnetic field surrounding the MFRs. By comparing to the AIA 1600 angstrom images, the footpoints of the overlying field lines are well anchored to the area where the initial brightening of the AIA 1600 angstrom was strongly enhanced, and the flare ribbons were observed at the footpoints of the MFR with positive twist. Therefore, we suggest that a reconnection occurred at the null point possibly drives the M5.5 flare. (3) Most of the M-class flares were far from the PIL where the X9.3 flare was observed. Therefore, we suggest that the MFR concerned with the X9.3 flare would be stable before September 6th.

Keywords: solar flares, magnetic fields, Magnetohydrodynaimcs (MHD)

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM14] Frontiers in solar physics

convener:Shinsuke Imada(Institute for Space-Earth Environmental Research, Nagoya University), Alphonse Sterling(NASA/MSFC), Takaaki Yokoyama(School of Science, University of Tokyo), Toshifumi Shimizu(Institute of Space and Astronautical Science, JAXA)

Over recent decades, Sun-observing satellite missions have told us much about the dynamic solar atmosphere. These satellites can observe magnetic activity in the solar corona at wavelengths inaccessible from ground-based telescopes, such as X-rays and EUV. Additionally, the seeing-free conditions of space allow for consistent, high-spatial resolution at visible wavelengths; e.g. the HInode satellite can observe solar surface magnetic field elements down to ~0.2 arcsec. From observations such as these, we have identified three important points regarding what is required form future space-based solar missions to solve fundamental solar problems, such as how the corona is heated and what drives solar eruptions: (1) seamless observation over all temperature regimes of the solar atmosphere, from the chromosphere to the corona, at the same time; (2) high spatial and temporal resolution to resolve elemental structures of the solar atmosphere, and to track their evolution; and (3) plasma diagnostic capability to quantify the dynamics of elementary process taking place in the solar atmosphere. To meet these requirements, recently the solar physics community in Japan proposed the Solar-C_EUVST mission, which will be launched in the mid-2020s. Furthermore, additional top-rate solar observatories, such as the Parker Solar Probe (PSP), Solar Orbiter, and the Daniel K. Inouye Solar Telescope (DKIST), will be operating in the years leading up to Solar-C_EUVST. In this session we will discuss what solar physics observational and numerical-simulation studies are required prior to the mid-2020s, to prepare most efficiently for the new observational era. We welcome contributions dealing with remote-sensing space-based observations (e.g. from Hinode and SDO), in-situ observations from near- and deep-space (e.g., PSP, Pioneer), ground-based observations, and numerical studies.

[PEM14-07] The Chromospheric Layer SpectroPolarimeter (CLASP2) Mission: Introduction

★Invited Papers

*David E. McKenzie[1], Ryohko Ishikawa[2], Ryouhei Kano[2], Joten Okamoto[2], Laurel Rachmeler[1], Javier Trujillo Bueno[3], Frederic Auchere[4], Ken Kobayashi[1], Donguk Song[2], Masaki Yoshida[2] (1.NASA Marshall Space Flight Center, 2.National Astronomical Observatory of Japan, 3.Instituto Astrofísica de Canarias, 4.Institut d'Astrophysique Spatiale)

[PEM14-08] Initial results from CLASP2 rocket experiment to measure magnetic fields in the solar chromosphere

★Invited Papers

*Joten Okamoto[1], Ryoko Ishikawa[1], David McKenzie[2], Javier Trujillo Bueno[3], Frederic Auchere[4], Laurel Rachmeler[2], Ryohei Kano[1], Donguk Song[1], Christian Bethge[5], Ken Kobayashi[2], Masaki Yoshida[1], Tanausu del Pino Aleman[3], CLASP2 team (1.National Astronomical Observatory of Japan, 2.NASA Marshall Space Flight Center, 3.Instituto Astrofisica de Canarias, 4.Institut d'Astrophysique Spatiale, 5.Universities Space Research Association)

[PEM14-09] Mathematical modelling of effect of flows in magnetic flux tubes

*Samuel Joseph Skirvin[1], Viktor fedun[1], Gary Verth[1] (1.University of Sheffield)

[PEM14-10] Numerical study of fast and slow wave heating of the magnetic chromosphere

*WANG YIKANG[1], Takaaki Yokoyama[1], Haruhisa Iijima[2] (1.The University of Tokyo, 2.Nagoya University)

[PEM14-11] Solar photospheric jet-like structures formed by slow shock

*Yuji Kotani[1], Kazunari Shibata[2] (1.Department of Astronomy, Kyoto University, 2.Kwasan and Hida Observatories, Kyoto University)

[PEM14-12] Chromospheric magnetic field: A comparison of He I 10830 Å observation with nonlinear force-free field extrapolation

*Yusuke Kawabata[1], Andrés Asensio Ramos[2], Satoshi Inoue[3], Toshifumi Shimizu[4] (1.National Astronomical Observatory of Japan, 2.Instituto de Astrofísica de Canarias, 3.Institute for Space-Earth Environmental Research, Nagoya University, 4.Institute of Space and Astronautical Science, JAXA)

The Chromospheric Layer SpectroPolarimeter (CLASP2) Mission: Introduction

*David E. McKenzie[1], Ryohko Ishikawa[2], Ryouhei Kano[2], Joten Okamoto[2], Laurel Rachmeler[1], Javier Trujillo Bueno[3], Frederic Auchere[4], Ken Kobayashi[1], Donguk Song[2], Masaki Yoshida[2]

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A major challenge for solar physics is to decipher the magnetic structure of the chromosphere, because of its vital role in the transport of energy into the corona and solar wind. Routine satellite measurements of the chromospheric magnetic field will dramatically improve our understanding of the chromosphere and its connection to the rest of the solar atmosphere. Before such a satellite can be considered for flight, we must refine the measurement techniques by exploring emission lines with a range of magnetic sensitivities. In 2015, the CLASP mission achieved the first measurement of linear polarization produced by scattering processes in a far UV resonance line (hydrogen Lyman-alpha), and the first exploration of the magnetic field (via the Hanle effect) and geometrical complexity in quiet regions of the chromosphere-corona transition region. These measurements are a first step towards routine quantitative characterization of the local thermal and magnetic conditions in this key layer of the solar atmosphere.

Nonetheless, Lyman-alpha is only one of the magnetically sensitive spectral lines in the UV spectrum. The CLASP2 mission extended the capability of UV spectropolarimetry by acquiring groundbreaking measurements in the Mg II h and k spectral lines near 280 nm, whose cores form about 100 km below the Lyman-alpha core. These lines are sensitive to a larger range of field strengths than Lyman-alpha, through both the Hanle and Zeeman effects. CLASP2, launched from White Sands Missile Range in April 2019, captured measurements of linear and circular polarization to enable the first determination of all 4 Stokes parameters in chromospheric UV radiation. Coupled with numerical modeling of the observed spectral line polarization (anisotropic radiation pumping with Hanle, Zeeman, and magneto-optical effects), CLASP and CLASP2 are pathfinders for determination of the magnetic field's strength and direction, as well as of the geometry of the plasma in the upper solar chromosphere.

In this presentation we will introduce the CLASP and CLASP2 missions. We will summarize the results of the 2015 flight of CLASP; and we will describe the modifications, performance characteristics, and observing plan for the CLASP2 flight in 2019. Initial results from the 2019 flight will be shown in the partner presentation by Okamoto.

Keywords: chromosphere, polarization, sounding rocket

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Initial results from CLASP2 rocket experiment to measure magnetic fields in the solar chromosphere

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The magnetic field in the chromosphere is one of the most important parameters needed to understand the dynamics of the solar atmosphere and to solve the coronal heating problem. To verify a new technique proposed to determine the magnetic field in the upper solar chromosphere, we developed a new instrument, CLASP2 (Chromospheric LAyer SpectroPolarimeter), which allows to measure the four Stokes profiles across the Mg II k and h lines around 280 nm. The launch operation was performed on 2019 April 11 at the White Sands Missile Range in New Mexico, USA. During its suborbital flight, CLASP-2 observed for 6 minutes three targets, including the center of the solar disk for 18 s to calibrate the instrument, a strong plage for 155 s to measure magnetic fields via the Hanle and Zeeman effects, and a quiet limb region for 136 s to measure scattering polarization and its modification through the Hanle and magneto-optical effects.
The spectropolarimetric observations were successfully done and we detected clear polarization signals in the plage and in the quiet limb region. Here we show some preliminary results. First, we confirm the theoretically-predicted scattering polarization pattern across the Mg II k and h lines. The spatial variation of the observed polarization signals encodes information on the magnetic field via the Hanle, Zeeman, and magneto-optical effects. Second, we show clear circular polarization signals in several spectral lines induced by the Zeeman effect, from which we derive the spatio-temporal variations of the line-of-sight field strength in the upper chromosphere. Third, with the slit-jaw instrument, we could observe the predicted broad-band scattering polarization of the hydrogen Lyman-alpha line, including its center-to-limb variation. During the CLASP2 flight, we also carried out coordinated observations with the IRIS and Hinode satellites.

Keywords: chromosphere, magnetic field, rocket experiment

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Mathematical modelling of effect of flows in magnetic flux tubes

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1. University of Sheffield

Magnetohydrodynamic (MHD) waves are thought to play a crucial role in the energy budget of the solar atmosphere. It is well thought that these waves contribute to the heating of the solar chromosphere and corona. As a result, understanding the physics and behaviour of these waves within the context of a realistic solar atmospheric environment is of great importance. The solar atmosphere is dynamic and contains structures which may support the propagation of these waves. Many, if not all, of these structures will have plasma flow present, however the exact velocity profile of these flows are as yet unobservable.

We derive a new governing equation describing the generalised case for a spatially arbitrary flow in a 2-dimensional magnetic slab. This equation reduces to the familiar known forms if the flow is constant or removed entirely. This second order differential equation with varying coefficients has no known analytic solution, as such the dispersion diagram cannot be derived analytically and a numerical method must be used instead.

We therefore also introduce the idea for a new method of retrieving the dispersion diagram describing the types of waves which can exist in the system. This method is based on the shooting method and requires that the total pressure perturbation and total horizontal velocity (displacement) is matched at the boundaries of the slab.

This theoretical study of waves propagating in a spatially dependant flow in a magnetic slab will be verified via 2-3D numerical modelling to visualise the effect of the flow.

Keywords: Jets, Flows, Solar, MHD Waves

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Numerical study of fast and slow wave heating of the magnetic chromosphere

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The problem how to heat the solar chromosphere is still under debate especially in the magnetic chromosphere. MHD waves are considered as important energy transporter and make contribution to chromospheric heating. Previous researches usually discuss propagation of MHD waves in the chromosphere with great detail but the setting of flux tube and wave generation is artificial. There are also studies by realistic simulations but they are used for comparison with observations without discussing detail physical processes. In our study. by using the result of a two-dimensional realistic MHD simulation, we identify shock waves and separate fast and slow mode waves. We further estimate the heating rate by them. We find that fast wave heating rate is larger than slow wave heating rate in the chromosphere. In addition, the wave heating rate is consistent with radiative cooling rate in classic atmospheric empirical model.

Keywords: Sun, Chromosphere, MHD wave

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Solar photospheric jet-like structures formed by slow shock

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Jet phenomena with a bright loop in their footpoint have been observed in the solar corona and chromosphere, and these are called anemone jets. These jets are formed by magnetic reconnection, and from the scale universality of magnetohydrodynamics (MHD), it can be expected that anemone jets exist even in the solar photosphere. However, it is not obvious whether jets can be generated by magnetic reconnection even in the solar photosphere where magnetic energy is not dominant. To verify whether anemone jets exist in the solar photosphere, we perform 3D MHD simulation including gravity with the solar photospheric parameter. As a result of the simulation, jet-like structures are formed by magnetic reconnection even in the solar photosphere. We find this jet-like strucutures are caused by slow shock formed by reconnection and propagating roughly in the direction of the background field. In this talk, we will introduce the formation mechanism of this jet-like structure.

Keywords: magnetic reconnection, slow shock, solar jet, solar photosphere

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Chromospheric magnetic field: A comparison of He I 10830 Å observation with nonlinear force-free field extrapolation

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Magnetic field structures in the solar corona are essential to understand the dynamical nature of the plasmas responsible for occurrence of flares and coronal mass ejections. The coronal magnetic field, however, is difficult to be directly observed because of the weak polarization signal in thermally broadened spectral lines. To overcome the difficulty, the nonlinear force-free field (NLFFF) modeling has been extensively used to infer the three-dimensional (3D) magnetic field in the solar corona. The assumption in the NLFFF extrapolation is that the plasma beta is low, but this condition is considered to be incorrect in the photosphere.

We attempt to reveal the non-potential magnetic field distribution in the chromosphere through spectropolarimetric observations and how significantly the magnetic field at the chromospheric height derived by the current NLFFF modeling with photospheric magnetic field is deviated from the measured chromospheric magnetic field. We examine the direct measurements of the chromospheric magnetic field in the whole active regions through the spectropolarimetric observations at He I 10830 Å. In addition, the photospheric magnetic field is measured with Hinode and Solar Dynamics Observatory. The results of NLFFF extrapolation from the photosphere are compared with the direct measurements. Our analysis shows that chromospheric magnetic field may have larger non-potentiality compared to the photospheric magnetic field at some locations. Moreover, the large non-potentiality in the chromospheric height may not be reproduced by the NLFFF extrapolation from the photospheric magnetic field. The magnitude of the underestimation of the non-potentiality at the chromospheric height may reach 30-40 degree in signed shear angle. We conclude that the magnetic field in the upper atmosphere may have higher non-potentiality than previously thought based on the NLFFF.

Keywords: Sun, Magnetic field, Chromosphere

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM15] Plasma Theory and Simulation

convener:Seiji Zenitani(Kobe University), Fan Guo(Los Alamos National Laboratory), Takayuki Umeda(Institute for Space-Earth Environmental Research, Nagoya University), Takanobu Amano(Department of Earth and Planetary Science, University of Tokyo), Yasuhiro Nariyuki(Faculty of Education, University of Toyama)

This session invites contributions in plasma theories and simulations. Theoretical and/or numerical results on plasma processes (magnetic reconnection, collisionless shocks, wave-particle interactions, and boundary problems) and their applications in space, solar, astrophysical, and laboratory environments are welcome. Results in computational techniques for simulations and for data analysis are also welcome, including applications of Machine Learning. The session will be held in English.

[PEM15-01] An adaptive load balancing method for particle-in-cell simulations

*Yosuke Matsumoto[1] (1.Graduate School of Science, Chiba University)

[PEM15-02] Relation between Alfven-ion-cyclotron and Weibel instabilities in the collisionless perpendicular shock transition region: Upstream plasma parameter dependence

*Takuro Nishigai[1], Takanobu Amano[1] (1.Department of Earth and Planetary Science, University of Tokyo)

[PEM15-03] Full PIC simulations of the surface charging on the night side of Phobos

*Masaki Tanabe[1], Naoki Terada[1], Yohei Miyake[2], Hideyuki Usui[2] (1.Graduate school of science, Tohoku University, 2.Graduate school of system informatics Kobe University)

[PEM15-04] An Analysis of Slow-Shock and Slow Shock-Like Structures Observed in the 2D Hybrid Magnetic Reconnection Simulations

*Nehpreet Kaur Walia[1], Kanako Seki[1], Takanobu Amano[1] (1. Department of Earth & Planetary Science, Graduate School of Science, University of Tokyo)

[PEM15-05] Outstanding issues in plasma Riemann problem

*Tohru Hada[1] (1.Interdisciplinary Graduate School of Engineering Sciences, Kyushu University)

[PEM15-06] A simple stochastic model of electron diffusion by whistler waves in a non-uniform magnetic field

*Yasuhiro Nariyuki[1] (1.Faculty of Education, University of Toyama)

An adaptive load balancing method for particle-in-cell simulations

*Yosuke Matsumoto[1]

1. Graduate School of Science, Chiba University

Particle-in-cell (PIC) simulations have been used for understanding particle accelerations, particle transport and magnetic field generation in space and astrophysical phenomena. The PIC simulation bases on the Vlasov equation in which the distribution function of each particle species evolves in the phase space in response to the electric and magnetic field time evolution. While the evolution of the distribution function is represented by motions of finite numbers of macro particles, the electric and magnetic field evolution are represented by a disretized form of the Maxwell equations; the PIC simulation is composed of Eulerian and Lagrangian methods.

Using massively parallel supercomputer systems with a parallelized PIC code is a powerful way to elucidate such nonlinear phenomena. When using very large numbers of processor cores (say, greater than 1000 cores), the code needs to adopt a domain decomposition method, in which each MPI process is associated with a portion of the whole region, for an efficient parallelization. Although this parallelism introduces somewhat cumbersome implementations to the code for exchanging arbitrary numbers of particles among MPI processes every time step, resulting high scalability allows us to examine with unprecedentedly large-scale simulations. Indeed, we have elucidated important acceleration mechanisms in collision-less shocks by using the Japanese flagship supercomputer system with a hundred of thousands of processor cores (e.g., Matsumoto et al., 2017).

In this presentation, we report an upgrade with an implementation of an adaptive load balancing method to our PIC code. The load imbalance among MPI processes in PIC simulations arises if particles were in-homogeneously distributed in the simulation domain as a result of time evolution. This imbalance becomes problematic when using very large numbers of MPI processes (say greater than millions of cores), and we expect to meet this situation with the next generation Japanese flagship system called FUGAKU. A few approaches have been proposed and implemented in PIC codes. For example, in PSC and SUMILEI codes (Germaschewski et al., 2016; Derouillat et al., 2018), each domain of a MPI process is further divided into sub-domains, and these "patches" are exchanged among the processes so that the total number of particles in each MPI domain is equally distributed. The exchange of patches are determined according to the Hilbert curve passing through them. The resulting shape of each domain is rather irregular, which complicates inter-process communications. Alternatively, we adopt the recursive multi-section algorithm which have been successfully implemented into the cosmological N-body simulations (Makino, 2004; Ishiyama et al., 2009). This method requires rather simple inter-process communications because each MPI domain is a rectangular shape. We successfully implemented this method to the PIC code for the first time with benchmark tests of the Weibel instability and collision-less shock simulations.

Keywords: particle-in-cell simulation, load balancer, high performance computing

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Relation between Alfven-ion-cyclotron and Weibel instabilities in the collisionless perpendicular shock transition region: Upstream plasma parameter dependence

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1. Department of Earth and Planetary Science, University of Tokyo

One of the most important problems in space physics is the mechanism by which charged particles accelerated to non-thermal energies. The collisionless shocks in plasmas have been studied extensively observationally, numerically, and theoretically, since they are believed to be the major sources of non-thermal high energy particles through the first-order Fermi acceleration. In this study, we investigate plasma instabilities in the collisionless shock transition region. In a collisionless shock wave having a sufficiently large Alfven Mach number, some of the upstream ions are reflected by a potential barrier in the shock. A variety of instabilities excitedby the velocity difference between the reflected ions and the upstream ions play a crucial role in the dissipation at the shocks.

Low-frequency and long-wavelength instabilities generated in the transition region may have large saturation levels, and can affect the entire shock stricture. In particular, we focus on Alfven Ion Cyclotron (AIC) instability and Weibel instability, both of which are excited by an effective temperature anisotropy generated by the reflected ions. It is well known that the AIC instability generates a rippled shock surface (Winske & Quest, 1988). On the other hand, the Weibel instability dominates at very high Mach number shocks as seen in supernova remnants. Large-scale Particle-in-Cell simulations have found electron acceleration in spontaneous magnetic reconnection generated in the amplified magnetic field and dense current filaments (Matsumoto et al., 2015). This electron acceleration may play an important role in pre-acceleration required for the Fermi acceleration. Qualitatively, the Weibel instability will be the dominant mode at very high Mach numbers (or weak magnetic field), and otherwise, the AIC instability should be dominant. However, the relation between the two instabilities has not been understood.

In this study, we adopt an idealized model for describing the dynamics in the shock transition layer. We consider a homogeneous plasma in the upstream rest frame, which consists of three particle species: the upstream ions, upstream electrons, and reflected ions. The initial velocity distributions are assumed to be Maxwellian distributions for the upstream ions and electrons while the reflected ions form a ring distribution in the direction perpendicular to the ambient magnetic field. Under these conditions, we performed linear analysis for a wavenumber parallel to the ambient magnetic field using the cold plasma approximation. We found that the AIC and Weibel instabilities both appear from single dispersion relation in different limiting cases. In other words, the AIC instability changed to Weibel instability in the limit of no magnetic field (or infinite Mach numbers). Two-dimensional Particle-in-Cell (PIC) simulation also shows that, as the Alfven Mach number increased, the generated mode structure changes from AIC-like to Weibel-like. In this presentation, we will report simulation results on the transition between the two different regimes and how it depends on upstream physical parameters such as the Alfven Mach number and ion-to-electron mass ratio.

Keywords: collisionless perpendicular shock, Alfven-ion-cyclotron instability, Weibel instability

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Full PIC simulations of the surface charging on the night side of Phobos

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We calculated the surface charging on the night side of Phobos caused by the solar wind interaction and analyzed the charging process.
It is known that the surface soils of airless bodies exposed to the solar wind are altered by space weathering. This process at Phobos is important for determining its origin using surface remote sensing and sample analysis by the Martian Moons Exploration (MMX) mission. Meanwhile, the solar wind, a supersonic plasma flow, makes complicated plasma structure around these bodies. Among these structures, surface charging has a close relation with space weathering processes.
Previous studies suggested that there are many types of current systems associated with the surface charging: Solar wind current, photoelectron current and secondary electron current. In order to keep a current balance on the surface, the surface charges up in a steady state. The charging process is different between the dayside and nightside of bodies. While the dayside surface potential is determined by the balance of the solar wind and photoelectron currents, the nightside charging process is complicated. When solar wind plasmas flow into small airless bodies, most of them are absorbed by the dayside of the surface. This removal of plasma at the dayside results in a wake region in the downstream. Then, solar wind ions are accelerated and go into the wake region by ambipolar electric field. While a previous theoretical analysis suggested that the nightside surface potential charged up to several hundred volts, details of electromagnetic field and density distribution around bodies have not been clarified.
In order to understand the process of surface charging, we calculated the plasma environment around a small body by self-consistent 2-D particle-in-cell simulations.
In this study, we calculated a quasi-steady state solution of the electric potential around Phobos in the solar wind by self-consistent PIC simulations. Though Phobos' mean radius is about 11 km, we changed it to 1 km in the simulations to save computational resources. To reveal charging mechanism of Phobos, we adjusted the ratios of the solar wind bulk velocities to thermal velocities and Phobos radius to gyro radii to real ones. 2-D electrostatic PIC simulations were performed under a southward interplanetary magnetic field condition. Compared with theoretical analysis, we found that the surface potential nearly corresponds to theoretical results at the shallow wake region. However, at the deep wake region, the result of simulation shows different potential. This result suggests that the surface potential is affected by not only ambipolar diffusion but also plasma void and non-neutral regions around the wake.
To evaluate the dependence of the surface potential on the solar wind condition, we calculated two types of conditions: Nominal and strong solar wind conditions. While previous studies showed that the surface is charged strongly in the strong solar wind condition, our calculation showed an opposite result at the deep wake region.

Keywords: charging, Phobos, plasma wake, ambipolar difusion, self-similar solution, particle-in-cell simulation

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An Analysis of Slow-Shock and Slow Shock-Like Structures Observed in the 2D Hybrid Magnetic Reconnection Simulations

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Slow-shocks are present in the Petschek's reconnection model to achieve fast magnetic reconnection. The presence of slow-shocks has been established in the MHD and Hall-MHD regime by various simulations[e.g., 1, 2], however in the kinetic regime, slow-shocks are not always observed. Some hybrid and PIC studies have found slow-shocks in their reconnection simulations [e.g., 3], while in some no slow-shocks or slow shock-like-structure [e.g., 4,5] is seen. As for satellite observations, [6] and [7] reported the detection percentage of slow-shocks as 20% and 10% in the dayside magnetopause and the magnetotail, respectively. The possible reasons behind the low detection probability of slow-shocks can be the proximity of the crossings studied to the X-point, presence of flux-ropes, or high turbulence. The error in the determination of shock normal and the shock frame of reference can also lead to non-detection of slow-shocks. In order to study the structure of magnetic reconnection as we transition from ion inertial scale to MHD scale and to check the influence of the above mentioned parameters on the boundary structure, we performed 2D hybrid simulations.

The simulations were performed with two different beta values, and were checked for the presence of slow-shocks using Rankine-Hugoniot conditions, and the specific conditions for Mach number, normal angles etc. [6]. It was found that for high beta case, slow-shocks can be seen as close as ~10 λ_i (i = ion inertial length) from the X-point. For low plasma beta, a transition region exits, in which a slow shock-like structure is seen until ~70 λ_i. From ~70 λ_i slow-shock structure is present at all points. The slow-shock detection percentage in our simulations are found to be highly dependent on the determination of shock normal and on the angle at which the artificial spacecraft crosses the reconnection boundary. The ion distribution functions obtained show clear difference between the regions where slow-shocks are found and where they aren't. The downstream of slow-shocks is not thermalized and has two-component population, crescent-shaped hot beam population and cold population. These structures of ion distribution functions are similar to the ones observed by Geotail spacecraft slow-shock observations [8]. We will also report the trajectories and the energization mechanisms of particles of both the populations.

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Keywords: Magnetic reconnection, Slow-mode shocks, Hybrid simulation

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Outstanding issues in plasma Riemann problem

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The Riemann problem is an initial value problem for a given physical system (such as the hydrodyanmcis (HD), magnetohydrodynamics (MHD), or plasma in general) in which the initial conditions consist of two constant states forming a discontinuity. Obviously, it has numerous applications in space plasma, e.g., the formation of planetary bow shocks, magnetopause, interplanetary shocks, heliopause, and termination shocks. Despite the importance of the problem, there remain several issues remain unsolved. In particular, the solution of the MHD Riemann problem is not always uniquely determined due to the presence of intermediate shocks (Wu, 1987; Takahashi and Yamada, 2014). In this presentation, first we will briefly review our current understanding of the MHD Riemann problem and then will propose a method to determine the solution. For practical applications to space plasma, we will also comment on how plasma kinetic effects may modify the solution qualitatively.

Keywords: Riemann problem, discontinuities

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A simple stochastic model of electron diffusion by whistler waves in a non-uniform magnetic field

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Scattering/acceleration of electrons by electromagnetic waves is a fundamental process to generate relativistic electrons in the inner magnetosphere. Although quasi-linear theories have widely been used to discuss the electron diffusion, the significance of nonlinear wave-particle interactions is also commonly recognized. Recently, we proposed a simple model of the charged particle diffusion including both stochastic and coherent processes [Nariyuki, POP, 2019]. In this presentation, we apply the model to electron diffusion in a simplified dipole magnetic field. Dependence of pitch-angle diffusion on parameters is discussed in detail.

Keywords: electron diffusion, whistler wave, stochastic model

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM15] Plasma Theory and Simulation

convener:Seiji Zenitani(Kobe University), Fan Guo(Los Alamos National Laboratory), Takayuki Umeda(Institute for Space-Earth Environmental Research, Nagoya University), Takanobu Amano(Department of Earth and Planetary Science, University of Tokyo), Yasuhiro Nariyuki(Faculty of Education, University of Toyama)

This session invites contributions in plasma theories and simulations. Theoretical and/or numerical results on plasma processes (magnetic reconnection, collisionless shocks, wave-particle interactions, and boundary problems) and their applications in space, solar, astrophysical, and laboratory environments are welcome. Results in computational techniques for simulations and for data analysis are also welcome, including applications of Machine Learning. The session will be held in English.

[PEM15-07] Nonlinear Interaction of Radiation Belt Electrons with Obliquely Propagating Whistler-mode Chorus Emissions

*Yoshiharu Omura[1], Yi-Kai Hsieh[1] (1.Reserach Institute for Sustainable Humanosphere, Kyoto University)

[PEM15-08] Energy-consistent finite difference method for compressible magnetohydrodynamic simulations

*Haruhisa Iijima[1] (1.Institute for Space-Earth Environmental Research, Nagoya University)

[PEM15-09] **Implementing neural network's inference into the magnetohydrodynamic simulation code**

*Yuki Sawamura[1], Yosuke Matsumoto[1] (1.Chiba University)

[PEM15-10] Visualizing Magnetospheric Topology in Global 3D MHD Simulations

*DongSheng CAI[1] (1.University of Tsukuba)

[PEM15-12] Plasma State inside of the Super Massive Kerr Black Hole and Problem of the Gravitational Wave Source

*Hiroshi Oya[1] (1.Department of Geophysics Graduate School for Science Tohoku University)

Nonlinear Interaction of Radiation Belt Electrons with Obliquely Propagating Whistler-mode Chorus Emissions

*Yoshiharu Omura[1], Yi-Kai Hsieh[1]

1. Reserach Institute for Sustainable Humanosphere, Kyoto University

Whistler-mode chorus emissions are generated at the equator in the parallel direction to the magnetic field, and propagate toward higher latitudes changing the wave normal angle gradually to oblique directions. Interaction between the wave and energetic electrons through Landau resonance becomes effective in the oblique propagation. As observed from the guiding center of a Landau resonant electron moving with the parallel phase velocity, the wave phase becomes stationary. With the perpendicular wave number and the deviation of the gyrating particle position from the guiding center, the electron sees a wave phase of a right-handed circularly polarized wave, which causes efficient acceleration by the perpendicular component of the wave electric field [1]. The interaction time between the resonant electron and the wave packet is maximized with the frequency close to half the cyclotron frequency, because the parallel phase velocity becomes nearly equal to the parallel group velocity. The efficient acceleration of resonant electrons causes damping of the wave at half the cyclotron frequency. Although our previous model assumed that the nonlinear wave damping was due to the parallel wave electric field in the presence of the gradient of magnetic field [2], we have confirmed that the nonlinear trapping due to the perpendicular components of the wave fields plays the major role in the electron acceleration and resultant wave damping in the nonuniform magnetic field [3]. In addition to the nonlinear damping, propagation characteristics of upper and and lower band chorus wave packets are much different. The Gendrin angle, at which the group velocity takes the parallel direction, exists only for the lower band chorus, while the group velocity of the upper band chorus takes highly oblique directions [4], and this difference enhances separation of the two bands in space. A single chorus element can be generated at the equator forming a long-lasting rising tone emission covering half the cyclotron frequency. As the wave packet propagates away from the equator, it splits into lower band and upper band wave packets because of the nonlinear damping through Landau resonance at half the cyclotron frequency, and the wave packets propagate in different directions.

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angles by utilizing the gyroaveraging method, Radio Science, 52, 1268–1281.

Keywords: whistler-mode chorus, oblique propagation, relativistic electrons

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Energy-consistent finite difference method for compressible magnetohydrodynamic simulations

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We propose a finite difference scheme for solving the fully compressible magnetohydrodynamic equations with the energy consistency in the discrete sense. One notable advantage of this scheme is that the conservation properties of the internal, kinetic, and magnetic energy equations can be satisfied in the discrete level without solving the total energy equation. This characteristic of the proposed scheme is achieved by carefully chosing the differentiated variables of the basic equations. The predicted conservation properties are demonstrated with linear and nonlinear numerical tests. We found that the proposed method can handle the extremely stringent problems, such as the propagation of shock wave in the ambient plasma beta of 10^{-6} or less.

Keywords: Magnetohydrodynamics (MHD), Numerical simulation, Computational fluid dynamics (CFD)

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Implementing neural network's inference into the magnetohydrodynamic simulation code

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1. Chiba University

For understanding astrophysical phenomena, magnetohydrodynamic (MHD) simulations have been powerful research tools with increasing computational capability. CANS+ is a public MHD simulation code (Matsumoto et al., 2019) and provides a suite of solvers of nonlinear MHD equations. As other modern MHD simulation codes, CANS+ employs the HLLD approximate Riemann solver and the hyperbolic divergence cleaning method, but with the fifth-order accurate reconstruction technique (MP5 scheme) for providing numerical solutions with high accuracy and stability. Because the total computational cost of CANS+ is mostly due to the reconstruction and the numerical flux calculation, improving these numerical operations remains as a task in terms of computation speeds.
Recently, the machine learning has attracted much attention in different research fields. Especially, the deep learning (or neural network, DNN) has been applied to big data analysis in our daily life and become an important computational technology. In addition, the DNN is compatible with GPUs, and it is also a research subject of high-performance computing.

We introduce this algorithm as a new alternative to the most computationally expensive parts in CANS+. These expensive operations can be replaced by the DNN inference, which is further accelerated by use of GPUs. In this study, we deal with the 1D shock tube problem and generated training data by CANS+ simulations which are initialized by randomly selected conditions. The training data size is up to 300,000 sets.
The input data for the DNN are the primitive variables in six computatinal cells, and the true label data are the numerical flux. The dataset was standardized before training. We examined three network models to achieve high accuracy, and compared each accuracy and calculation time to find the best performance model.
Model 1 predicts the flux associated with all the primitive variables by one network. Model 2 and Model 3 predicts different pairs of the numerical flux according to the transverse and longitudinal components of the MHD equations. As a result, we found the three models can predict the numerical flux with 99.99% accuracy for the validation data which was not used in the training of the networks.

In this presentation, we detail the network structure and their prediction performance for the validation data as result of hyper parameter tunings. We also show performance of the CANS+ code implemented with these networks by examining 1D simulations.

Keywords: MHD simulation, neural network, machine learning, shock tube problem

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Visualizing Magnetospheric Topology in Global 3D MHD Simulations

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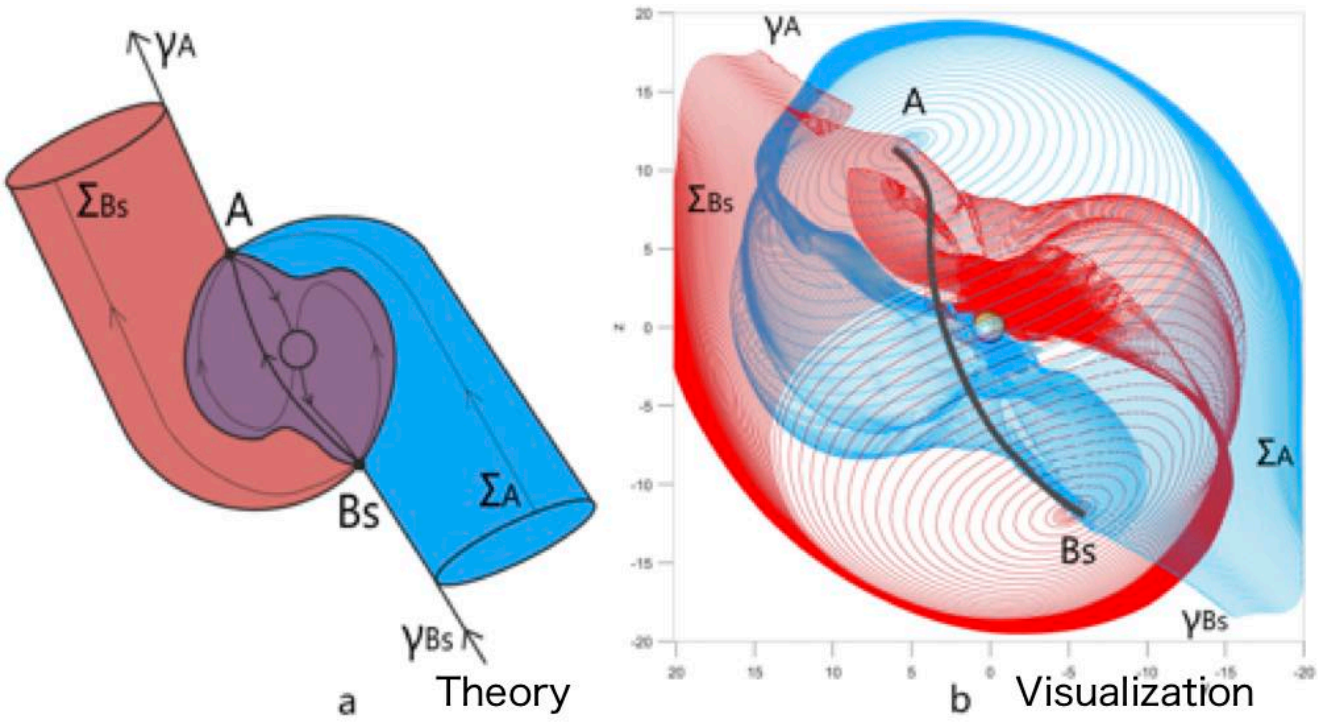
This report focuses on visualizing a global three-dimensional magnetospheric field topology. A global magnetospheric field topology can be determined by the combinations of types of nulls in the magnetic field, where all the nulls are saddle points due to the solenoidal condition, and we obtain the eigenvalues of nulls and determine the so-called saddle connections (for examples, Arnold and Silverman, 1978). We apply the visualization algorithm by Krauskopf and Osinga (1999) to visualize the global earth magnetic field topology in a northward interplanetary magnetic field (IMF) from a 3D global MHD (Magneto-Hydro-Dynamic) simulation. In so doing, we determine the two-dimensional and one-dimensional stable or unstable manifolds, respectively, are computed from the nulls found in a 3-D global MHD simulation to visualize 3D magnetospheric topology. Present results show that (i) first time, the theoretical magnetic field topology by Lau and Fin (1990) are recovered, (ii) the magnetospheric manifold spanned by the null near the north pole is very complicate than that near the south pole, (iii) the neutral line can be determined as the saddle connecting lines, and (iv) the global magnetospheric topology may lead to understanding the magnetospheric dynamics better.

Keywords: topology, saddle connection



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Plasma State inside of the Super Massive Kerr Black Hole and Problem of the Gravitational Wave Source

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1.Introduction
The motivation of the present studies has been raised by results of the related studies on Sgr A,at the center of our Galaxy, which is concluded to consist of super massive binary system whose member Kerr black holes (BH) have masses of 2.27 million and 1.94 million solar mass, orbiting with a period of 2200 sec. To accept the existence of this binary system we are required to consider a possible model, for the inside of the Kerr black hole, which prevent the propagation of the gravitational waves.
2.Relation between the Event Horizon(EH) and Distribution Limit of the Material(ML)
Though there is basic difference between EH and ML, no clear separation could be discussed in current theory of the gravitational waves from BH. We propose, however in the present study, the significance of the quasi vacuum space ,existing between EH and ML inside of Kerr black hole, that is formed by condensation of the distribution of high energy plasma inside EH by keeping the same rotation parameter a(=J/Mc for angular momentum J, Mass M, and the light velocity c) for the state EH>ML, as if EH=ML.
3.Condensation Mechanism and a Model of Plasma Distribution within ML
Condensation of plasma inside of EH is caused basically by the gravity for which we can find equilibrium state by centrifugal force and pressure gradient of high energy plasma. To keep the rotation parameter to be a constant value in the process of diminishing ML, the role of Lorentz factor that appears in angular momentum of the moving particles in plasma with velocity close to the light velocity has essential significance. We evaluate the equilibrium in a frame of local Minkowsky space time which can be found inside of the moving plasma which consists of two components; the first component has number density Nb (N:total number density, b: fractional coefficient) where element plasma particles rotate around a common axis with velocity c((1-e)^(1/2)) (e: fractional coefficient with condition e <<1) and the second component has number density N(1-b) with spherical shell like velocity distribution centered around cz (z: fractional coefficient 1>z).
4.Example of the Calculated Plasma Distribution Based on the Model within ML
For the case, of 2 million solar mass Kerr black hole, that is interested in the present study, we have calculated ML that shows 1/6 of EH as an example. For this case where EH is 2.97x10^11 cm, plasma density ,Lo; plasma number density, and mean distance d becomes Lo=3.66x10^4 g/cc, N=2.29x10^28 /cc, and d=3.52x10^(-10) cm, respectively, when we assume EH=ML. When we consider ML=(1/6)EH, however, it follows that the inside plasmas are confined within a spherical shell zone close to ML with thickness of 0.15ML; the most dense case of parameters, in this case, show that Lo=8.16x10^9 g/cc; N=5.10x10^33 /cc . The mean separation distance of ions becomes to be 5.81x10(-12) cm, for this case, which approaches to the quantum physical radius of proton, 10^(-13) cm.
5.Propagation of the Gravitational Waves and Their EH Encounter
The gravitational waves generated by accelerated motions of material region inside ML propagate in space time range between ML and EH which has 6 times wider than source range. It has been confirmed by our previous work (1) that the velocity of gravitational waves that approach the event horizon becomes zero.
6.Discussion
Observation evidences which oppose to the results of present study are reports of LIGO that show many cases of merger of the black hole binary. There are however possibilities of discussion because their

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conclusion of sources for observed gravitational waves as merger of star mass black hole binaries is based on the theories, of the generation of the gravitational waves, which have not considered effect of the event horizon on the propagating gravitational waves.
(1) https://www.terrapub.co.jp/e-library/9784887041714/index.html

Keywords: Black Hole Binary, Event Horizon, Gravitational Wave

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM16] Magnetospheric Multi Scale (MMS) mission: Accomplishments and Future Plans

convener:Yoshifumi Saito(Solar System Science Division, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency), James L Burch(Southwest Research Institute), Barbara L Giles(NASA Goddard Space Flight Center), Hiroshi Hasegawa(Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency)

NASA's Magnetospheric Multiscale (MMS) formation flying satellites have been making unprecedentedly high time resolution measurements of collisionless plasmas in and around Earth's magnetosphere since it was launched in 2015. After completing its nominal mission in 2018, MMS has continued its observations including targeting the magnetic reconnection in the Earth's magnetotail.
The major purpose of this session is to summarize the new world of electron physics that MMS has so far revealed and also to consider a future observation plan recently submitted by the mission team for the extended mission of MMS especially during the coming several years.
The collaboration with multiple missions including Geotail, Cluster II, THEMIS, Arase and other solar terrestrial probes while MMS focuses into electron scale is the key to understanding multiscale phenomena in the Earth's magnetosphere.
We solicit contributions from satellite observations, numerical simulations, laboratory observations, and theories that relate MMS observations. Contributions to the possible future observation plans are especially welcome.
This is a joint session with American Geophysical Union (AGU).
We hope this session will promote further international collaboration among Japan, United States and space physicists all over the world.

[PEM16-01] Advances in Reconnection, Acceleration and Turbulence with MMS

★Invited Papers

*James L Burch[1] (1.Southwest Research Inst.)

[PEM16-02] Observations of multi-scale wave coupling and plasma mixing in the magnetotail separatrix

★Invited Papers

*Justin C. Holmes[1], Rumi Nakamura[1], Daniel Schmid[1], Owen Wyn Roberts[1], Takuma Nakamura[1], Zoltan Vörös[1] (1.Space Research Institute)

[PEM16-03] Direct measurements of energy transfer from hot protons to EMIC waves in ULF waves at the outer magnetosphere

*Naritoshi Kitamura[1], Masafumi Shoji[2], Masahiro Kitahara[3], Takanobu Amano[1], Yoshiharu Omura[4], Satoko Nakamura[2], Yoshizumi Miyoshi[2], Hiroshi Hasegawa[5], Yuto Katoh[3], Yoshifumi Saito[5], Mariko Teramoto[7], Reiko Nomura[6], Shoichiro Yokota[8], Daniel J Gershman[9], Adolfo F Vinas[9,10], Barbara L Giles[9], Scott A Boardsen[9,11], Craig J Pollock[12], Christopher T Russell[13], Robert J Strangeway[13], Narges Ahmadi[14], Per-Arne Lindqvist[15], Robert E Ergun[14], James L Burch[16] (1.Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, 2.Institute for Space-Earth Environmental Research, Nagoya University, 3.Department of Geophysics, Graduate school of Science, Tohoku University, 4.Research Institute for Sustainable Humanosphere, Kyoto University, 5.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 6.National Astronomical Observatory of Japan, 7.Kyushu Institute of Technology, 8.Department of Earth and Space Science, Graduate School of Science, Osaka University, 9.NASA Goddard Space Flight Center, 10.Department of Physics, American University, 11.University of Maryland, 12.Denali Scientific, 13.Institute of Geophysics and Planetary Physics, University of California, Los Angeles, 14.Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, 15.Royal Institute of Technology, 16.Southwest Research Institute)

[PEM16-04] Electron Scattering and Acceleration by Whistler Waves at Collisionless Shocks

★Invited Papers

*Mitsuo Oka[1], Fumiko Otsuka[2], Shuichi Matsukiyo[2], Tai Phan[1], The MMS team (1.University of California Berkeley, 2.Kyushu University)

[PEM16-05] The relation between high-frequency whistler waves and energetic electrons in the quasi-perpendicular bow shock

Chika Umegaki[1], *Takanobu Amano[1], Naritoshi Kitamura[1], Olivier Le Contel[2], Narges Ahmadi[3], Barbara L Giles[4] (1.Department of Earth and Planetary Science, University of Tokyo, 2.Laboratoire de Physique des Plasmas, CNRS/Ecole Polytechnique/Sorbonne Université/Univ. Paris-Sud/Obs. de Paris, 3.Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, 4.NASA Goddard Space Flight Center)

[PEM16-06] Future Plans of the Magnetospheric Multiscale Mission

★Invited Papers

*Steven M Petrinec[1], James L Burch[2], Stephen A Fuselier[2,3], Michael Hesse[4], Roy Torbert[2,5], Tai D Phan[6], Barbara L Giles[7] (1.Lockheed Martin Advanced Technology Center, Palo Alto, CA USA, 2.Southwest Research Institute, San Antonio, TX, USA, 3.University of Texas at San Antonio, TX, USA, 4.University of Bergen, Bergen, Norway, 5.University of New Hampshire, Durham, NH, USA, 6.University of California, Berkeley, CA, USA, 7.NASA Goddard Space Flight Center, Greenbelt, MD, USA)

Advances in Reconnection, Acceleration and Turbulence with MMS

*James L Burch[1]

1. Southwest Research Inst.

The NASA Magnetospheric Multiscale (MMS) mission was launched in March 2015 to investigate electron-scale phenomena (magnetic reconnection, particle acceleration and turbulence) in the boundary regions of the Earth's magnetosphere. Four spacecraft in tetrahedral configuration with scale sizes of 7 - 160 km perform high time resolution plasma measurements (30 ms for electrons, 150 ms for ions), accurate 3D electric and magnetic field measurements, and energetic particles and ion composition measurements to investigate conversion of magnetic energy to charged particle energy in the electron diffusion region (EDR) of reconnection. These capabilities also allow investigation of ion diffusion regions, flux transfer events, hot flow anomalies, bow shocks, Kelvin-Helmholtz instabilities, and many other phenomena in the geospace boundary regions. A rather complete picture of asymmetric reconnection at the dayside magnetopause and the magnetosheath has been obtained. Predictions about the source of the reconnection electric field, the location of the electron stagnation region Earthward of the X-line, and the existence of electron crescent distributions in the electron diffusion region (EDR) have been confirmed and described in greater detail. New discoveries include similar crescent distributions in electron outflow jets, generation of high-frequency waves by the crescent distributions, and energy conversion occurring near the X-line only for significant guide fields while otherwise confined to the stagnation region. Observations of reconnection in the magnetotail reveal multiple electron crescent distributions as suggested by simulations, generation of high-frequency waves by the multiple crescents, electron acceleration to several hundred keV by turbulent electric fields, and reconnection rates of 0.1 - 0.2 as predicted by simulations. The tetrahedron formation will be maintained until 2022 after which different configurations (string of pearls, leader with following three-spacecraft cluster, etc.) may be used for targeted investigations. The current orbit with perigee of ~1.3 R_E, apogee of 29 R_E, and inclination of 28 deg., will be maintained.

Keywords: Magnetospheric Multiscale, Magnetic Reconnection, Particle Acceleration

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Observations of multi-scale wave coupling and plasma mixing in the magnetotail separatrix

*Justin C. Holmes[1], Rumi Nakamura[1], Daniel Schmid[1], Owen Wyn Roberts[1], Takuma Nakamura[1], Zoltan Vörös[1]

1. Space Research Institute

One of the notable features of the Magnetospheric MultiScale (MMS) mission is the four spacecraft formation that enables direct measurement of electron scale features using various reconstruction and curlometer methods. We present an example of these techniques in the separatrix region associated with an electron diffusion region encounter by MMS on July 11th 2017, where spacecraft separation was less than 20 km. The overall structure of the inflow-outflow boundary is shown with gradient reconstruction to be on ion-gyro scales with evidence for time-dependent compression of the magnetic field. Possible $\mathbf{J}\cdot\mathbf{E}$ dissipation and coupling between lower-hybrid, Buneman, and electron beam-mode waves near the magnetic peak can be inferred from curlometer measurements of current and local structure of the electric field. As in previous observations and simulations of reconnection separatrices, lower-hybrid waves appear to enable parallel, electrostatic mixing between inflow and outflow plasmas, enhanced by larger scale, time-dependent behavior of the reconnection outflow. To continue investigating these multi-scale phenomena, it is important to utilize MMS’ s unique capabilities for simultaneous observations of ion and electron scale physics in future extended mission phases.

Keywords: plasma, reconnection, separatrix, magnetotail

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Direct measurements of energy transfer from hot protons to EMIC waves in ULF waves at the outer magnetosphere

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We report the temporal variation of energy transfer from hot anisotropic protons to electromagnetic ion cyclotron (EMIC) waves during a compressional ULF wave event using the data obtained by the four MMS (Magnetospheric Multiscale) spacecraft traversing the duskside outer magnetosphere. For the ULF wave, the period was about 2-5 minutes (Pc5 frequency range), and the magnetic and ion pressures were in antiphase, such that the total pressure remained almost constant. To derive the propagation velocity of the ULF wave, we applied timing method to the filtered (0.001-0.05 Hz) magnetic field data from the four spacecraft. The derived phase velocity was ~40 km/s that was comparable to $\mathbf{E} \times \mathbf{B}$ drift velocities. Thus, they were mirror mode type structures that have zero frequency in the plasma rest flame and we can therefore investigate the spatial size of the structure from the period and the velocity. The burst ion data from Fast Plasma Investigation Dual Ion Spectrometer (FPI-DIS) with a time resolution of 150 ms are available for two of the EMIC wave events during the ULF wave. To directly detect energy transfer from hot protons to EMIC waves, we apply the Wave-Particle Interaction Analyzer (WPIA) method to the data. The energy transfer rate by cyclotron resonance was calculated as the dot product of the wave component of the perpendicular electric fields and ion current perpendicular to the magnetic field around the resonance velocity which is called the resonant current. The energy transfer rate peaked at the local minima of magnetic field intensity, which corresponds to the maxima of the ion pressure in the compressional ULF wave. This result indicates that the spontaneous EMIC wave generation is affected by ULF waves, and preferential locations for the cyclotron resonant energy transfer are magnetic field intensity troughs with the spatial size of only ~3 times of hot proton gyro-radius. In these troughs, the relatively low resonance velocity owing to small magnetic field intensities and the enhanced hot proton flux can contribute to the enhanced energy transfer from hot protons to EMIC waves by cyclotron resonance.

Keywords: MMS spacecraft, EMIC wave, Wave-particle interaction

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Electron Scattering and Acceleration by Whistler Waves at Collisionless Shocks

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Electrons are accelerated to non-thermal energies at shocks in space and astrophysical environments. While Shock Drift Acceleration (SDA) has been considered a key process of electron acceleration at collision-less shocks, it has also been recognized that SDA needs to be combined with an additional stochastic process to explain the observed power-law energy spectra. Here, we report observations of Earth’ s bow shock by the Magnetospheric Multiscale (MMS) mission and present in-situ evidence of pitch-angle scattering of non-thermal electrons by whistler waves. As the solar activity picks up in the coming years, we anticipate conjunctive, simultaneous observations of interplanetary shocks by, for example, MMS and Geotail, enabling us to further advance our understanding of electron acceleration at shocks.

Keywords: shock, particle acceleration

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The relation between high-frequency whistler waves and energetic electrons in the quasi-perpendicular bow shock

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The dissipation at the collisionless shock must be provided by nonlinear wave-particle interactions. Therefore, the generation of waves and associated heating have been the central topic of collisionless shock research. A fraction of ions that are reflected back at the shock (the reflected ions) and the strong current associated with the steep magnetic field gradient provide the primary sources of free energy that drive various kinds of instabilities. Indeed, waves at all the spatial and temporal scales (i.e., from the electron scale to MHD scale) have been observed at the Earth's bow shock. However, the relative roles played by the waves for the heating and acceleration of particles are still largely unknown.

Meanwhile, Oka et al. (2006) discovered that the so-called whistler critical Mach number regulates the non-thermal electron acceleration efficiency as quantified by the spectral index. The whistler wave is essentially a high-frequency counterpart of low-frequency Alfven waves that may have higher phase and group velocities. This thus defines the critical Mach number beyond which whistler waves of any frequency/wavenumber are no longer able to propagate upstream against the flow. The definition, therefore, considers the wave property alone and has nothing to do with particle energization. Nonetheless, Oka et al. (2006) clearly demonstrated that harder spectra were observed primarily at the super-critical regime, whereas large scatters in spectral indices, perhaps intrinsic to the solar wind, were seen at the sub-critical shocks. The observations can, in principle, be explained by considering a self-generation mechanism of high-frequency whistlers by accelerated electrons (Amano & Hoshino, 2010). The self-generated waves may then trigger the stochastic shock drift acceleration (SSDA) that leads to the formation of a power-law spectrum (Katou & Amano 2019).

In this study, we use Magnetospheric Multiscale (MMS) measurements of the bow shock to investigate the relation between the properties of high-frequency whistler waves and energetic electron production. We compare the wave properties between bow shock crossing events with efficient and inefficient energetic electron production. We found that the whistler waves observed in the efficient events were more intense and had bi-directional propagation characteristics with respect to the background magnetic field. In contrast, at least one of these properties was not satisfied with waves seen in the inefficient events. The efficient events were highly super-critical with respect to the whistler critical Mach number, whereas the inefficient events were either marginal or sub-critical. This observation implies the presence of a wave generation mechanism that becomes active only in the super-critical regime. Theoretical interpretation of the measured wave properties will be discussed.

Keywords: shock wave, plasma wave, particle acceleration

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Future Plans of the Magnetospheric Multiscale Mission

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The Magnetospheric Multiscale (MMS) mission has been extremely successful at sampling the microphysics of collisionless magnetic reconnection with unprecedented temporal and spatial multipoint resolution. As this exciting mission moves forward, changes in the MMS spacecraft configuration and evolution of the orbit provide new science opportunities. While MMS continues its prime science objective of observing the physical processes of magnetic reconnection *in situ*, additional outstanding science questions will be addressed by taking advantage of the changed orbit and spacecraft configurations, and via planned conjunctions with other active science missions. The future plans of the MMS mission are presented.

Keywords: Magnetic reconnection, Magnetopause, Magnetosphere

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM17] Space Weather and Space Climate

convener:Ryuho Kataoka(National Institute of Polar Research), Antti A Pulkkinen(NASA Goddard Space Flight Center), Kanya Kusano(Institute for Space-Earth Environmental Research, Nagoya University), Kaori Sakaguchi(National Institute of Information and Communications Technology)

We share the latest scientific papers to understand how the space environment changes in various time scales, and to discuss how we will react via international and interdisciplinary collaborations. More specifically, welcomed papers include space climate studies to reconstruct the long-term variations from radio isotopes; cutting-edge observational and modeling studies of the ionosphere, geospace, heliosphere and the sun; simulation and statistical studies to predict the future space weather and space climate; applied science such as operational space weather forecast and mitigation of the social impact due to extreme space hazards. Specific topics in 2020 will be extreme events, theoretical maxima and benchmarks for hazard assessments, and space weather and deep space human spaceflight activities at Moon and at Mars.

[PEM17-01] Thailand-Japan collaboration on the first VHF radar for plasma bubbles monitoring

★Invited Papers

*Kornyanat Hozumi[1], Takuya Tsugawa[1], Pornchai Supnithi[2], Punyawi Jamjareegulgarn[3], Yuichi Otsuka[4], Susumu Saito[5], Shinichi Hama[1], Udomsit Tangtrakunphaisan[3], Mamoru Ishii[1] (1.National Institute of Information and Communications Technology (NICT),Tokyo, Japan, 2.King Mongkut's Institute of Technology Ladkrabang, Bangkok (KMITL), Thailand, 3.King Mongkut's Institute of Technology Ladkrabang, Prince of Chumphon Campus, Chumphon, Thailand, 4.Institute for Space-Earth Environmental Research (ISEE), Nagoya University, Nagoya 464-8601, Japan, 5.National Institute of Maritime, Port and Aviation Technology, Electronic Navigation Research Institute (ENRI), Tokyo, Japan)

[PEM17-02] COSPAR/URSI International Reference Ionosphere 2020

*Dieter Bilitza[1,2] (1.George Mason University Fairfax, 2.SPDF NASA GSFC Greenbelt)

[PEM17-03] Full-scale spatial characteristics of pulsating aurora derived from color digital camera images from the International Space Station

*Sota Nanjo[1], Yuta Hozumi[1], Keisuke Hosokawa[1], Ryuho Kataoka[2,3], Yoshizumi Miyoshi[4], Shin-ichiro Oyama[2,4,5], Mitsunori Ozaki[6], Kazuo Shiokawa[4], Satoshi Kurita[4] (1.The University of Electro-Communications, 2.National Institute of Polar Research, 3.Department of Polar Science, School of Multidisciplinary Science, SOKENDAI, The Graduate University for Advanced Studies, 4.Institute for Space-Earth Environmental Research, Nagoya University, 5.Ionospheric Physics Research Unit, University of Oulu, 6.Kanazawa University)

[PEM17-04] The longterm trend of temperature in mesopause region between 1990 and 2020

*Tao Yuan[1] (1.Utah State University)

[PEM17-05] Statistical analysis of ionospheric total electron content (TEC): Estimation of extreme values in a hundred years in Japan

*Michi Nishioka[1], Susumu Saito[2], Chihiro Tao[1], Daikou Shiota[1], Takuya Tsugawa[1] (1.National Institute of Information and Communications Technology, 2.Electronic Navigation Research Institute)

[PEM17-06] Drastic time variations of transfer function of geomagnetically induced current (GIC)

*Satoko Nakamura[1,2], Yusuke Ebihara[2], Shigeru Fujita[3], Tada-nori Goto[4], Shinichi Watari[5] (1.Institute for Space-Earth Environmental Research (ISEE), Nagoya University, 2.Research Institute for Sustainable Humanosphere, Kyoto University, 3.Meteorological College, Japan Meteorological Agency/ Nationa

Institute of Polar Research, 4.Graduate School of Life Science, University of Hyogo, 5.National Institute of Information and Communications Technology)

Thailand-Japan collaboration on the first VHF radar for plasma bubbles monitoring

*Kornyanat Hozumi[1], Takuya Tsugawa[1], Pornchai Supnithi[2], Punyawi Jamjareegulgarn[3], Yuichi Otsuka[4], Susumu Saito[5], Shinichi Hama[1], Udomsit Tangtrakunphaisan[3], Mamoru Ishii[1]

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Recently, the GNSS (Global Navigation Satellite System) including GPS has been used in various situations in economy and society. It becomes an indispensable social infrastructure. As one of the GNSS, Japan operates QZSS (Quasi-Zenith Satellite System, nickname is Michibiki). Because its radio waves can reach Thailand, it is expected that Thailand can utilize various applications using Japanese QZSS. GNSS is considered as a key technology for self-driving vehicles in the future.

On the other hand, it is not generally known for the public that the "plasma bubbles", one of the phenomena of space weather, have a significant effect on the accuracy of GNSS. Plasma bubbles occur around the magnetic equator, for example in Thailand, and generally travel eastward, for example to Japan, after their generation. It is a serious problem not only in Thailand and Japan but also all over the world.

NICT and KMITL have been conducting collaborative research in the space weather field, including establishment and operation of Southeast Asia Low-latitude Ionospheric Network (SEALION) for 17 years. Based on this strong relationship, NICT and KMITL have jointly installed the VHF radar in KMITL Chumphon campus, and started its operation to observe plasma bubbles from January 2020. Chumphon is close to the magnetic equator where plasma bubbles are expected to be generated. Therefore it is one of the best places to observe plasma bubbles from their initial generation stage. The VHF radar station will augment existing SEALION stations and sensors to give more complete understanding of ionosphere and coupling to upper and lower atmosphere. The operation of the VHF radar together with the SEALION will lead to a significant progress in the use of advanced satellite-based navigation in Southeast Asia and Japan, and contribute to the further development of both Southeast Asia and Japan.

Keywords: Plasma Bubble, VHF Radar, GNSS, Space Weather, Ionosphere

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COSPAR/URSI International Reference Ionosphere 2020

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This presentation will give an overview of the current status of the International Reference Ionosphere (IRI) project and model. Shortcomings and improvements of the model were discussed during several IRI-related meetings in 2018 and 2019. We will report the outcome of these meetings and the decisions made regarding the 2020 release of IRI. IRI-2020 will include several important improvements and additions in particular a more accurate description of the electron density in the lower ionosphere, in the F-region and in the topside, and a better representation of the variability of ion temperature. We will highlight some of the ongoing activities that are geared towards future improvements of IRI. Great advances have been made in progressing IRI from the standard climate model to a model that can represent the real-time space weather changes. This is achieved by assimilating real-time ground and space data into the background IRI model. An important upcoming milestone in 2020 is the re-certification as the ISO standard for the ionosphere. The International Standardization Organization (ISO) requires this re-evaluation of a standard every five years.

We will present the latest usage statistics of the model that show the continued increase of IRI usage across many disciplines and for many applications. A good metric are the acknowledgements of IRI usage in scientific journals and the wide range of these journals.

Keywords: IRI, Ionosphere, Climatology

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Full-scale spatial characteristics of pulsating aurora derived from color digital camera images from the International Space Station

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Astronauts have been taking a large number of photographs of the Earth from the International Space Station (ISS) using digital single lens reflex (DSLR) cameras. Images obtained from this observation often contain upper atmospheric phenomena such as airglow and aurora. We have introduced a method for projecting the photographs of aurora from ISS onto the geographic coordinate system using night city lights in the images as markers [Nanjo et al., 2020, submitted]. The temporal resolution of the ISS photography is less than 1 sec with a wide field-of-view (FOV) coverage (as wide as the FOVs of multiple ground-based all-sky imagers). Besides, the FOV of the ISS photography sweeps for a long distance (4-5 hours in local time) in a short time interval (~10 min). Since the typical pulsating period of pulsating aurora (PsA) is 2-40 sec and their spatial scale ranges from a few tens to a few hundreds of km, we are able to employ the ISS photographs for investigating large-scale characteristics of spatio-temporal variations of PsA. First, we analyzed the MLT dependence of pulsating period. However, it was difficult to claim that there is a clear dependence of period on MLT for all the intervals of interest. Next, we focused on the color of aurora in the ISS image. The DSLR camera has three color channels (i.e., R, G and B). Typical greenish aurora (557.7 nm) could correspond to the G channel and the bluish band emission of nitrogen molecule (e.g., 427.8 nm) could correspond to the B channel. The electrons, responsible for the band emission of nitrogen, are known to have relatively higher energy than those causing greenish aurora. Therefore, the intensity ratio of B and G channels (B/G ratio) can be used as a proxy for the characteristics energy of precipitating electrons. We analyzed the B/G values from the ISS images for multiple events and found that the B/G value is higher 1) in the morning sector, 2) within PsA rather than within discrete aurora, 3) during ON-time of PsA than during OFF-time. These characteristics are consistent with previous findings regarding the energy of PsA electrons, which implies the feasibility of using the B/G ratio as a proxy for the energy of precipitating electrons.

Keywords: International Space Station, Digital Single Lens Reflex camera, aurora, pulsating aurora

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The longterm trend of temperature in mesopause region between 1990 and 2020

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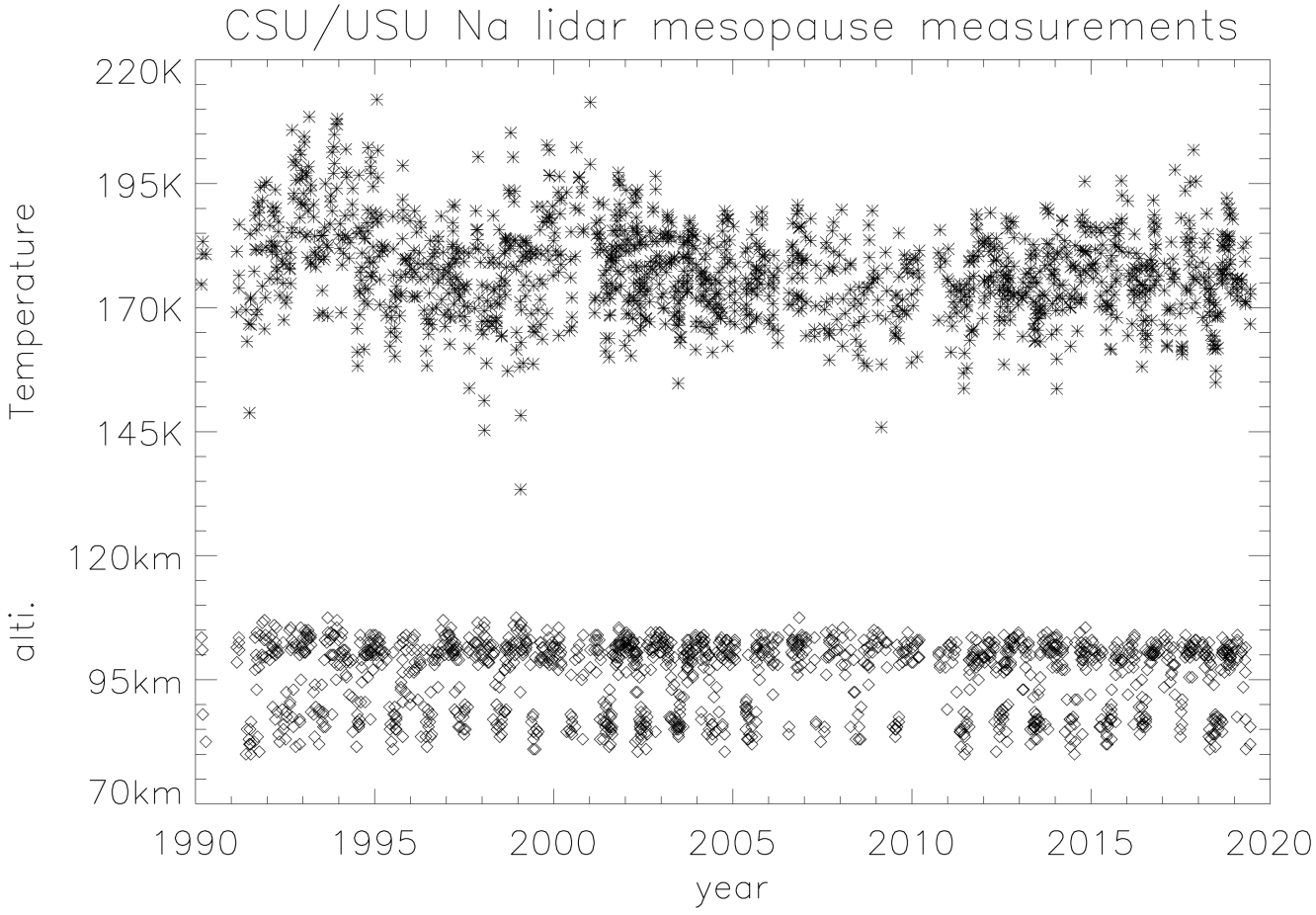
The mesopause in the upper atmosphere is a boundary between mesosphere and thermosphere with the coldest atmospheric temperature. It is formed mainly by the combining effects of radiative cooling of CO2 and the vertical adiabatic circulation in the upper atmosphere. A continuous multidecade nocturnal temperature data base of an advanced Na lidar between 1990 and 2020, obtained in USA at middle latitudes, provides an unprecedented opportunity to study the longterm variations of this important atmospheric boundary. In this paper, in addition to the temperature longterm trend in mesosphere and lower thermosphere, we focus on the longterm trend of radiative mesopause mostly during winter and dynamic mesopause during summer, including mesopause height and temperature longterm variations. A longterm study by Whole Atmosphere Community Climate Model with thermosphere and ionosphere extension also indicated the similar mesopause changes, mostly caused by stratosphere and lower mesosphere cooling and contraction.

Keywords: longterm trend, space climate, mesopause



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Statistical analysis of ionospheric total electron content (TEC): Estimation of extreme values in a hundred years in Japan

*Michi Nishioka[1], Susumu Saito[2], Chihiro Tao[1], Daikou Shiota[1], Takuya Tsugawa[1]

1. National Institute of Information and Communications Technology, 2. Electronic Navigation Research Institute

The ionospheric condition is one of the most important space weather features for users of radio-based systems, such as the Global Navigation Satellite Systems (GNSS), high frequency (HF) communication systems, and space-based remote sensing systems. Radio wave which propagates in the ionosphere experiences a delay due to the electrons in the ionosphere. Total delay is proportional to the ionospheric total electron content (TEC) through the propagation path. Therefore, ionospheric TEC is a key parameter for users of radio-based systems. The purpose of this study is to understand the extreme values of TEC in some periods, especially with a probability of once per one, ten, and a hundred years in Japan. In order to estimate the extreme values of TEC, cumulative distribution of daily TEC is derived using 22-year TEC data from 1997 to 2018. The result shows the extreme value with probabilities with once per one year and ten years are 85TECU and 110TECU, respectively at Tokyo. On the other hand, 22-year TEC data would not be enough to estimate the extreme TEC value with a probability of once per a hundred years. Therefore, we also used long-term data of ionosonde observation in addition to 22-year TEC data. Ionosonde observation has been conducted in Tokyo since 1950s. Manually scaled parameters are available from 1957 to present. We analyzed manually scaled F2 layer critical frequency (foF2) for 62 years from 1957 to 2018. First, we study the relationship between TEC and foF2 for 22 years. Then the relationship is applied for the statistical distribution of foF2 for 62 years. The extreme value of TEC with a probability once per a hundred years is estimated as about 170TECU at Tokyo.

Keywords: ionosphere, total electron content, extreme event

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Drastic time variations of transfer function of geomagnetically induced current (GIC)

*Satoko Nakamura[1,2], Yusuke Ebihara[2], Shigeru Fujita[3], Tada-nori Goto[4], Shinichi Watari[5]

1. Institute for Space-Earth Environmental Research (ISEE), Nagoya University, 2. Research Institute for Sustainable Humanosphere, Kyoto University, 3. Meteorological College, Japan Meteorological Agency/ Nationa Institute of Polar Research, 4. Graduate School of Life Science, University of Hyogo, 5. National Institute of Information and Communications Technology

Geomagnetically induced currents (GICs) flow in power grid in response to geomagnetic field variations. Because of the potential threat of power outage, GIC is regarded as one of the important aspects of space weather. We calculated the transfer function in frequency domain that describes a linear relationship between the GICs measured at 3 substations in Japan and the geomagnetic field measured at the Kakioka observatory. The transfer function is found to show a drastical time variation. For the periods at 2-10 minutes, the amplitude of the transfer function in night time is about 1 order of magnitudes larger than in day time. The day-night difference reduces for the periods >100 minutes. In addition, the amplitude of the transfer function tends to increase with local rainfall amount. These regular and irregular variations associated with local weather can be explained in terms of resistivity of earthing resistivity. The resistivity of the non-frozen soil decreases by about 40% when the temperature increases from 15˚C to 35˚C, resulting in the reduction of the earthing resistivity. Rainwater permeating into the soil also results in reduction of the earthing resistivity. Reduction of the earthing conductivity gives rise to magnification of the GICs. These results imply that a weather condition strongly affects the magnitude of GIC in Japan and challenge the conventional wisdom that the transfer function is almost steady in this time scale.

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM17] Space Weather and Space Climate

convener:Ryuho Kataoka(National Institute of Polar Research), Antti A Pulkkinen(NASA Goddard Space Flight Center), Kanya Kusano(Institute for Space-Earth Environmental Research, Nagoya University), Kaori Sakaguchi(National Institute of Information and Communications Technology)

We share the latest scientific papers to understand how the space environment changes in various time scales, and to discuss how we will react via international and interdisciplinary collaborations. More specifically, welcomed papers include space climate studies to reconstruct the long-term variations from radio isotopes; cutting-edge observational and modeling studies of the ionosphere, geospace, heliosphere and the sun; simulation and statistical studies to predict the future space weather and space climate; applied science such as operational space weather forecast and mitigation of the social impact due to extreme space hazards. Specific topics in 2020 will be extreme events, theoretical maxima and benchmarks for hazard assessments, and space weather and deep space human spaceflight activities at Moon and at Mars.

[PEM17-07] The Heliophysics Space Weather Science Application Program

★Invited Papers

*James F Spann[1], Nicola J Fox[1], James E Favors[1] (1.NASA Headquarters)

[PEM17-08] Space Weather Research Support at the National Science Foundation

★Invited Papers

*Lisa M Winter[1] (1.National Science Foundation Office of Polar Programs)

[PEM17-09] Toward cycle 25: Future perspective on space radiation environment in the inner heliopshere

★Invited Papers

*Yoshizumi Miyoshi[1], Shinsuke Imada[1], Ryuho Kataoka[2], Kanako Seki[3], Hiroko Miyahara[4], Aiko Nagamatsu[5], Daikou Shiota[6], Tatsuhiko Sato[7] (1.Institute for Space-Earth Environmental Research, Nagoya University, 2.National Institute for Polar Research, 3.The University of Tokyo, 4.Musashino Art University, 5.JAXA, 6.NICT, 7.JAEA)

[PEM17-10] Development of real-time prediction system of CME arrival and magnetic field with ensemble SUSANOO-CME simulation

*Daikou Shiota[1,4], Seiji Yashiro[2], Ryuho Kataoka[3], Kazumasa Iwai[4], Yusuke Ebihara[5] (1.National Institute of Information and Communications Technology (NICT), 2.Catholic University of America, 3.National Institute of Polar Research, 4.Institute for Space-Earth Environmental Research, Nagoya University, 5.Research Institute for Sustainable Humanosphere, Kyoto University)

[PEM17-11] A dynamical model of the heliosphere with adaptive mesh refinement

*Tomoaki Matsumoto[1], Daikou Shiota[2], Ryuho Kataoka[3], Hiroko Miyahara[4], Shoko Miyake[5] (1.Hosei University, 2.NICT, 3.National Institute of Polar Research, 4.Musashino Art University, 5.National Institute of Technology, Ibaraki College)

[PEM17-12] Validation and operation of a coronal mass ejection arrival time forecasting system using interplanetary scintillation observations

*Kazumasa Iwai[1], Daikou Shiota[2], Munetoshi Tokumaru[1], Ken'ichi Fujiki[1], Mitsue Den[2], Yuki Kubo[2] (1.Institute for Space–Earth Environmental Research (ISEE), Nagoya University, 2.National Institute of Information and Communications Technology)

The Heliophysics Space Weather Science Application Program

*James F Spann[1], Nicola J Fox[1], James E Favors[1]

1. NASA Headquarters

NASA is a mission driven agency whose science mission is focused on discovering the secrets of the universe, looking for life elsewhere, and safeguarding and improving life on Earth. Heliophysics plays a key role in every aspect of the NASA science mission, including understanding the drivers of and enabling the prediction of space weather. Heliophysics has an established research program that motivates and funds solar and space physics, which is the essence and foundation of space weather research. The Heliophysics Division has established a Space Weather Science Application Program, SWxSA. The objective of this program is to enable the transition of the knowledge and understanding of space weather to operation environments and to conduct missions that directly impact the advancement of understanding and directly enable better forecasting. We do this by partnering with sister national and international agencies, the commercial sector, and academia. SWxSA leverages relevant NASA capabilities to reach this objective, specifically the Community Coordinated Modelling Center. This talk provides an overview of SWxSA and new initiatives relevant to space weather in the NASA Heliophysics Division, and will highlight SWxSA involvement in the NASA Artemis effort to move forward to the Moon and beyond.

Keywords: space weather, heliophysics, solar and space physics

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Space Weather Research Support at the National Science Foundation

*Lisa M Winter[1]

1. National Science Foundation Office of Polar Programs

The National Science Foundation (NSF) is the only United States federal agency whose mission includes support for all fields of fundamental science and engineering, except for medical sciences. The Geospace Section is engaged in supporting advances and discoveries in space physics and space weather. It does so by stimulating research in the development of integrative geospace system models, CubeSat-based science missions, observing infrastructure, and targeted education and outreach activities. This presentation will provide an overview of current and planned programs pertaining to space weather research at NSF with emphasis on extreme space weather and storm benchmark research.

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Toward cycle 25: Future perspective on space radiation environment in the inner heliopshere

*Yoshizumi Miyoshi[1], Shinsuke Imada[1], Ryuho Kataoka[2], Kanako Seki[3], Hiroko Miyahara[4], Aiko Nagamatsu[5], Daikou Shiota[6], Tatsuhiko Sato[7]

1. Institute for Space-Earth Environmental Research, Nagoya University, 2. National Institute for Polar Research, 3. The University of Tokyo, 4. Musashino Art University, 5. JAXA, 6. NICT, 7. JAEA

During solar cycle 25, Japan and international community plan to proceed toward lunar and Marian exploration. The space radiation environment from GCR, the solar energetic particle (SEP) and the trapped particles cause serious damage of the spacecraft, the international gateway and human activity. For example, the intermittent enhancement of SEP associated with the solar flare prevent human activity on the lunar surface and causes serious damage on astronauts during the cruising phase to Mars. Therefore, understanding on the physical process of these space radiations and prediction their variability will be one of the important subjects of the space weather for upcoming cycle 25. We would like to review possible future perspective for studies on space radiation environment for solar cycle 25 by showing several examples of new observations and modeling.

Keywords: Space Weather, Cycle 25, Heliospheric Physics

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Development of real-time prediction system of CME arrival and magnetic field with ensemble SUSANOO-CME simulation

*Daikou Shiota[1,4], Seiji Yashiro[2], Ryuho Kataoka[3], Kazumasa Iwai[4], Yusuke Ebihara[5]

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The predictions of CME arrival to the Earth and the southward magnetic field brought by the CME flux ropes are one of crucial tasks for space weather forecast.
We have developed an MHD simulation of the interplanetary propagation of multiple CMEs with their internal magnetic flux ropes, called as SUSANOO-CME (Shiota & Kataoka 2016). The simulation solves propagation of solar wind and CMEs in the inner heliosphere from 25 solar radii where all the balk flow exceeds fast mode speed. The information of solar wind and CME is specified at the inner boundary with empirical and analytical models using real-time observations of the Sun and the corona.
Recently, we have been constructing a prediction system of CME impacts (CME arrival and magnetic field) utilizing SUSANOO-CME with the real-time solar observations for the purpose of use in space weather forecast in NICT. The system is capable of performing ensemble simulation with different sets of multiple CME input parameters, which is controlled from web-browser interfaces. We developed a methods to visualize results of each ensemble case and summarize time profiles of the ensemble simulations, which are also accessible through a web-browser. In this presentation, we will report the current status of the development and discuss the remaining issues and the future development.

Keywords: CME, solar wind, space weather forecast

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A dynamical model of the heliosphere with adaptive mesh refinement

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A change in the heliospheric environment plays an important role in the modulation of the galactic cosmic rays (GCRs). The magnetic field structure and the speed of the solar wind affect the GCRs transport in the heliosphere. In the previous studies, the simple Parker spiral models have been utilized for calculating the modulation of GCRs.

We have here developed a dynamical model of the heliosphere based on MHD simulations. This model is a framework for simulating the heliospheric environment that the planets are inhabiting. The model was constructed as a part of Project Gm7. We utilized the adaptive mesh refinement (AMR) code, SFUMATO, to obtain local high-resolution around the heliospheric current sheet (HCS) because the GCRs are transported efficiently in the HCS.

Recently we modified the heliospheric model several points. First, we extended the computational domain of a distance of 14 au from the Sun up to a distance of 100 au. The extension of the computational domain allows us to reproduce highly tightly winding spirals of the HCS. The AMR captures the tightly winding spirals with a relatively low numerical diffusion. Second, we improved the robustness of the numerical method. We modified the numerical scheme by solving the advection of the internal energy besides the total energy in the conservation forms of MHD equations. This modification ensures the positivity of the internal energy even for very high speed and low beta plasmas.

Keywords: Heliosphere, MHD, AMR

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Validation and operation of a coronal mass ejection arrival time forecasting system using interplanetary scintillation observations

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1. Institute for Space–Earth Environmental Research (ISEE), Nagoya University, 2. National Institute of Information and Communications Technology

Coronal mass ejections (CMEs) cause disturbances in the environment of the Earth when they arrive at the Earth. However, the prediction of the arrival of CMEs still remains a challenge. We have developed an interplanetary scintillation (IPS) estimation system based on a global magnetohydrodynamic (MHD) simulation of the inner heliosphere to predict the arrival time of CMEs. In this system, the initial speed of a CME is roughly derived from white-light coronagraph observations. Then, the propagation of the CME is calculated by a global MHD simulation. The IPS response is estimated by the three-dimensional density distribution of the inner heliosphere derived from the MHD simulation. The simulated IPS response is compared with the actual IPS observations made by the Institute for Space-Earth Environmental Research, Nagoya University, and shows good agreement with that observed.
We demonstrated how the simulation system works using a halo CME event generated by a X9.3 flare observed on September 5, 2017. We find that the CME simulation that best estimates the IPS observation can more accurately predict the time of arrival of the CME at the Earth. We have validated this system using more than 10 halo CMEs and found that the error of the arrival time is reduced to less than 5 hours by using the IPS based forecasting system. These results suggest that the accuracy of the CME arrival time can be improved if our current MHD simulations include IPS data. A part of this system has been installed in a space weather forecasting of NICT, the space weather forecasting center of Japan, and operated for the daily forecasting.

Keywords: Coronal mass ejections (CMEs), interplanetary scintillation (IPS), magnetohydrodynamic (MHD) simulation , solar wind, Heliosphere

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM17] Space Weather and Space Climate

convener:Ryuho Kataoka(National Institute of Polar Research), Antti A Pulkkinen(NASA Goddard Space Flight Center), Kanya Kusano(Institute for Space-Earth Environmental Research, Nagoya University), Kaori Sakaguchi(National Institute of Information and Communications Technology)

We share the latest scientific papers to understand how the space environment changes in various time scales, and to discuss how we will react via international and interdisciplinary collaborations. More specifically, welcomed papers include space climate studies to reconstruct the long-term variations from radio isotopes; cutting-edge observational and modeling studies of the ionosphere, geospace, heliosphere and the sun; simulation and statistical studies to predict the future space weather and space climate; applied science such as operational space weather forecast and mitigation of the social impact due to extreme space hazards. Specific topics in 2020 will be extreme events, theoretical maxima and benchmarks for hazard assessments, and space weather and deep space human spaceflight activities at Moon and at Mars.

[PEM17-13] ^{14}C during the ~660 BCE solar proton event from Japanese tree rings

★Invited Papers

*Hirohisa Sakurai[1], Fusa Miyake[2], Fuyuki Tokanai[1], Kazuho Horiuchi[3], Hiroko Miyahara[4], Kimiaki Masuda[2], Motonari Ooyama[5], Minoru Sakamoto[6], Takumi Mitsutani[7], Toru Moriya[1] (1.Faculty of Science, Yamagata University, 2.ISEE, Nagoya University,, 3.Hirosaki University, 4.Graduate School of Science and Technology, Hirosaki University, 5.Botanical Gardens, Tohoku University, 6.National Museum of Japanese History, 7.National Institutes for Cultural Heritage, Nara National Research Institute for Cultural Properties)

[PEM17-14] Variability of High Energy particle Environment associated with Solar Activities

★Invited Papers

*Shinsuke Imada[1], Daikou Shiota[2], Kazumasa Iwai[1], Takashi Minoshima[3], Haruhisa Iijima[1], Yoshizumi Miyoshi[1] (1.Institute for Space-Earth Environmental Research, Nagoya University, 2.NICT, 3.JAMSTEC)

[PEM17-15] MHD-SDE Hybrid Simulation of the Cosmic Ray Modulation

*Shoko Miyake[1], Tomoaki Matsumoto[2], Ryuho Kataoka[3,9], Tatsuhiko Sato[4], Daikou Shiota[5], Hiroko Miyahara[6], Shinsuke Imada[7], Haruka Ueno[8] (1.National Institute of Technology, Ibaraki College, 2.Hosei University, 3.National Institute of Polar Research, 4.Japan Atomic Energy Agency, 5.National Institute of Information and Communications Technology, 6.Musashino Art University, 7.Nagoya University, 8.Japan Aerospace Exploration Agency, 9.SOKENDAI)

[PEM17-16] Geosynchronous Energetic Particle Variations based on FY-2 Series Satellites Observations

*chunqin wang[1], guohong shen[1], shenyi zhang[1], huanxin zhang[1] (1.national space sciend center,CAS)

[PEM17-17] 10 years observation of charged pariticle flux with MAXI/RBM on the International Space Station

*Satoshi NAKAHIRA[1], Ryuho Kataoka[2], Haruka Ueno[1] (1.Japan Aerospace Exploration Agency, 2.National Institute of Polar Research)

[PEM17-18] Statistical Analysis of the Relation between Coronal Mass Ejections and Solar Energetic Particles

*Kosuke Kihara[1], Yuwei Huang[2], Nobuhiko Nishimura[3], Nariaki Nitta[4], Seiji Yashiro[5], Kiyoshi Ichimoto[2], Ayumi Asai[2] (1.Department of Astronomy, Kyoto University, 2.Astronomical Observatory, Kyoto University, 3.Institute for Space Earth Environmental Research, 4.Lockheed Martin Advanced Technology Center, 5.The Catholic University of America)

^{14}C during the ~660 BCE solar proton event from Japanese tree rings

*Hirohisa Sakurai[1], Fusa Miyake[2], Fuyuki Tokanai[1], Kazuho Horiuchi[3], Hiroko Miyahara[4], Kimiaki Masuda[2], Motonari Ooyama[5], Minoru Sakamoto[6], Takumi Mitsutani[7], Toru Moriya[1]

1. Faculty of Science, Yamagata University, 2. ISEE, Nagoya University,, 3. Hirosaki University, 4. Graduate School of Science and Technology, Hirosaki University, 5. Botanical Gardens, Tohoku University, 6. National Museum of Japanese History, 7. National Institutes for Cultural Heritage, Nara National Research Institute for Cultural Properties

Annual rings record the intensity of cosmic rays that had entered into the Earth’ s atmosphere. Several rapid ^{14}C increases in the past, such as the 775 CE and 994CE ^{14}C spikes, have been reported to originate from extreme solar proton events (SPEs). Another rapid ^{14}C increase, also known as the ca. 660 BCE event in German oak tree rings as well as increases of ^{10}Be and ^{36}Cl in ice cores, was presumed similar to the 775 CE event; however, as the ^{14}C increase of approximately 10‰ in 660 BCE had taken a rather longer rise time of 3–4 years as compared to that of the 775 CE event, the occurrence could not be simply associated to an extreme SPE. In this study, to elucidate the rapid increase in ^{14}C concentrations in tree rings around 660 BCE, we have precisely measured the ^{14}C concentrations of earlywoods and latewoods inside the annual rings of Japanese cedar for the period 669–633 BCE. Based on the feature of ^{14}C production rate calculated from the fine measured profile of the ^{14}C concentrations using an 11-Box model of carbon cycle, we found that the ^{14}C rapid increase occurred within 665–663.5 BCE, and that duration of ^{14}C production describing the event is distributed from one month to 3.4 years. The possibility of occurrence of consecutive SPEs over up to three years is offered.

Keywords: 14C, ~660 BCE event, SPE

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Variability of High Energy particle Environment associated with Solar Activities

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1. Institute for Space-Earth Environmental Research, Nagoya University, 2. NICT, 3. JAMSTEC

It is thought that the longer-term variations of the solar activity may affect the Earth’s climate. Therefore, predicting the next solar cycle is crucial for the forecast of the “solar-terrestrial environment”. To build prediction schemes for the next solar cycle is a key for the long-term space weather study. Recently, the relationship between polar magnetic field at the solar minimum and next solar activity is intensively discussed. Because we can determine the polar magnetic field at the solar minimum roughly 3 years before the next solar maximum, we may discuss the next solar cycle 3 years before. Further, the longer term (~5 years) prediction might be achieved by estimating the polar magnetic field with the Surface Flux Transport (SFT) model. So far, we success to predict next solar cycle by using SFT model (see Iijima et al., 2017, for detail). Further, Flare/Coronal Mass Ejection (CME), solar wind prediction study has been also largely progressed (Kusano et al., 2012, Shiota et al. 2014, Iwai et al., 2019). We believe that it is good time to try to extend our models to predict future Flare/Coronal Mass Ejection (CME) and/or Solar Energetic Particles (SEP). In this talk we will introduce what we have achieved and what we will do in the future to understand the variability of high energy particle environment associated with solar activities.

Keywords: Sun, Space weather, High energy particle

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MHD-SDE Hybrid Simulation of the Cosmic Ray Modulation

*Shoko Miyake[1], Tomoaki Matsumoto[2], Ryuho Kataoka[3,9], Tatsuhiko Sato[4], Daikou Shiota[5], Hiroko Miyahara[6], Shinsuke Imada[7], Haruka Ueno[8]

1. National Institute of Technology, Ibaraki College, 2. Hosei University, 3. National Institute of Polar Research, 4. Japan Atomic Energy Agency, 5. National Institute of Information and Communications Technology, 6. Musashino Art University, 7. Nagoya University, 8. Japan Aerospace Exploration Agency, 9. SOKENDAI

A reliable prediction of the space weather conditions on the radiation exposure caused by galactic cosmic rays (GCRs) is one of challenges topics in the field of space weather forecast. In order to understand heliospheric environments during extremely weak solar cycle such as past grand minima and the current solar cycle, we have developed a hybrid simulation model for the cosmic-ray modulation, which solves the stochastic differential equations (SDEs) describing a propagation of the GCRs in a dynamical MHD model of the heliosphere. We have calculated the dynamical model of the heliosphere with an adaptive mesh refinement technique. Space weather forecast system, SUSANOO, is imposed on the inner boundary of the dynamical model. By considering the solar wind velocity and the heliospheric magnetic field obtained from the dynamical model of the heliosphere, we have calculated the trajectories and the momentum histories of the GCRs that have a charge-sign dependence caused by the drift motion in the heliospheric magnetic field. In this presentation, we will show preliminary results of our MHD-SDE hybrid simulation for the cosmic-ray modulation during recent solar cycle.

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Geosynchronous Energetic Particle Variations based on FY-2 Series Satellites Observations

*chunqin wang[1], guohong shen[1], shenyi zhang[1], huanxin zhang[1]

1. national space sciend center,CAS

FY2 series satellites are the principal observational platforms for covering dynamic weather events and the near-earth space environment in China.High energy particle detectors carried on the satellites have provided continuous and simultaneous monitoring of the geosynchronous energetic particle environment.The energetic particle detector flown on FY2G and FY2H satellite consists of two instruments.The high energy electron instrument senses electron flux from 200keV to greater than 4MeV with eleven channels.The high energy proton instrument senses protons with seven channels from 4MeV to 300 MeV.We present several observations performed from 2015 to 2019 based on FY2G and FY2H. A precise description and preliminary analysis of particle dynamic during disturbances such as magnetic storm,sub storm and solar eruption suggests that the detector can reach an accurate response to various disturbances and can provide refined particles data. Further comparisons of particles dynamic observations with different instruments on other satellites demonstrate that the energetic particle fluxes can enter into a coherent level, yet intensive disturbances can cause great difference between observations of satellites, which can be helpful for data assimilation of multi-satellite as well as further research in more complicated magnetosphere energy particle dynamic.

Keywords: FY2 satellites, energetic protons, energetic electrons

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10 years observation of charged pariticle flux with MAXI/RBM on the International Space Station

*Satoshi NAKAHIRA[1], Ryuho Kataoka[2], Haruka Ueno[1]

1. Japan Aerospace Exploration Agency, 2. National Institute of Polar Research

High energy charged particles in lower earth orbit are considered to relate to the plasma waves of the geospace. Recently, they are attracting more attention from Arase's observations. In this research, we focused on the observatories in the exposed facility of International Space Station (ISS), which is flying the altitude around 400 km and an inclination angle of 51.6 degrees. Here we employed Radiation Belt Monitor (RBM) consists of Si PiN diode equipped on Monitor of All-sky X-ray Image (MAXI) in operation from 2009 August to now. The RBM is sensitive to electrons above 0.3 MeV and the particle trigger counts are accumulated on a one-second basis. Since it has a two field-of-view towards horizontal and zenithal directions, the RBM has a capability to measure the anisotropy. Additionally, we utilized the SEDA-AP of the same platform, operated from 2009 August to 2018 March. Standard Dose Monitor (SDOM) can measure the energy spectra for electrons of 0.28—20.01 MeV with 7-channels at every 10-second interval.

We first searched for highly variable time intervals from MAXI/RBM time series data with 1-s time cadence, obtained from 2009 August to 2019 December. We applied peak-finding method to detect local maxima. When three peaks which has prominence higher than 7-sigma within 180 seconds we identified the time intervals to be "variable".As a result we obtain about 4400 events. Showing various patterns of time variation, it sometimes changes more than 3 orders of magnitude within a few seconds. Those time variations can be produced by both intrinsic time variation of its flux and spatial structure scanned by ISS flying at a velocity of 7.7 km/s.

Then, we tried to classify them by the time variation patterns. We calculated distance (similarity) for all combinations of extracted time series by the "Dynamic Time Warping" method, and then they are grouped by the "Ward" method. Consequently, they are roughly classified into five types; (1) several ~1s width spikes over a few minutes, (2) dense ~1s width shots over a few minutes, (3) a broad peak usually with small short-time variations, (4) doubleed peak and (5) quasi-periodic fluctuations of baseline with a time scale of ~10 seconds. We will discuss the origin of these variation patterns by employing MeV electron information of SEDA-AP/SDOM. Finally, we statistically discuss the solar wind parameter dependence or geomagnetic activitiy dependence of those variable events found in 10 years.

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Statistical Analysis of the Relation between Coronal Mass Ejections and Solar Energetic Particles

*Kosuke Kihara[1], Yuwei Huang[2], Nobuhiko Nishimura[3], Nariaki Nitta[4], Seiji Yashiro[5], Kiyoshi Ichimoto[2], Ayumi Asai[2]

1. Department of Astronomy, Kyoto University, 2. Astronomical Observatory, Kyoto University, 3. Institute for Space Earth Environmental Research, 4. Lockheed Martin Advanced Technology Center, 5. The Catholic University of America

Solar energetic particles (SEPs), which originate in powerful eruptions in the solar corona, give rise to critical radiation hazards for astronauts and airline passengers, causing damages to satellites, which result in serious societal impacts. Although past studies show some relations between coronal mass ejections (CMEs) and SEP events, they have considerable scatters and it suggests that there are some unknown factors between them. In order to advance our understandings of how the properties of CMEs affect that of SEPs, we have conducted a statistical study of the relation between CMEs and SEP events. Instead of correlating SEP properties with CMEs as conduced in a majority of past studies, we started from all the 257 fast ($v > 900$ km/s) and wide (Angular width $> 60^\circ$) CMEs that occurred between December 2006 and October 2017. We detected their associated SEP events in >10 MeV protons from the three directions, GOES, STEREO-A, and STEREO-B. For the detected CME-SEP pairs, we computed three timescales of SEP events, onset time (TO), rise time (TR), and duration (TD), and correlated them with the CME speed and the longitude of the CME source location relative to the Parker spiral footpoint ($\Delta\Phi$). It is found that near the Parker spiral footpoint ($|\Delta\Phi| < 60^\circ$), TO tends to be short and negatively correlates with CME speed. The correlation between TO, TR and $\Delta\Phi$is weaker than TO, but TD and CME speeds have a positive correlation.

Keywords: Solar Energetic Particles, Coronal Mass Ejections, Space Weather

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM17] Space Weather and Space Climate

convener:Ryuho Kataoka(National Institute of Polar Research), Antti A Pulkkinen(NASA Goddard Space Flight Center), Kanya Kusano(Institute for Space-Earth Environmental Research, Nagoya University), Kaori Sakaguchi(National Institute of Information and Communications Technology)

We share the latest scientific papers to understand how the space environment changes in various time scales, and to discuss how we will react via international and interdisciplinary collaborations. More specifically, welcomed papers include space climate studies to reconstruct the long-term variations from radio isotopes; cutting-edge observational and modeling studies of the ionosphere, geospace, heliosphere and the sun; simulation and statistical studies to predict the future space weather and space climate; applied science such as operational space weather forecast and mitigation of the social impact due to extreme space hazards. Specific topics in 2020 will be extreme events, theoretical maxima and benchmarks for hazard assessments, and space weather and deep space human spaceflight activities at Moon and at Mars.

[PEM17-19] A New Parameter of Photospheric Magnetic Field to Determine Eruptive-Flare Producing Solar Active Regions

*Pei Hsuan Lin[1], Kanya Kusano[1], Daikou Shiota[2], Satoshi Inoue[1], K. D. Leka[3] (1.Institute for Space-Earth Environmental Research, Nagoya University, 2.National Institute of Information and Communications Technology (NICT), 3.NorthWest Research Associates)

[PEM17-20] Realistic MHD Modeling of delta-sunspots: How to Generate Most Violent Active Regions of the Sun

*Shin Toriumi[1], Hideyuki Hotta[2] (1.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 2.Graduate School of Science, Chiba University)

[PEM17-22] Deep Flare Net Extended to 4-Class Solar Flare Prediction

*Naoto Nishizuka[1], Komei Sugiura[1], Yuki Kubo[1], Mitsue Den[1], Mamoru Ishii[1] (1.National Institute of Information and Communications Technology)

[PEM17-23] Investigation of statistical relationships between loop structures in X-ray coronal image and CME using automatic recognition of coronal loops

*Yusuke Iida[1], Yusuke Kawabata[2], Toshifumi Shimizu[3] (1.Niigata University, 2.NAOJ, 3.JAXA/ISAS)

[PEM17-24] Determination of 3D velocity fields of disappearing and erupting solar filaments using SMART/SDDI at Hida observatory

*Nami Kimura[1], Kenichi Otsuji[1], Ayumi Asai[1], Yosuke Alexandre Yamashiki[1] (1.Kyoto University)

A New Parameter of Photospheric Magnetic Field to Determine Eruptive-Flare Producing Solar Active Regions

*Pei Hsuan Lin[1], Kanya Kusano[1], Daikou Shiota[2], Satoshi Inoue[1], K. D. Leka[3]

1. Institute for Space-Earth Environmental Research, Nagoya University, 2. National Institute of Information and Communications Technology (NICT), 3. NorthWest Research Associates

Solar flares and coronal mass ejections (CMEs) are eruptive phenomena caused by the coronal magnetic fields. In particular, large eruptive events originate in active regions (AR) with strong surface magnetic fields. However, it is still unclear what determines the capability of an AR to specifically produce eruptive flares and CMEs, and this hinders our knowledge of the initiation mechanism for the eruptive component of these phenomena. In this study, we propose a new parameter r_m to measure the possibility that a flare which occurs in an AR can be eruptive and produce a CME. The parameter r_m is defined by the ratio of the magnetic flux of twist higher than a threshold Tc to the surrounding –and specifically the overlying –magnetic flux. The value of r_m for each AR can be estimated using the nonlinear force-free field (NLFFF) extrapolation models of the coronal magnetic field. Based on the data obtained by the Solar Dynamics Observatory (SDO)/Helioseismic and Magnetic Imager (HMI), we calculated the values of r_m for 29 ARs at 51 times prior to flares larger than M5.0 class. We find that the foot-point of field lines with twist larger than 0.2 can well represent the flare ribbons, and field lines overlying and “fencing in” the highly twisted region will work to confine the eruption, generating confined flares. Discriminant function analysis shows that r_m is moderately able to discriminate those ARs which have the capability to produce eruptive flares. Regarding the events that cannot be classified according to r_m correctly, we find that there are external overlying field lines that are not captured by NLFFF extrapolation in those confined events with large r_m. This is probably one of the reasons to cause the failed classification. The other events that cannot be well classified based on r_m are also discussed in this study

Keywords: Solar Physics , CME, Solar flares, Coronal magnetic field

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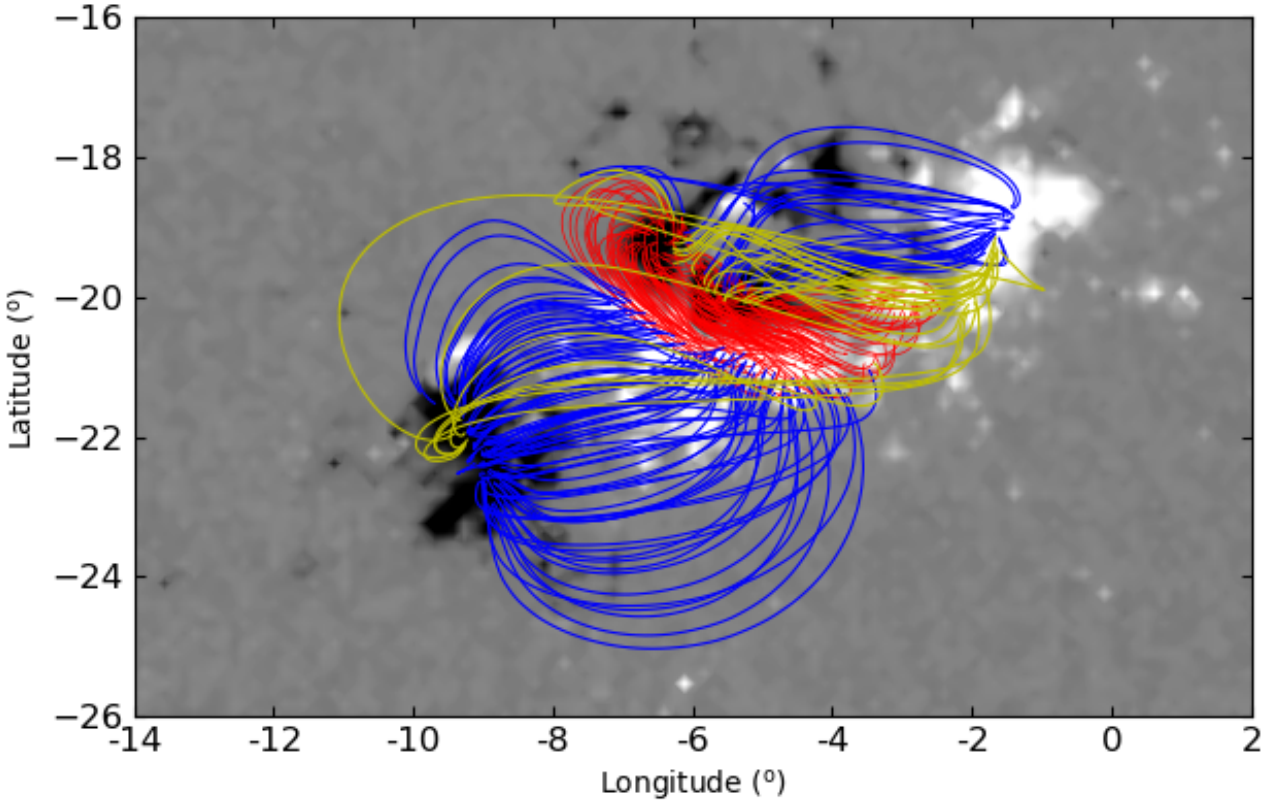

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Realistic MHD Modeling of delta-sunspots: How to Generate Most Violent Active Regions of the Sun

*Shin Toriumi[1], Hideyuki Hotta[2]

1. Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 2. Graduate School of Science, Chiba University

Observations revealed that the delta-shaped sunspots, in which opposite polarities are closely neighboring that they share a common penumbra, produce the strongest solar flares in history. In this study, for the first time, we succeed in simulating the entire process where a subsurface magnetic flux tube is elevated by the turbulent background convection and spontaneously forms delta-shaped sunspots in the photosphere, by utilizing the novel radiative MHD code R2D2, which simultaneously solves the thermal convection from the deepest convection zone to the surface layer of the Sun. We find that within the delta-spots, strongly sheared polarity inversion lines, spot rotations, and flux rope structures are built, all of which are consistent with the observations of flare-prolific active regions. In the presentation, we discuss the key roles of turbulent convection in producing the delta-spots, the most eruptive category of active regions.

Keywords: Solar flares, Coronal mass ejections, MHD simulation, Magnetic flux emergence, Sunspots

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Deep Flare Net Extended to 4-Class Solar Flare Prediction

*Naoto Nishizuka[1], Komei Sugiura[1], Yuki Kubo[1], Mitsue Den[1], Mamoru Ishii[1]

1. National Institute of Information and Communications Technology

We developed a 4-class solar flare prediction model by extending Deep Flare Net (DeFN), which is an operational model to predict flares using a deep neural network. The solar flares are classified by GOES classes (X, M, C, etc.), and, the larger amount of flare X-rays increases the ionization of ionospheric D-layer, results in greater absorption of the radio signals. The model can forecast the flare occurrence probabilities of 4 classes of flares and predict the maximum classes of flares that occur in the following 24 h after observation images. From $4x10^5$ observation images taken during 2010-2017 by Solar Dynamic Observatory, we automatically detected sunspots and calculated 79 features for each region, to which flare occurrence labels of X-, M-, and C-class were attached. We adopted the features used in Nishizuka et al. (2017) and (2018), where we added ones from database in 2016-2017: for example, line-of sight/vector magnetogram in the photosphere, coronal hot brightening at 131 A (T~10^5 K) and the X-ray and 131 A intensity data 1 and 2 h before an image. For operational evaluation, we divided the database into two for training and testing: the dataset in 2010-2015 for training and the one in 2016-2017 for testing. The DeFN model consists of deep multilayer neural networks, formed by adapting skip connections, batch normalizations and weighted cross entropy. To statistically predict flares, the DeFN model was trained to optimize the skill score, i.e., the Gandin Murphy-Gerrity score (GMGS). As a result, we succeeded in predicting flares with GMGS=0.63 for 4-class flares including X, M, C and non-flares. Furthermore, we also developed a system to visualize the impact on the HF radio communication, based on our flare prediction results.

Keywords: Solar Flare Prediction, Space Weater Forecasting, Deep Learning , Soft X-ray Emission, Operational System, HF radio communications

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Investigation of statistical relationships between loop structures in X-ray coronal image and CME using automatic recognition of coronal loops

*Yusuke Iida[1], Yusuke Kawabata[2], Toshifumi Shimizu[3]

1. Niigata University, 2. NAOJ, 3. JAXA/ISAS

We investigate the statistical relationships between the various parameters of loop structures in X-ray images taken by Hinode/XRT and coronal mass ejection using automatic recognition of loop structures.

It is known that the presence of the S-shaped loop structures (Sigmoid) in the X-ray image correlates with the occurrence of coronal mass ejection (CME). Kawabata et al. (2018) investigated 211 flare events observed by the Hinode satellites to reveal the statistical relationships between Sigmoid, flare and CME. They found that and the absence of Sigmoid has good correlation with no occurrence of CME, which mean that loop structures, especially Sigmoid, in X-ray images are probably useful for the CME prediction. However, the loop structures were automatically extracted and the Sigmoids were visually determined and it is difficult to explore the further statistical investigation. To this end, we develop the automatic recognition code of loop structures including the Sigmoid detection.

The method is developed based on the OCCULT-2 algorithm (Aschanwden+, 2010; 2013) and we change several limitations of the loop tracing algorithm for the recognition of Sigmoidal structures. The developed code is applied to the X-ray data of 211 flare events (~50,000 X-ray images) analyzed in Kawabata et al. (2018). We found the significant correlations between the absence of the Sigmoid and no occurrence of CMEs, which is confirmed by Kawabata et al. in the visual analysis. Further, it is newly found that the maximum, average and mean intensity of loop structures are DARKER in the CME occurring active regions than those in the non-CME active regions. We will show our interpretation of the result and discuss the further application for CME prediction.

Keywords: Coronal mass ejection, Solar corona, Image recognition, Big data

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Determination of 3D velocity fields of disappearing and erupting solar filaments using SMART/SDDI at Hida observatory

*Nami Kimura[1], Kenichi Otsuji[1], Ayumi Asai[1], Yosuke Alexandre Yamashiki[1]

1. Kyoto University

Solar flares, explosions on the solar surface, and associated eruptive phenomena affect the interplanetary environment, space weather, and these sometimes cause various damages on our infrastructures. Therefore, it is becoming more and more important to forecast space weather. Filament eruptions, eruptions of cool and plasmas floating in the solar corona into the interplanetary space, highly related to coronal mass ejections, and therefore, they are thought to be one of the sources of magnetic storms. However, the relation among filament eruptions, coronal mass ejections, and magnetic storms has not yet been clarified well. One of the reasons for this is the lack of accurate measurements of the velocity field of filaments and the temporal evolution. We have not been able to determine precisely whether the plasma is actually ejected into the interplanetary space. It is impossible to obtain the line of the sight velocity field of the filament plasma only by the H-alpha line center (6562.808 Angstrom) image.

The SDDI (Solar Dynamics Doppler Imager) installed in SMART (Solar Magnetic Activity Research Telescope) in Hida observatory can take the solar chromospheric full-disk dataset with 0.25 Angstrom step between -9 to +9 Angstrom centered at H-alpha line. This means that we can get a spectrum of the H-alpha line for the entire region of the filament. In this study, by applying the Beckers's “cloud model” to the filament observation at 73 wavelengths, we can detect the line of sight velocity up to 400km/s. We calculated the line of sight velocities of the filament eruption which started at 23:30UT on 2016 August 9. The filament is located at the north east limb of the sun, and ejected to become a CME. We tracked the three-dimensional morphological changes of the filament structure entirely from the pre-ejection stage to the disappearance by checking the dense part in H-alpha and AIA images by eyes. We also confirmed the magnetic structure of the erupted filament by using a magnetogram taken with Solar Dynamic Observatory (SDO) /Helioseismic and Magnetic Imager (HMI). We also compared the activities of filament eruption and CME from the aspect of the time variation of the speed and direction to obtain the detailed evolution of the filament eruption which is useful for the space weather forecast.

Keywords: space weather, filament dissapearance, filament eruption

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM18] Study of coupling processes in solar-terrestrial system

convener:Mamoru Yamamoto(Research Institute for Sustainable Humanosphere, Kyoto University), Yasunobu Ogawa(National Institute of Polar Research), Satonori Nozawa(Institute for Space-Earth Environmental Research, Nagoya University), Akimasa Yoshikawa(Department of Earth and Planetary Sciences, Kyushu University)

The Earth accepts vast input of energy and material from the Sun. The Earth's environment is maintained by the balance between their inputs and outputs. It is therefore important to study energy and mass transport on the Earth. This is an international session that discusses studies of the coupling processes in the Sun-Earth system based on the project "Study of coupling processes in solar-terrestrial system" that was approved by the Master Plan 2014/2017 of Science Council of Japan. We continue proposing the project to the Master Plan 2020. The facilities and networks included are Equatorial MU Radar (EMU) in Indonesia to study the whole equatorial atmosphere, the EISCAT_3D radar system in northern Scandinavia to study detailed structures and elementary processes of the magnetosphere-ionosphere coupling in the polar region, and global networks of various ground-based instruments and observation data. We will show the current status of the project and discuss sciences by soliciting variety papers. This session is open to the world, and we strongly encourage submission of papers related to other facilities and projects, i.e., atmospheric or incoherent scatter radars, observation networks, satellites, and simulation or theoretical studies, etc.

[PEM18-01] Study of coupling processes in the solar-terrestrial system = Current status in 2020 =

*Mamoru Yamamoto[1], Hiroyuki Hashiguchi[1], Tatsuhiro Yokoyama[1], Hiroshi Miyaoka[2], Yasunobu Ogawa[2], Kazuo Shiokawa[3], Satonori Nozawa[3], Akimasa Yoshikawa[4], Toshitaka Tsuda[1] (1.Research Institute for Sustainable Humanosphere, Kyoto University, 2.National Institute of Polar Research, 3.Institute for Space-Earth Environmental Research, 4.Graduate School of Science, Kyushu University)

[PEM18-02] Status of Equatorial MU Radar project in 2020

*Mamoru Yamamoto[1], Hiroyuki Hashiguchi[1], Tatsuhiro Yokoyama[1], Toshitaka Tsuda[1] (1.Research Institute for Sustainable Humanosphere, Kyoto University)

[PEM18-03] Current Status of the EISCAT_3D project and the Japan’s contribution

*Hiroshi Miyaoka[1], Yasunobu Ogawa[1], Satonori Nozawa[2], Koji Nishimura[1], Taishi Hashimoto[1], Shin-ichiro Oyama[2], Takuji Nakamura[1], Ryoichi Fujii[2], Craig James Heinselman[3] (1.National Institute of Polar Research, 2.Institute for Space-Earth Environmental Research, Nagoya University, 3.European Incoherent Scatter Scientific Association)

[PEM18-04] Current status of the ground-based multi-point network by the PWING Project and the Optical Mesosphere Thermosphere Imagers (OMTIs)

*Kazuo Shiokawa[1], Yuichi Otsuka[1] (1.Institute for Space-Earth Environmental Research, Nagoya University)

[PEM18-05] IUGONET data analysis system for a study of coupling processes in the solar-terrestrial system

*Atsuki Shinbori[1], Yoshimasa Tanaka[2], Norio Umemura[1], Shuji Abe[3], Satoru UeNo[4] (1.Institute for Space-Earth Environment Research (ISEE), Nagoya University, 2.National Institute of Polar Research, 3.International Center for Space Weather Science and Education (ICSWSE), Kyushu University, 4.Kwasan and Hida Observatories, Graduate School of Science, Kyoto University)

[PEM18-06] Statistical study of Sporadic Sodium Layers (SSLs) above Tromsø (2)

*Satonori Nozawa[1], Takuo T. Tsuda[2], Norihito Saito[3], Takuya Kawahara[4], Satoshi Wada[3], Yasunobu Ogawa[5], Hitoshi Fujiwara[6], Toru Takahashi[7], Tetsuya Kawabata[1], Chris Hall[8], Asgeir Brekke[8] (1.Institute

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Study of coupling processes in the solar-terrestrial system = Current status in 2020 =

*Mamoru Yamamoto[1], Hiroyuki Hashiguchi[1], Tatsuhiro Yokoyama[1], Hiroshi Miyaoka[2], Yasunobu Ogawa[2], Kazuo Shiokawa[3], Satonori Nozawa[3], Akimasa Yoshikawa[4], Toshitaka Tsuda[1]

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Energy from the sun is divided into radiation and solar wind (high-speed particles), which are maximum at the equatorial and polar regions, respectively. We study the flow of the energy and materials in the whole atmosphere by establishing following two large atmospheric radars at these singular points, and global observation network.

(1) Equatorial fountain
The energy and material flows that occur in all height regions of the equatorial atmosphere are named as "Equatorial Fountain." These processes from the bottom also cause various effects in the upper atmosphere. We establish Equatorial MU Rdar (EMU radar) in Indonesia as main instrument for the studies.
(2) Energy inputs into polar upper atmosphere and its response
The energy/particle inflow results in auroral Joule heating and ion drag of the atmosphere. The ion outflow from the polar ionosphere controls ambient plasma constituents in the magnetosphere. We will contribute the international EISCAT_3D radar project that has started in northern Scandinavia since 2017.
(3) Global network of observation and data
We develop a global observation network of compact radio and optical remote sensing equipment from the equator to polar region. Data from the observations will be archived and utilized by the data exchange framework of IUGONET.

This project was selected as one of important projects in both Masterplan 2014, 2017, and 2020. It was also selected as a new project in the roadmap 2014 by the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT). We now apply this plan to MEXT Roadmap 2020.

Keywords: coupling processes in solar-terrestrial system, SCJ Masterplan, MEXT Roadmap

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Status of Equatorial MU Radar project in 2020

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Research Institute for Sustainable Humanosphere, Kyoto University (RISH) has been studying the atmosphere and ionosphere by using radars. The first big facility was the MU (Middle and Upper atmosphere) radar installed in Shiga, Japan in 1984. This is one of the most powerful and multi-functional radar, and is successful of revealing importance of atmospheric waves for the dynamical vertical coupling processes. The next big radar was the Equatorial Atmosphere Radar (EAR) installed at Kototabang, West Sumatra, Indonesia in 2001. The EAR was operated under close collaboration with LAPAN (Indonesia National Institute for Aeronautics and Space), and conducted the long-term continuous observations of the equatorial atmosphere/ionosphere. The EAR, however, had a limited sensitivity to the MU radar as the total output power is just 1/10 to the MU radar. Our new project is to establish "Equatorial MU (EMU) Radar" just next to the EAR site in Indonesia. The EMU will have an active phased array antenna with the 163 m diameter and 1055 cross-element Yagis. Total output power of the EMU will be more than 500 kW. The EMU is the "MU radar class" facility, and can detect turbulent echoes from the mesosphere (60-80 km). In the ionosphere incoherent-scatter observations of plasma density, drift, and temperature would be possible. Multi-channel receivers will realizes radar-imaging observations. Preparation for the EMU progress in many aspect including site survey for the construction, discussion with local government, etc. In March 2019, RISH and LAPAN have 1st Internal School on Equatorial Atmosphere (ISQUAR) 2019 with more than 100 participants at Bandung, Indonesia. ISQUAR aims to promote interesting studies of the equatorial atmosphere and use of the atmospheric radar including the EMU. The EMU is one of the key element in the project "Study of coupling processes in the solar-terrestrial system" that is one of the important project in the Master Plan 2014 and 2017 of the Science Council of Japan (SCJ). The project kept the same status at the SCJ Masterplan 2020.

Keywords: equatorial atmosphere, atmosphere radar, SCJ Masterplan

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Current Status of the EISCAT_3D project and the Japan’s contribution

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The European Incoherent Scatter(EISCAT) Scientific Association with associate members from Sweden, Norway, Finland, UK, China and Japan, has officially started the construction of the 1st stage of EISCAT_3D in September 2017 toward its completion by the end of 2021, including the commissioning of the radar system. EISCAT_3D is the major upgrade of the existing EISCAT mainland radars, with a multi-static phased array system composed of one core (transmit-receive) site and 4 receive-only remote sites to provide us 50-100 times higher temporal resolution than the present system. The construction of EISCAT_3D is planned to implement by 4-staged approach, starting from the core site with half transmitting power about 5MW and 2 receiving-remote sites in Sweden and Finland as the 1st stage. At Skibotn, the core site in northern Norway, geoengineering surveys and groundworks have been almost completed with the extension of power lines and optical fiber cables. The site buildings are scheduled to be built in 2020 summer to start the installation of the radar systems.

The National Institute of Polar Research (NIPR) has been contributing in-kind to the construction of EISCAT_3D by supplying radar transmitter units in collaboration with the EISCAT scientific association and ISEE/Nagoya University. The EISCAT_3D program in Japan was successfully granted by the Science Council of Japan as one of the high-priority programs of the Master Plan 2014/2017/2020 and the Roadmap 2014 program by MEXT (Ministry), as a core facility of a comprehensive program: “Study of Coupling Processes in the Solar-Terrestrial System”. Under these positive evaluations, high energy-efficient transmitter power amplifiers (SSPAs) has been developed and provided for the engineering verification test at the EISCAT Tromso site since 2016. In February 2020, NIPR has concluded an MOU with EISCAT to supply in-kind the Subarray Transmitter Units which have been selected through the international tendering process by the EISCAT_3D project office.
In this paper, we will overview the recent progress of the project and our prospect for the contribution to the EISCAT_3D project.

Keywords: incoherent scatter radar, space weather, Arctic

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Current status of the ground-based multi-point network by the PWING Project and the Optical Mesosphere Thermosphere Imagers (OMTIs)

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The PWING project (study of dynamical variation of Particles and Waves in the INner magnetosphere using Ground-based network observations, 2016-2020) deploy all-sky airglow/aurora imagers, 64-Hz sampled induction magnetometers, 40-kHz VLF receivers, and 64-Hz riometers at 8 stations at magnetic latitudes of ~60 degree around the north-pole to cover longitudinal variation of aurora and electromagnetic disturbances in the inner magnetosphere. The Optical Mesosphere Thermosphere Imagers (OMTIs) consist of 21 all-sky cooled-CCD imagers, 5 Fabry-Perot interferometers, 3 airglow temperature photometers, and 3 meridian-scanning photometers to measure two-dimensional airglow images in the mesopause region and in the thermosphere, wind and temperatures in the lower thermosphere, and airglow rotational temperatures in the mesopause region. These PWING and OMTIs instruments are in automatic operation at various locations from high to equatorial latitudes in Canada, US (Alaska), Russia, Norway, Finland, Iceland, Japan, Thailand, Indonesia, Nigeria, and Australia. In the presentation, we introduce current status and recent major results obtained by these multi-instrument ground networks around the world. Details of the PWING project and OMTIs can be seen at http://www.isee.nagoya-u.ac.jp/dimr/PWING/PWING_web_e.htm and at http://stdb2.isee.nagoya-u.ac.jp/omti/, respectively.

Keywords: multi-point ground network, Optical Mesosphere Thermosphere Imagers, PWING Project

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IUGONET data analysis system for a study of coupling processes in the solar-terrestrial system

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The earth’ s atmosphere in a height range of more than 80 km is called the upper atmosphere, and this region is influenced by both the solar activity and the atmospheric waves propagating from the lower atmosphere. Therefore, in order to understand the physical mechanism of the short-term and long-term variations in the upper atmosphere and atmosphere-plasma interaction in this region, we need to perform an integrated analysis of various kinds of ground-based and satellite observation data taken by different technics. Since these observation data were separately being managed by each institute, it was difficult for users to effectively find and analyze them for promotion of an interdisciplinary study. To solve this problem, the Inter-university Upper atmosphere Global Observation NETwork (IUGONET) project [Hayashi et al., 2013] has been initiated in 2009, consisting of five institutes (Tohoku University, National Institute of Polar Research, Nagoya University, Kyoto University, and Kyushu University). In this project, we have added data information (metadata) for various kinds of ground-based observation data in the solar-terrestrial physics and built a practical database (IUGONET Type-A) to share them on the Internet. We have also developed several integrated data analysis tools (IUGONET Data Analysis Software: UDAS and UDAS egg: UDAS Easy Guide to Generate your load routines) as one of the functions of Space Physics Environment Data Analysis Software (SPEDAS) [Angelopoulos et al., 2019] to analyze and visualize various kinds of ground-based and satellite observation data. In the IUGONET Type-A, users can easily learn characteristics of observation data through the quick look images/plots and how to use several basic commands to visualize the data. Recently, we have added a new function of UDAS Web (ASCII Downloader) to convert CDF into ASCII files on this website so that users can easily read and analysis the observational data with their own tools. We have further started to develop the SPEDAS MATLAB software. In order to enhance an international use of these IUGONET products and to promote an interdisciplinary study of coupling processes on the sun-earth system, we have held tutorial seminars and workshops several times in Japan and foreign countries (India, Indonesia, Nigeria, Malaysia etc.). As a result, many scientific papers [e.g., Dao et al., 2017; Batubara et al., 2018; Koushik et al., 2018] and Master/Doctor theses become published by preparing an analysis environment, and the IUGONET products effectively works as an international platform. This fact suggests that the IUGONET project is in the position enough to serve the subjects of a large research project: Study of coupling processes in the solar-terrestrial system (Master Plan 2014/2017/2020, Load Map 2014) through a collaboration with other ground-based and satellite observation plans and international programs. Judging from the above situations, the common data analysis platform developed by the IUGONET project leads to new scientific results of coupling process in the solar-terrestrial system, human development and strong international cooperation to a whole equatorial region (South America, Africa) in addition to India and Indonesia in future. Therefore, it can be concluded that the IUGONET activity plays an important role in promoting the equatorial and polar atmospheric observations, international collaboration and data science (data assimilation), which are three main subjects of Master Plan (2014/2017/2020).

Keywords: Inter-university Upper atmosphere Global Observation NETwork (IUGONET), human development, International cooperation, Promotion of new scientific results of coupling

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process of the solar-terrestrial system, Integrated analysis, Database

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Statistical study of Sporadic Sodium Layers (SSLs) above Tromsø (2)

*Satonori Nozawa[1], Takuo T. Tsuda[2], Norihito Saito[3], Takuya Kawahara[4], Satoshi Wada[3], Yasunobu Ogawa[5], Hitoshi Fujiwara[6], Toru Takahashi[7], Tetsuya Kawabata[1], Chris Hall[8], Asgeir Brekke[8]

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This study is the first statistical study of SSLs differentiating in-situ generated SSLs from advected SSLs at high latitudes, and evaluates necessary conditions for generating a SSL. Based on about 3000 hours of sodium density data obtained with the Tromsø sodium LIDAR over 7 year seasons (October-March) between 2012 and 2018, we have identified 36 events of Sporadic Sodium Layer (SSL) in the polar mesosphere and lower thermosphere (MLT) region. A SSL is a thin sodium layer (about 1-2 km) with high sodium density (usually factor of 2 or more higher than that of a normal layer), and its life time is said to be about a few minutes to a few hours. Observational results of SSLs are summarized as follows: (1) SSLs appeared for shorter than 5 % of the overall observational time, confirming it is a rare event at high latitude. (2) The advent altitude distributed from 94 km to 106 km; no clear trend is found. (3) The advent time distributed from 18 LT to 1 UT: no events are found before 18 LT or later 1 LT. (4) No relationship is found between advent time and altitude. (5) The peak density tends to be lower as height increasing. (6) Lifetimes do not show a clear relationship with advent altitudes. We have investigated necessary conditions for a SSL to form in the polar MLT region. Auroral electron precipitation as well as appearance of a sporadic E layer would be one of necessary conditions to form a SSL.

By using an advantage of five directional measurements, we have derived movement velocities of SSLs using detection times (i.e., advent times) at five positions by assuming a SSL has a linear front perpendicular to the movement direction, and have compared wind velocity. The movement directions are dominantly from south-eastward to south westward except for 3 events: most SSLs moved southward in the meridional direction. Based on comparison of the velocities, we have found that 29 out of 36 events (81%) are likely classified to be advection events, while 7 events are left for candidates of in-situ generation events. We will discuss difference of “advection” and “in-situ” events in terms of height/horizontal structures of sodium densities.

Keywords: SSL, Tromsoe, Coupling between plasma and neutral particles, Sodium LIDAR

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM18] Study of coupling processes in solar-terrestrial system

convener:Mamoru Yamamoto(Research Institute for Sustainable Humanosphere, Kyoto University), Yasunobu Ogawa(National Institute of Polar Research), Satonori Nozawa(Institute for Space-Earth Environmental Research, Nagoya University), Akimasa Yoshikawa(Department of Earth and Planetary Sciences, Kyushu University)

The Earth accepts vast input of energy and material from the Sun. The Earth's environment is maintained by the balance between their inputs and outputs. It is therefore important to study energy and mass transport on the Earth. This is an international session that discusses studies of the coupling processes in the Sun-Earth system based on the project "Study of coupling processes in solar-terrestrial system" that was approved by the Master Plan 2014/2017 of Science Council of Japan. We continue proposing the project to the Master Plan 2020. The facilities and networks included are Equatorial MU Radar (EMU) in Indonesia to study the whole equatorial atmosphere, the EISCAT_3D radar system in northern Scandinavia to study detailed structures and elementary processes of the magnetosphere-ionosphere coupling in the polar region, and global networks of various ground-based instruments and observation data. We will show the current status of the project and discuss sciences by soliciting variety papers. This session is open to the world, and we strongly encourage submission of papers related to other facilities and projects, i.e., atmospheric or incoherent scatter radars, observation networks, satellites, and simulation or theoretical studies, etc.

[PEM18-07] A journey of energy from solar wind to polar ionosphere as viewed from global MHD simulation

★Invited Papers

*Yusuke Ebihara[1], Takashi Tanaka[2] (1.Research Institute for Sustainable Humanosphere, Kyoto University, 2.International Center for Space Weather Science and Education, Kyushu University)

[PEM18-08] Review of the mid-latitude SuperDARN and the future of the SuperDARN

*Nozomu Nishitani[1] (1.Institute for Space-Earth Environmental Research, Nagoya University)

[PEM18-09] Investigation of global electromagnetic coupling from polar to equatorial ionosphere

*Akimasa Yoshikawa[1], Hideaki Kawano[1], Shuji Abe[2], Teiji Uozumi[2], Akiko Fujimoto[4], Akihiro Ikeda[5], Taisei Kabasawa[3], Satoshi Kuroki[3], Moe Hayashi[3], Takayama Kumi[3], Aoi Nakamizo[6], Shinichi Ohtani[7] (1.Department of Earth and Planetary Sciences, Kyushu University, 2.International Center for Space Weather Science and Education, Kyushu University, 3.Graduate school of Earth and Planetary Sciences, Kyushu University, 4.Faculty of Computer Science and Systems Engineering, Kyushu Institute of Technology , 5.National Institute of Technology Kagoshima College, 6.National Institute of Information and Communications Technology, 7.APL/JHU)

A journey of energy from solar wind to polar ionosphere as viewed from global MHD simulation

*Yusuke Ebihara[1], Takashi Tanaka[2]

1. Research Institute for Sustainable Humanosphere, Kyoto University, 2. International Center for Space Weather Science and Education, Kyushu University

The Sun emits different forms of energy to interplanetary space. The most significant form is the solar electromagnetic radiation that arrives at Earth's atmosphere directly. The second and third ones are the solar wind kinetic energy and the magnetic energy of the interplanetary magnetic field (IMF), which are the ultimate sources of the energy consumed in the polar ionosphere. Despite of numerous studies, the pathway and the conversion of the solar wind energy (including the solar wind kinetic energy and the magnetic energy of IMF) into the polar ionosphere are not well-known. The results obtained by the global magnetohydrodynamics (MHD) simulation suggest that the development of dynamo is a key in understanding the energy transfer and conversion. When the solar wind is supersonic, the first dynamo appears in the bow shock, which converts the solar wind kinetic energy to the internal energy and the magnetic energy. When the IMF is southward, the second dynamo appears in the mantle region, which converts the internal energy to the kinetic energy and the magnetic energy. The mantle dynamo is closely associated with the generation of the Region 1 field-aligned currents (FACs). A line integral of the Poynting flux, which is called a S-curve, shows a spiral with its center moving toward the polar ionosphere. The spiral shape is a manifestation of the magnetospheric convection, and the earthward displacement is caused by a twist of the flux tube associated with the FACs. When the near-Earth reconnection takes place in the plasma sheet, the third dynamo appears in the inner magnetosphere, which generates Region 1-sense FACs known as substorm current system. The fourth dynamo appears in the low-altitude magnetosphere when the ionospheric Hall current is partially blocked. The upward FAC associated with the forth dynamo is related to the westward traveling surge in the MHD simulation. However, the upward FAC is connected to the divergent (not convergent) Pedersen current, which is different from conventional wisdom. The EISCAT_3D observations are expected to resolve this problem, and provide insightful information about the interface between the magnetosphere and the ionosphere during the transient phenomena, such as an auroral expansion.

Keywords: Solar wind-magnetosphere-ionosphere coupling, MHD simulation

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Review of the mid-latitude SuperDARN and the future of the SuperDARN

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1. Institute for Space-Earth Environmental Research, Nagoya University

The Super Dual Auroral Radar Network (SuperDARN) is a powerful tool for monitoring ionospheric plasma convection and electron density changes. The SuperDARN began its official operation in 1995 For the first few years, the SuperDARN field of view (FOV) was limited to high latitudes. About ten years later, the first purpose-built mid-latitude SuperDARN radars started operation at sites in Virginia and Hokkaido in 2005 and 2006, respectively. Subsequent construction of additional radars at mid-latitudes have greatly expanded the SuperDARN FOV, and made accessible a range of research topics that are distinctive to the subauroral and mid-latitude ionosphere. In this paper we review the accomplishments of the mid-latitude SuperDARN in several scientific and technical areas, as well as the history of the mid-latitude SuperDARN. We also discuss the future directions of the SuperDARN, including the expansion of SuperDARN FOV to even lower latitudes up to the equatorial region.

Keywords: SuperDARN, mid-latitude, low-latitude

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Investigation of global electromagnetic coupling from polar to equatorial ionosphere

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Kyushu university group operates global geomagnetic field observation through MAGDAS project and electric field observation by using multi-point FM-CW Radar from polar to equatorial ionosphere. Based on these observational data, we investigate global electromagnetic coupling from polar to equatorial ionosphere, including magnetosphere-ionosphere coupling at polar region, formation of global ionospheric current system, vertical coupling between atmosphere and ionosphere, day-side and night-side electromagnetic coupling of plasma dynamics around dip equator, global distribution of ULF pulsations, diagnoses of plasma sphere by using FLR. We are also working on theoretical research for clarifying above electromagnetic coupled system, and feed-back effect of ionospheric dynamics to magnetospheric dynamics . In this talk, we will introduce progress and new direction of our research project.

Keywords: Polar equatorial electromagnetic coupling, atmosphere-ionosphere-magnetosphere vertical coupling, global obserbation

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM18] Study of coupling processes in solar-terrestrial system

convener:Mamoru Yamamoto(Research Institute for Sustainable Humanosphere, Kyoto University), Yasunobu Ogawa(National Institute of Polar Research), Satonori Nozawa(Institute for Space-Earth Environmental Research, Nagoya University), Akimasa Yoshikawa(Department of Earth and Planetary Sciences, Kyushu University)

The Earth accepts vast input of energy and material from the Sun. The Earth's environment is maintained by the balance between their inputs and outputs. It is therefore important to study energy and mass transport on the Earth. This is an international session that discusses studies of the coupling processes in the Sun-Earth system based on the project "Study of coupling processes in solar-terrestrial system" that was approved by the Master Plan 2014/2017 of Science Council of Japan. We continue proposing the project to the Master Plan 2020. The facilities and networks included are Equatorial MU Radar (EMU) in Indonesia to study the whole equatorial atmosphere, the EISCAT_3D radar system in northern Scandinavia to study detailed structures and elementary processes of the magnetosphere-ionosphere coupling in the polar region, and global networks of various ground-based instruments and observation data. We will show the current status of the project and discuss sciences by soliciting variety papers. This session is open to the world, and we strongly encourage submission of papers related to other facilities and projects, i.e., atmospheric or incoherent scatter radars, observation networks, satellites, and simulation or theoretical studies, etc.

[PEM18-11] Comparison of FM-CW Ionosonde and MAGDAS observations with S4 index in Peru during 15-18 March 2019

*Akiko Fujimoto[1], Akimasa Yoshikawa[2], Akihiro Ikeda[3], Shuji Abe[2], Moe Hayashi[2] (1.Kyushu Institute of Technology, 2.Kyushu University, 3.National Institute of Technology, Kagoshima College)

[PEM18-12] **Complimenting regional GPS-TEC computerized ionospheric tomography (CIT) with ionosonde data assimilation**

*Nicholas Ssessanga[1], Mamoru Yamamoto [1], Susumu Saito[2], Akinori Saito[3], Michi Nishioka[4] (1.RISH , 2.ENRI, 3.Kyoto Univ., 4.NICT)

[PEM18-13] A study of equatorial plasma bubble structure using VHF radar and GNSS scintillations over the low-latitude region

*Acharaporn Bumrungkit[1], Susumu Saito[2], Pornchai Supnithi[1] (1.King Mongkut's Institute of Technology Ladkrabang (KMITL), 2.Electronic Navigation Research Institute (ENRI), National Institute of Maritime, Port, and Aviation Technology (MPAT))

[PEM18-14] **Evolution of a Mesospheric Bore in a Duct Observed by Ground-Based Double-Layer Imagers and Satellite Observations Over the Tibetan Plateau Region**

*Qinzeng Li[1], Jiyao Xu[1], Jia Yue[2], Xiao Liu[3], Wei Yuan[1] (1.State Key Laboratory of Space Weather, National Space Science Center, Chinese Academy of Sciences, Beijing, China, 2.Department of Atmospheric and Planetary Sciences, Hampton University, Hampton, Virginia, USA, 3.School of Mathematics and Information Science, Henan Normal University, Xinxiang, China)

[PEM18-15] Discussion 1

*Mamoru Yamamoto[1] (1.Research Institute for Sustainable Humanosphere, Kyoto University)

[PEM18-16] Discussion 2

*Mamoru Yamamoto[1] (1.Research Institute for Sustainable Humanosphere, Kyoto University)

Comparison of FM-CW Ionosonde and MAGDAS observations with S4 index in Peru during 15-18 March 2019

*Akiko Fujimoto[1], Akimasa Yoshikawa[2], Akihiro Ikeda[3], Shuji Abe[2], Moe Hayashi[2]

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An FM-CW (Frequency Modulated Continuous Wave) radar is a type of HF (High Frequency) radar. We have installed three FM-CW stations along the Japanese longitude, at Japan, Russia and Philippine, in order to measure the electric fields that penetrate the ionosphere (Yumoto, 2006). One of the FM-CW project goals is to understand the relationship between Equatorial Electrojet (EEJ) and the generation mechanism of the Equatorial Spread F (ESF) associated with Equatorial Plasma Bubbles (EPBs). The ionospheric plasma-density irregularities, especially ESF, could result in the scintillation of trans-ionospheric GNSS/GPS signals. The study on the generation mechanisms of ESF is the important issue to estimate the occurrence of the ionospheric scintillation for the safety human activity using the space region. The abnormal magnetic field variation along the magnetic equator, EEJ, is reported to be associated with the ESF.

In 2018, we installed a new FM-CW radar at Sicaya Observatory in Peru. ICSWSE (International Center for Space Weather Science and Education, Kyushu University) also has the ground-based magnetometer network (MAGDAS) on the world including Peru MAGDAS chain. The Sicaya FM-CW observation will give the opportunity of the simultaneous ionospheric observation, the geomagnetic field variation recorded by MAGDAS system at Huancayo and the GPS scintillation status given by S4 index operated by IGP (The Geophysical Institute of Peru).

During 15-18 March 2019, we have the high-time resolution (every 3 minutes) Ionosonde campaign observation in Sicaya. The geomagnetic activity was the weak disturbed with Dst index -41 nT at 12:00 UT on 17 March 2019. The amplitude of EEJ was smaller than the normal EEJ variation and the depressed EEJ structure was recorded at the Sicaya in the evening sector on 17 March with the high S4 value at Brazil (where is located on the east side from Sicaya). The Sicaya Ionogram shows the long-term ESF on 17 March with the couple hours. We will demonstrate the comparison of Ionospheric irregularities with the magnetic activity in the equatorial region for the GPS scintillation.

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Complimenting regional GPS-TEC computerized ionospheric tomography (CIT) with ionosonde data assimilation

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The accurate probing of the three-dimensional (3-D) structure of the ionosphere endures a unique set of challenges that include for example high campaign costs, poor distribution of instruments and collected data, and geometric limitations. To remedy these challenges, over the East-Asian sector (covering 110°–160°E and 10°–60°N, and extending from 80 to 20,000 km in altitude) a near real-time regional 3-D computerized ionospheric tomography (CIT) technique has been developed using a plethora of GPS (Global Positioning System) observations of total electron content. A validation of the CIT results using ionosonde and occulation data shows the technique adequately reconstructs the regional ionosphere vertical structure, however, with room for improvement in estimating the peak height and avoiding physically unrealistic negative densities in the final solution. This paper presents preliminary results from a technique that addresses these problems, by incorporating CIT results into a data assimilation (DA) technique. The DA technique adds ionosonde bottomside measurements into CIT results, thereby improving the accuracy of the reconstructed peak height and bottomside 3-D structure. Further, we assume that ionosphere electron densities are better described by probability log-nomal distribution, which introduces the non-negativity constraint.

Keywords: Ionosphere, Tomography, Data assimilation , GPS-TEC, Ionosonde

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A study of equatorial plasma bubble structure using VHF radar and GNSS scintillations over the low-latitude region

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The ionospheric irregularity can cause the deleterious effects on the signal in space, such as global navigation satellite system (GNSS) signals. In low-latitude region, the irregularity of the electron density in the ionosphere frequently occurs, which is called the equatorial plasma bubble (EPB). The amplitude GNSS scintillations are caused by the Fresnel diffraction with the irregularities 300 to 500 meters scale sizes depending on the wavelengths corresponding to the signal frequency, which are L1 (1575.4 MHz), L2 (1227.6 MHz), and L5 (1176.45 MHz). The ionospheric irregularity with spatial scale sizes of a few meters associated with EPBs have been detected by VHF band. Multi-beam observations by a VHF radar can show precise spatial structures of EPBs. In this work, we aim to achieve a better understanding of the EPB effects on the multi-frequency GNSS signals by analyzing the amplitude scintillation index (S4) and relate it with the EPB structures. The multi-constellation and multi-frequency (MC/MF) GNSS scintillation receiver which is installed at Kototabang (geographic; 0.20S, 100.32E) is utilized to observe the signals from GPS and Galileo constellations at the frequencies of L1 and L5. The Equatorial Atmosphere Radar (EAR) which is located at the same site and operated at 47.0 MHz is used to detect the EPB structures. We compare the EPB structures shown by the EAR with the S4 indices at each ionospheric pierce points (IPPs) of GNSS signals. Figure 1 shows the spatial distribution of EAR echoes which are mapped at a certain altitude of 350 kilometers and the GNSS IPPs with S4 indices which are mapped from the altitudes of 250 (the black dots) and 350 (the red dots) kilometers to the same altitude of the EAR echoes. With this result, the three-dimensional relationship between the EPB structure and GNSS signal paths can be found. We consider inside the echo area, the S4 value of GPS satellite (G26) is equal to 0.07 and Galileo (E30) is 0.13. In this case, the signal of the G26 passes through only the lower portion of the EPB, which would be considered as the reason why the S4 enhancement is not significant but just noticeable. Further detailed analysis of the S4 enhancements of MC/MF GNSS signals with EPB structures will be presented at the meeting.

Keywords: Equatorial plasma bubble, Scintillation, VHF radar

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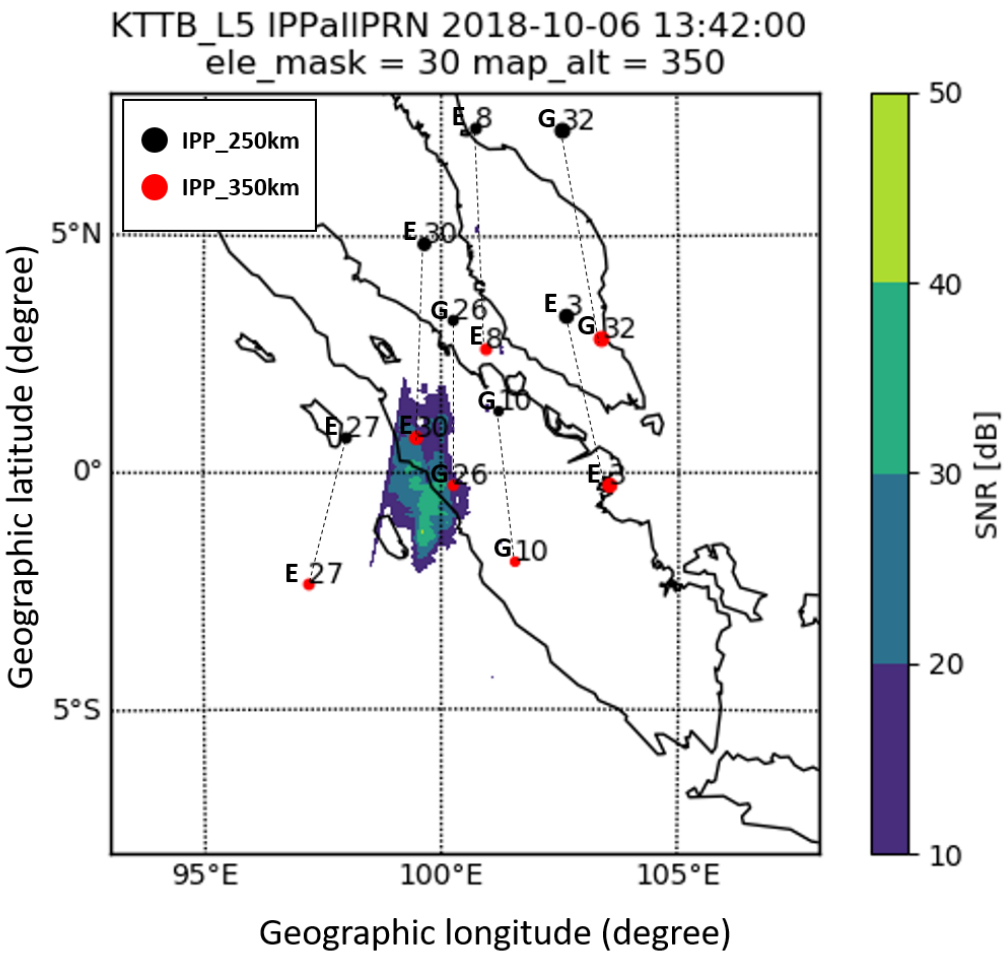

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Evolution of a Mesospheric Bore in a Duct Observed by Ground-Based Double-Layer Imagers and Satellite Observations Over the Tibetan Plateau Region

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A mesospheric bore event was observed in the airglow layers of both OH and OI (557.7 nm) bands by two all-sky airglow imagers in Lhasa (29.66ºN, 90.98ºE) on the Tibetan Plateau and the Day Night Band (DNB) of the Visible Infrared Imaging Radiometer Suite (VIIRS) onboard the Suomi National Polar-orbiting Partnership (NPP) satellite on the night of 16–17 December 2014. Simultaneous temperature and OH intensity observations from the SABER instrument onboard the TIMED satellite and wind measurement by a Doppler meteor radar were used to characterize the environment of the bore propagation. A large mesospheric inversion layer was identified from the temperature measured by the SABER instrument. The observed winds in the height range of the OH layer were almost orthogonal to the propagation direction of the mesospheric bore. Both hydraulic jump theory and observations showed that the duct initially shrank followed by an expansion. The duct mainly existed in the OH layer but was weak in the OI layer, as revealed by the double-layer imaging and satellite observations. The horizontal wavelengths and observed phase speeds of the bore packet decreased as the duct shrank and increased as the duct expanded. The intensity amplitude of the bore packet decreased slowly and then decreased sharply after dissipation. With the variation of the depth of the duct, the bore may have leak out of the duct. The presented study advances the understanding of mesospheric bore evolution and how the ducted environment influences the propagation of the bore.

Keywords: airglow, middle and upper atmosphere, mesospheric bore

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Discussion 1

*Mamoru Yamamoto[1]

1. Research Institute for Sustainable Humanosphere, Kyoto University

We discuss topics of the project "Study of coupling processes in solar-terrestrial system".

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Discussion 2

*Mamoru Yamamoto[1]

1. Research Institute for Sustainable Humanosphere, Kyoto University

We discuss topics of the project "Study of coupling processes in solar-terrestrial system".

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM19] Dynamics of the Inner Magnetospheric System

convener:Kunihiro Keika(Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo), Aleksandr Y Ukhorskiy(Johns Hopkins University Applied Physics Laboratory), Yoshizumi Miyoshi(Institute for Space-Earth Environmental Research, Nagoya University), Lynn M Kistler(University of New Hampshire Main Campus)

The inner magnetosphere is highly variable because dynamical
variations of incoming energy from the solar wind, magnetospheric tail,
and the ionosphere. Cross-regional/cross-scale/cross-energy couplings
are key processes to understand this dynamical system, and coordinated
observations by multi-satellites and ground-based observations are
very essential to reveal these processes. In the 24th solar cycle,
a number of satellites such as Van Allen Probes, MMS, THEMIS, DSX and
Arase, coordinated ground-based observations (THEMIS-GBO, SuperDARN,
EISCAT, magnetometers, riometer, etc), and numerical simulations
(global kinetic model, MHD model, micro PIC, hybrid simulations) have
successfully investigated the inner magnetosphere system. Papers on recent results
on the inner magnetosphere and/or its coupling with the other regions,
including the ionosphere and the outer magnetosphere are invited. And
presentations on new projects for the inner magnetosphere are also
welcome.

[PEM19-01] Solar wind as a Source of Magnetospheric Plasma

★Invited Papers

*Robert Colby Allen[1], Sarah K Vines[1], Stefano A Livi[2], Don G Mitchell[1], Chris P Paranicas[1], Kareem Sorathia[1], Sam Bingham[1] (1.Johns Hopkins University Applied Physics Laboratory, 2.Southwest Research Institute)

[PEM19-02] Magnetic field dipolarization and low-energy O^+ ion flux variations in the inner magnetosphere observed by Arase

*Masahito Nose[1], Ayako Matsuoka[2], Yoshizumi Miyoshi[1], Kazushi Asamura[2], Mariko Teramoto[3], Tomoaki Hori[1], Iku Shinohara[2] (1.Institute for Space-Earth Environmental Research, Nagoya University, 2.Research Division for Space Plasma, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 3.Kyushu Institute of Technology)

[PEM19-03] Jupiter's plasma circulation and particle precipitation associated with the inner magnetosphere probed with the Hisaki satellite

★Invited Papers

*Tomoki Kimura[1], Fuminori Tsuchiya[1], Chihiro Tao[2], Kazuo Yoshioka[3], Hajime Kita[4], Go Murakami[4], Atsushi Yamazaki[4], Reina Hikida[3], Fumiharu Suzuki[3], Ryoichi Koga[1], George Clark[5], Zhonghua Yao[6], Yasutaka Hiraki[7], Fran Bagenal[8], Peter Delamere[9], Keiichiro Fukazawa[10], Ichiro Yoshikawa[3], Masaki Fujimoto[4], Hisaki Science team (1.Tohoku University, 2.NICT, 3.University of Tokyo, 4.JAXA/ISAS, 5.Johns Hopkins University / Applied Physics Laboratory, 6.Liege University , 7.Advanced Knowledge Laboratory, Inc., 8.University of Colorado Boulder, 9.University of Alaska Fairbanks, 10.Kyoto University)

[PEM19-04] Cold ions perpendicularly heated by fast magnetosonic waves in the inner magnetosphere observed by Arase (ERG) satellite

*Kazushi Asamura[1], Masafumi Shoji[2], Yoshizumi Miyoshi[2], Ryosuke Fujii[2], Atsushi Miyazaki[2], Yasumasa Kasaba[3], Yoshiya Kasahara[4], Ayako Matsuoka[1], Vania Koleva Jordanova[5] (1.ISAS/JAXA, 2.Nagoya U., 3.Tohoku U., 4.Kanazawa U., 5.LANL)

[PEM19-05] Magnetosonic waves driven by proton ring distributions in the Martian magnetosphere

★Invited Papers

*Yuki Harada[1], Suranga Ruhunusiri[2], Jasper S Halekas[2], Jared R Espley[3], Gina A DiBraccio[3], James P McFadden[4], David L Mitchell[4], Christian Mazelle[5], Glyn Collinson[3], David A Brain[6], Takuya Hara[4], Masahito Nose[7], Oimatsu Satoshi[1], Kazuhiro Yamamoto[1], Bruce M Jakosky[6] (1.Graduate School of Science, Kyoto University, 2.Department of Physics and Astronomy, University of Iowa, 3.NASA Goddard Space Flight Center, 4.Space Sciences Laboratory, University of California, Berkeley, 5.IRAP, University of Toulouse, CNRS, UPS, CNES, 6.LASP, University of Colorado at Boulder, 7.ISEE, Nagoya Univ)

Solar wind as a Source of Magnetospheric Plasma

*Robert Colby Allen[1], Sarah K Vines[1], Stefano A Livi[2], Don G Mitchell[1], Chris P Paranicas[1], Kareem Sorathia[1], Sam Bingham[1]

1. Johns Hopkins University Applied Physics Laboratory, 2. Southwest Research Institute

Understanding the sources and subsequent evolution of plasma within a planetary magnetosphere holds intrinsic importance for magnetospheric dynamics. For example, the balance of endogenic and solar wind plasma can be used to study the relative importance of different solar wind-magnetosphere interactions (e.g., magnetic reconnection versus Kelvin-Helmholtz instabilities) as a source of magnetospheric plasma, which can provide insight into the properties and evolution of certain planetary magnetospheres. Recent observational studies have utilized ion charge state composition to determine when and where solar wind ion populations can access a magnetosphere. These populations have subsequently been observed within injection events, bringing these solar wind-originating particles to within geosychronous orbit. Additionally, recent global modeling of the Earth system has explored the various possible pathways of solar wind entry through the use of test particle simulations. Together these studies have found that solar wind-originating plasma enters the magnetosphere through both magnetic reconnection and Kelvin-Helmholtz instabilities, as well as through cusp dynamics, and can subsequently reach the inner magnetospheric region. This presentation will focus on observational and modelling results investigating these pathways of solar wind access to the magnetosphere, and the resulting effect on magnetospheric ion composition in the inner magnetosphere.

Keywords: Plasma, Composition, Magnetosphere

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Magnetic field dipolarization and low-energy O^+ ion flux variations in the inner magnetosphere observed by Arase

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1. Institute for Space-Earth Environmental Research, Nagoya University, 2. Research Division for Space Plasma, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 3. Kyushu Institute of Technology

Recent studies employing the Van Allen Probes [Chaston et al., 2015; Nosé et al., 2016; Gkioulidou et al., 2019] have shown that unidirectional/bidirectional energy-dispersed O^+ flux appears a few minutes after substorms in the inner magnetosphere and lasts for ~10 min with a decrease in its energy from ~5 keV to 10–100 eV. Nosé et al. [2016] found that the unidirectional energy-dispersed O^+ flux is observed in 80% of the total events and that its direction is parallel (antiparallel) to the magnetic field when the Van Allen Probes are located below (above) the geomagnetic equator. This strongly implies that these O^+ ions are extracted from the ionosphere at the onset of substorms and flow along the magnetic field toward the geomagnetic equator. Low-energy O^+ ions may be scattered near the geomagnetic equator and remain there, although the scattering mechanism is yet unknown. They will contribute to the O^+ content of the inner magnetospheric plasma, and the resultant increase in the O^+ density may provide a precondition for the O^+-rich ring current.

In the present study, we examine the low-energy O^+ ion flux variations observed by the Arase satellite in the inner magnetosphere. Magnetic field dipolarization is selected from the magnetic field data obtained by the fluxgate magnetometer (MGF) [Matsuoka et al., 2018] in the period of April 1–October 31, 2017 and July 1, 2018–January 31, 2019, and we find 243 events. Data from the low-energy particle experiments–ion mass analyzer (LEPi) [Asamura et al., 2018] are examined to check if the selected dipolarization events are accompanied by low-energy O^+ ion flux variations in the direction along the local magnetic field. There are some events of the low-energy O^+ ion flux enhancement, which (1) starts ~10 minutes after the dipolarization onset, (2) has energy-dispersed signatures with decreasing energy down to a few 10s of eV, (3) appears down to L ~ 4 with the lowest energy (10 eV), (4) can be observed in both storm and non-storm periods, and (5) has a field-aligned distribution (α ~ 0° below the equator and α ~ 180° above the equator). In the presentation, we will show the analysis results in more detail and discuss their contribution to the O^+ content of the inner magnetospheric plasma.

Keywords: Inner magnetosphere, Substorm, Ion composition

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Jupiter’s plasma circulation and particle precipitation associated with the inner magnetosphere probed with the Hisaki satellite

*Tomoki Kimura[1], Fuminori Tsuchiya[1], Chihiro Tao[2], Kazuo Yoshioka[3], Hajime Kita[4], Go Murakami[4], Atsushi Yamazaki[4], Reina Hikida[3], Fumiharu Suzuki[3], Ryoichi Koga[1], George Clark[5], Zhonghua Yao[6], Yasutaka Hiraki[7], Fran Bagenal[8], Peter Delamere[9], Keiichiro Fukazawa[10], Ichiro Yoshikawa[3], Masaki Fujimoto[4], Hisaki Science team

1. Tohoku University, 2. NICT, 3. University of Tokyo, 4. JAXA/ISAS, 5. Johns Hopkins University / Applied Physics Laboratory, 6. Liege University , 7. Advanced Knowledge Laboratory, Inc., 8. University of Colorado Boulder, 9. University of Alaska Fairbanks, 10. Kyoto University

The extreme ultraviolet (EUV) space telescope Hisaki is the first small scientific satellite mission of the Japan Aerospace Exploration Agency. The scientific scope of the mission is to investigate the dynamics of space and the atmospheric environments of planets in our solar system. Since its launch on 14 September, 2013 to the present day, Hisaki has observed Jupiter's aurora and Io plasma torus for more than 1200 days, which is an average of 200 observation days per year. The continuous long-term monitoring unveiled the dynamics in the aurora and torus, which are closely associated with the plasma circulation in the inner magnetosphere and particle precipitations into Jupiter’s upper atmosphere.

The plasma circulation from the inner to middle magnetosphere was found to be enhanced during large volcanic eruptions at Io in 2015 (Yoshikawa, 2017; Tsuchiya et al., 2018a; Kimura et al., 2018). Accompanying enhancement of neutral atom escape from Io's atmosphere (Koga et al., 2018a, b, and 19), radially outward mass and energy transports in the torus drastically changed during the Io volcanic eruptions, which are successfully quantified based on the Hisaki EUV spectroscopy (Yoshioka et al., 2018; Hikida et al., 2019). Radial profile of plasma and our analytic model of plasma mass loading process suggested that the outward transport is likely driven by the interchange instability (Tsuchiya et al., 2018a; Kimura et al., 2018). A hot plasma sector embedded in the torus was found in the Hisaki long-term monitoring data, and subcorotation speed of the hot plasma sector is dependent on the volcanic activities (Tsuchiya et al., 2018b). Correlations of the torus brightness structure with the dawn-dusk electric field structure and radiation belts are also discussed based on the GMRT radio arrays and Hisaki observations (Murakami et al., 2016; Kita et al., 2019).

Synergies with the Hubble Space Telescope and Juno spacecraft also provide new insights into the plasma precipitation in the inner and middle magnetosphere. Based on the HST-Hisaki coordinated observation, Kimura et al. (2015, 17) found simultaneous occurrence of the large-scale hot plasma injection in the inner magnetosphere with the middle magnetospheric disturbance based on imaging and monitoring of the short-lived auroral brightenings. They were recurring with a period of 2-3 days during the solar wind quiet period. Juno in-situ plasma measurements by Yao et al. (2019) suggested that the short-lived auroral brightening is triggered by the global reconfiguration of magnetosphere, which is likely associated with the centrifugally-driven magnetotail reconnection. The solar wind response of Jupiter's UV aurora monitored with Hisaki and Juno discovered a mysterious 10-hour time lag of the short-lived auroral brightening with respect to the solar wind shock arrival at Jupiter's polar region (Kita et al., 2019). The hot plasma injection at the central torus in the deep inner magnetosphere follows the short-lived auroral intensification (Suzuki et al., 2018), which implies a global energy and/or mass transport from the middle/outer to the inner magnetosphere (Kimura et al., 2017; Yoshikawa et al., 2017; Tsuchiya et al., 2018a).

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Keywords: Jupiter, inner magnetosphere, the Hisaki satellite

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Cold ions perpendicularly heated by fast magnetosonic waves in the inner magnetosphere observed by Arase (ERG) satellite

*Kazushi Asamura[1], Masafumi Shoji[2], Yoshizumi Miyoshi[2], Ryosuke Fujii[2], Atsushi Miyazaki[2], Yasumasa Kasaba[3], Yoshiya Kasahara[4], Ayako Matsuoka[1], Vania Koleva Jordanova[5]

1. ISAS/JAXA, 2. Nagoya U., 3. Tohoku U., 4. Kanazawa U., 5. LANL

Fast magnetosonic (MS) waves are commonly observed in the equatorial region of the inner magnetosphere. Past numerical simulations show MS waves can accelerate cold ions through cyclotron resonance, although the observational evidence is still unclear. Arase (ERG) satellite found events of perpendicular heating of cold ions simultaneously with plasma wave activities of the MS waves. We found more than 200 events of the perpendicular heating of low-energy (10eV/q - a few keV/q) ions in a period between April 2017 to June 2018, and 70% of them coincide with the MS waves. These heated ions are distributed to all the MLT regions within magnetic latitude of +/-10deg, which is consistent with the region where the MS waves frequently observed.

We have applied the WPIA (wave-particle interaction analysis) method to the selected ion heating event with the MS waves. The results show that the MS waves accelerate the ions with pitch angles near 90 degrees. Moreover, we found these ions give their energy to EMIC waves which appears just below the local proton cyclotron frequency. Since MS waves are considered to be generated by the ring distrbution of ions, this analysis indicates energy transfer from higher-energy ions to the cold ions in the inner magnetosphere.

Keywords: ion heating, magnetosonic wave, WPIA

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Magnetosonic waves driven by proton ring distributions in the Martian magnetosphere

*Yuki Harada[1], Suranga Ruhunusiri[2], Jasper S Halekas[2], Jared R Espley[3], Gina A DiBraccio[3], James P McFadden[4], David L Mitchell[4], Christian Mazelle[5], Glyn Collinson[3], David A Brain[6], Takuya Hara[4], Masahito Nose[7], Oimatsu Satoshi[1], Kazuhiro Yamamoto[1], Bruce M Jakosky[6]

1. Graduate School of Science, Kyoto University, 2. Department of Physics and Astronomy, University of Iowa, 3. NASA Goddard Space Flight Center, 4. Space Sciences Laboratory, University of California, Berkeley, 5. IRAP, University of Toulouse, CNRS, UPS, CNES, 6. LASP, University of Colorado at Boulder, 7. ISEE, Nagoya Univ

We present MAVEN observations of magnetosonic waves at the local proton cyclotron frequency in the Martian magnetosphere. As a consequence of the lack of a global magnetic field of internal origin, the upper atmosphere of Mars directly interacts with the solar wind, thereby forming an induced magnetosphere. The majority of the solar wind plasma diverts around the obstacle, but some fraction of the hot magnetosheath protons have access to the upper ionosphere of Mars due to their large gyroradii with respect to the size of the induced magnetosphere. As a result, ring/shell-like proton velocity distribution functions are formed just below the induced magnetospheric boundary in the presence of cold, dense protons of ionospheric origin.

Below the induced magnetospheric boundary, MAVEN detected narrowband compressional waves at the local proton cyclotron frequency (and its harmonics for some cases) typically in the presence of both hot ring protons and cold ionospheric protons. The occurrence of the waves at the local proton cyclotron frequency is strongly controlled by solar extreme ultraviolet (EUV) conditions, showing a distinct preference for high EUV. The wave properties and their dependence on local and upstream conditions can be mostly explained by a proton Bernstein mode instability driven by a positive perpendicular slope in proton velocity distribution functions. The wave properties and their association with ring protons exhibit striking similarities to the magnetosonic waves observed in the terrestrial inner magnetosphere. These "Martian magnetosonic waves" potentially facilitate energy transport from the precipitating hot protons of magnetosheath origin to the cold ionospheric protons.

Keywords: Mars, magnetosonic waves, proton ring distributions

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM19] Dynamics of the Inner Magnetospheric System

convener:Kunihiro Keika(Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo), Aleksandr Y Ukhorskiy(Johns Hopkins University Applied Physics Laboratory), Yoshizumi Miyoshi(Institute for Space-Earth Environmental Research, Nagoya University), Lynn M Kistler(University of New Hampshire Main Campus)

The inner magnetosphere is highly variable because dynamical
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including the ionosphere and the outer magnetosphere are invited. And
presentations on new projects for the inner magnetosphere are also
welcome.

[PEM19-06] **Formation of Energy-Dispersed Narrow band structure in the Plasmaspheric Region**

*Junhyun Lee[1], Ensang Lee[1], Khan-huk Kim[1] (1.Kyung Hee University)

[PEM19-07] Statistical characteristics and forming mechanisms of trunk structure of ring current ions: Arase ion observations

*Ryosuke Fujii[1], Yoshizumi Miyoshi[1], Masafumi Shoji[1], Kazushi Asamura[2], Lynn M Kistler[1,3], Vania Jordanova[4], Tomoaki Hori[1], Shoichiro Yokota[5], Satoshi Kasahara[6], Kunihiro Keika[6], Ayako Matsuoka[2], Iku Shinohara[2] (1.Nagoya University, 2.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 3.University of New Hampshire, 4.Los Alamos National Laboratory, 5.Osaka University, 6.The university of Tokyo)

[PEM19-08] Excitation of poloidal Pc 5 waves associated with the substorm nose structure: Arase observation

*Kazuhiro Yamamoto[1], Masahito Nose[2], Ayako Matsuoka[3], Mariko Teramoto[4], Reiko Nomura[5], Satoshi Kasahara[6], Shoichiro Yokota[7], Kunihiro Keika[6], Kazushi Asamura[3], Yoshiya Kasahara[8], Atsushi Kumamoto[9], Fuminori Tsuchiya[9], Masafumi Shoji[2], Yoshizumi Miyoshi[2] (1.Graduate School of Science, Kyoto University, 2.Institute for Space-Earth Environmental Research, Nagoya University, 3.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 4.Kyushu Institute of Technology, 5.National Astronomical Observatory of Japan, 6.Graduate School of Science, The University of Tokyo, 7.Graduate School of Science, Osaka University, 8.Graduate School of Natural Science and Technology, Kanazawa University, 9.Graduate School of Science, Tohoku University)

[PEM19-09] Study of the excitation mechanism of storm-time Pc5 ULF waves by ring current ions based on the drift-kinetic simulation

*Tomotsugu Yamakawa[1], Kanako Seki[1], Takanobu Amano[1], Naoko Takahashi[1], Yoshizumi Miyoshi[2] (1.Department of Earth and Planetary Science, School of Science, The University of Tokyo, 2.ISEE, Nagoya University)

[PEM19-10] Recent Progress in ULF Wave's Interaction with Cold Electrons and Ions in the Earth's Inner Magnetosphere

★Invited Papers

*Jie Ren[1], Qiugang Zong[1], Xuzhi Zhou[1], Chao Yue[1], Robert Rankin[2] (1.Peking University, 2.University of Alaska)

[PEM19-11] Nonlinear drift resonance between electrons and ULF waves under the convection electric field

*Li Li[1,2], Yoshiharu Omura[2], Xuzhi Zhou[1] (1.Peking Univ., 2.Kyoto Univ.)

Formation of Energy-Dispersed Narrow band structure in the Plasmaspheric Region

*Junhyun Lee[1], Ensang Lee[1], Khan-huk Kim[1]

1. Kyung Hee University

Ions in the plasmasphere show various spectral structures on their energy spectrograms. In this study we investigate an energy-dispersed narrow band structure on the energy-time spectrogram using the observations from the Helium Oxygen Proton Electron (HOPE) instrument onboard the Van Allen Probes (VAP) satellites. The band structure shows that the energy of the peak flux gradually decreases as the satellite moves away from Earth while keeping the width of the flux in energy narrow. In most cases, the nose-like structures, which have much broader energy bands, are observed in the preceding orbit. The band structure appears on the lowest energy edge of the preceding nose-like structure after the nose-like structure vanishes. Statistical analysis for the observations from October 2012 to December 2017 shows that the band structure occurs more frequently in the dusk sector and the energy of its innermost tip depends on the magnetic local time similar to the nose-like structure. These results suggest that loss of ions in the nose-like structure leads to the formation of the band structure. However, not all nose-like structures come to the band structure. Most of the band structures are observed for a period when solar wind speed is slow while the nose-like structures disappear without the formation of the band structure when they are formed under fast solar wind conditions.

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Statistical characteristics and forming mechanisms of trunk structure of ring current ions: Arase ion observations

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1. Nagoya University, 2. Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 3. University of New Hampshire, 4. Los Alamos National Laboratory, 5. Osaka University, 6. The university of Tokyo

The distribution of ring current ions is controlled by transportation, acceleration and loss processes in the magnetosphere. Various structures in the energy-time spectra of ion fluxes are observed by Earth-orbiting satellites. Besides the well-known structures such as “nose” or “wedge” structures, the “trunk” structure was found by Van Allen Probes. The structure looks like an elephant trunk and the energy of peak flux decreases toward the Earth along a satellite trajectory. A case study by Van Allen Probes showed that trunk structures are seen in energy spectra of helium and oxygen ions. However, the detailed characteristics of the trunk have not been well understood, and a statistical survey using long-term observation data is necessary to examine the details. In this study, we investigate characteristics of the trunk structure using the Low-energy particle experiments-ion mass analyzer (LEPi) / Medium-energy particle experiments-ion mass analyzer (MEP-i) onboard the Arase satellite for the period from April 2017 to March 2019. A number of trunk structures were identified in helium and oxygen ions as well as protons.

We analyze geomagnetic activity, local time, latitude and L-value dependences of the trunk. The minimum L-shell point of the trunk is distributed mostly around L = 2.0 –2.5 off the equator, extending from dusk to pre-midnight. Geomagnetic storm and substorm dependences are similar between the event and the non-event periods. We also perform particle backward tracing simulations using a dipole magnetic field and a SAPS electric field model in addition to some standard empirical models of large-scale convection electric field. As a result, we show that the trunk structure can be formed when the Alfven layer is deformed due to a local and temporally enhanced electric field.

The previous study suggested that an impulsively enhanced electric field or a temporary gap of injection from the tail region combined with the charge exchange process could cause the formation of the trunk. However, our result suggests a different generation mechanism: Temporary and local electric field enhancements causes the transportation of ions to low L-shell region and the formation of trunk structure.

Beside the trunk structures, “inverse trunk” in which the energy of peak flux increases in the lower L-shell are also found from the Arase observations. We show statistical characteristics of trunk and inverse trunk structures on the basis of the Arase observations and the forming mechanism of Trunk shown by simulations.

Keywords: ring current, Arase satellite, structure on E-t diagram, Trunk structure, simulation, Electric field

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Excitation of poloidal Pc 5 waves associated with the substorm nose structure: Arase observation

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In the terrestrial magnetosphere, poloidal ultra-low frequency (ULF) waves are frequently observed during substorm activities (Engebretson et al., 1992; Ren et al., 2015; Shi et al., 2018). Understanding the relation between substorm and poloidal ULF wave excitation is connected to investigation of energy flow from the solar wind to the magnetosphere. Recently, Yamamoto et al. (2019) found that protons at 10–30 keV injected by a substorm excite eastward propagating poloidal waves through drift-bounce resonance. These protons showed rapid temporal variations in flux intensity and the radial gradient of their phase space density, which triggered two wave packets of the poloidal waves. However, case studies of the drift-bounce resonance for this energy range (< ~50 keV) are seldom reported, and hence poloidal waves excited through other excitation scenarios remain to be investigated.

In the present study, we examined poloidal Pc 5 waves and steady spatial structure of energetic proton distributions observed by the Arase satellite (Miyoshi et al., 2018) on 19 November 2018. The poloidal waves with a frequency of 4.5 mHz were detected by Arase during 02:40-03:40 UT. The apogee of Arase satellite was located at ~21 MLT, and its geomagnetic latitude ranged from 0° to 10° during the event. The energetic protons at ~5 and ~15 keV penetrated down to L = 5.1–5.4 and created the multiple-nose structure (e.g., Ferradas et al., 2016). Since the SuperMAG Auroral Electrojet (SME) index (Newell and Gjerloev, 2011) increased up to ~260 nT just before the Arase satellite detected the nose structure, the multiple-nose structure is associated with a small substorm (so-called substorm nose structure).

The proton pitch angle distributions at 10–20 keV measured by the LEP-i and MEP-i instruments onboard Arase showed clear “fishbone-like” structure, and the phase of the proton flux oscillations varies with pitch angles. These features indicate that the proton fluxes are modulated through drift-bounce resonance (e.g., Zhu et al., 2020). Using the ion sounding technique (e.g., Su et al., 1977; Kivelson and Southwood, 1983), we also estimated the azimuthal wave number (m number) of the poloidal waves. We obtained the m number to be +150 (eastward propagation) from the LEP-i measurements. While the energy gradient of proton phase space density (f_{H+}) at 10–20 keV was negative during most of the wave period, the radial gradient of f_{H+} was anti-earthward and about 10 times greater than the energy gradient. In the linear theory of Southwood et al. (1969), steep anti-earthward gradient can excite poloidal waves if m number of the wave is positive. Therefore, we propose that the anti-earthward gradient formed by the substorm nose structure excites the poloidal waves through drift-bounce resonance. The radial extent of the poloidal waves coincides with that of the steep anti-earthward gradient (L = 5.3–6.1). This supports our interpretation. We also calculated the wave growth rate derived by Southwood et al. (1969), and found that the wave growth rate exceeds the damping rate by the ionosphere (γ / ω ~ 0.3, where γ and ω are the wave growth rate and the wave angular frequency, respectively). Thus we consider that the

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poloidal waves were observed even on the nigh side, where the ionospheric damping is strong (γ_{damp}/ω ~ 0.1, Newton et al., 1978).

Keywords: ULF waves, ring current, nose structure, drift-bounce resonance

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Study of the excitation mechanism of storm-time Pc5 ULF waves by ring current ions based on the drift-kinetic simulation

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Internally driven ULF waves are electromagnetic fluctuations in the inner magnetosphere, and can be generated by ring current ions associated with ion injections from the magnetotail during substorms. The excitation mechanism and global distribution of ULF waves are keys to understand dynamic variation of the outer radiation belt electrons, since ULF waves in the Pc5 range (1.67-6.67 mHz) are considered to contribute to the radial diffusion of radiation belt electrons [e.g. Elkington et al., 2003]. Promising candidates of excitation mechanism of internally driven ULF waves is drift-bounce resonance [Southwood, 1976]. Although previous spacecraft observations have suggested the resonant excitation [e.g., Dai et al., 2013; Yeoman and Wright., 2001], there are other possibilities such as periodic pressure inhomogeneity formed by time-dependent particle injections. Recently, Yamakawa et al. [2019] confirmed for the first time the drift resonance excitation of storm-time Pc5 waves in 3D dipole structure under the initial condition of phase space density (PSD) with north-south symmetry based on the drift-kinetic simulation. However, drift-bounce resonance excitation of ULF waves was not detected in the case of the symmetric initial PSD distribution, while this type of resonance was suggested by some spacecraft observations [e.g. Oimatsu et al., 2018]. This study aims to investigate the condition for the excitation of ULF waves associated with drift-bounce resonance based on the global drift-kinetic model.

In order to simulate the excitation of internally driven ULF waves, we perform a kinetic simulation for ring current particles using GEMSIS-RC model [Amano et al., 2011], in which five-dimensional drift-kinetic equation for the phase space density (PSD) of ring current ions and Maxwell equations are solved self-consistently under assumption that the first adiabatic invariant is conserved. In order to simulate consequence of ion injection from the plasma sheet, we set a localized high-pressure region around midnight consisting of H+ ions as an initial distribution. We compare two cases of the initial velocity distribution; the Maxwellian velocity distribution with the isotropic temperature of 16 keV (Case a) and the velocity distribution with asymmetric distribution in pitch angle direction in addition to the background Maxwellian distribution (Case b). In Case a, the simulation results show the drift resonance excitation of poloidal, toroidal, and compressional mode Pc5 waves in the dayside dusk sector. These waves are fundamental mode waves with azimuthal wave number m ~ - 20 propagating westward. Global distribution of the excited poloidal Pc5 waves indicates that they are excited where the local growth rate resultant from the positive PSD gradient in energy is positive [Yamakawa et al., 2019]. In Case b, excitation of the second harmonic poloidal Pc3 ULF waves due to the drift-bounce resonance was identified in the dayside dusk sector. Ions contributing to the growth of poloidal mode ULF waves tend to have the pitch angle of about 90 degrees for Pc5 waves and oblique pitch angle for Pc3 waves. We will also report on characteristics of excited ULF waves with a focus of the relative contribution of the drift and drift-bounce resonances.

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Keywords: ring current, ULF, drift-bounce resonance, drift-kinetic simulation, magnetic storm

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Recent Progress in ULF Wave's Interaction with Cold Electrons and Ions in the Earth's Inner Magnetosphere

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In terms of particle energy and species, the inner magnetosphere can be divided into three regions, including the inner and outer radiation belts, ring current and plasmasphere. It is widely accepted that ULF waves can cause the acceleration and transport of outer radiation belt electrons and ring current ions through drift/drift-bounce resonance. Recent studies in the last two or three years presented the observational evidence of cold particle acceleration/energization by ULF waves. Cold plasmaspheric electrons can be rapidly accelerated by the poloidal-mode ULF wave electric fields via drift-bounce resonance, which show bi-directional pitch angle distributions, phase space density enhancement and density enhancement. The spatial distributions in the equatorial plane, occurrence conditions as well as resonant energy range of the cold plasmaspheric electrons also have been investigated using six years Van Allen Probes data. Different species of cold plasmaspheric ions can be energized to different energies due to the mass dependence of **E**x**B** effect by ULF waves. Besides, observations suggest that the polarization drift can lead to the real acceleration of cold O^+ ions. The recent progress can promote our understanding of ULF waves' impact on the cold particles, and let the science community realize the potential research value of ULF waves in the dynamics of cold plasma environment.

Keywords: ULF Waves, Cold Plasma, Acceleration and Tansport

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Nonlinear drift resonance between electrons and ULF waves under the convection electric field

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In the Earth's inner magnetosphere, charged particles can be accelerated and transported by ultralow frequency (ULF) waves via drift resonance. We study the effects of the convection electric field on the nonlinear drift resonance process, which provides an inhomogeneity factor defined as the ratio of the driving amplitude to the square of the pendulum trapping frequency. The factor varies with magnetic local time and oscillates quasi-periodically at the particle drift frequency, which can externally drive the pendulum equation that describes the particle motion in the ULF wave field. To better understand the particle behavior governed by the driven pendulum equation, we carry out simulations to obtain the evolution of electron distribution functions in energy and L-shell phase space. We find that resonant electrons can remain trapped by the low-*m* ULF waves under strong convection electric field, whereas for high-*m* ULF waves, the electrons trajectories can be significantly modified. More interestingly, the electron drift frequency is close to the nonlinear trapping frequency for intermediate-*m* ULF waves, which result in chaotic motion of resonant electrons. These findings provides improved understanding of the nature of coherent and diffusive transports of particles in the inner magnetosphere.

Keywords: driven pendulum equation, ULF waves, convection electric field, drift resonance

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM19] Dynamics of the Inner Magnetospheric System

convener:Kunihiro Keika(Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo), Aleksandr Y Ukhorskiy(Johns Hopkins University Applied Physics Laboratory), Yoshizumi Miyoshi(Institute for Space-Earth Environmental Research, Nagoya University), Lynn M Kistler(University of New Hampshire Main Campus)

The inner magnetosphere is highly variable because dynamical
variations of incoming energy from the solar wind, magnetospheric tail,
and the ionosphere. Cross-regional/cross-scale/cross-energy couplings
are key processes to understand this dynamical system, and coordinated
observations by multi-satellites and ground-based observations are
very essential to reveal these processes. In the 24th solar cycle,
a number of satellites such as Van Allen Probes, MMS, THEMIS, DSX and
Arase, coordinated ground-based observations (THEMIS-GBO, SuperDARN,
EISCAT, magnetometers, riometer, etc), and numerical simulations
(global kinetic model, MHD model, micro PIC, hybrid simulations) have
successfully investigated the inner magnetosphere system. Papers on recent results
on the inner magnetosphere and/or its coupling with the other regions,
including the ionosphere and the outer magnetosphere are invited. And
presentations on new projects for the inner magnetosphere are also
welcome.

[PEM19-12] **An Empirical Model of Electron Flux from the Seven-Year Van Allen Probe Mission**

★Invited Papers

*Christine Gabrielse[1], James Roeder[1], Justin Lee[1], Seth Claudepierre[1,2], Drew L. Turner[3], T. Paul O'Brien[1], Joseph Fennell[1], J. Bernard Blake[1] (1.The Aerospace Corporation, 2.UCLA, 3.John Hopkins Applied Physics Lab.)

[PEM19-13] **Comparison of storm-time electron dynamics observed by Arase/ERG and POES missions**

*ALEXEI DMITRIEV[1,2], Shoichiro Yokota[3], Kunihiro Keika[4], Tomoaki Hori[5], Yoshizumi Miyoshi[5] (1.Institute of Space Science and Engineering, National Central University, Jungli City, Taiwan, 2.Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia, 3.Univesity Osaka, Japan, 4.Univesity Tokyo, Japan, 5.Univesity Nagoya, Japan)

[PEM19-14] Comprehensive Observations of Substorm-Enhanced Plasmaspheric Hiss Generation, Propagation, and Dissipation

*Nigang Liu[1], Zhenpeng Su[1], Zhonglei Gao[2], Huinan Zheng[1], Yuming Wang[1], Shui Wang[1], Yoshizumi Miyoshi[3], Iku Shinohara[4], Yoshiya Kasahara[5], Fuminori Tsuchiya[6], Atsushi Kumamoto[6], Shoya Matsuda[4], Masafumi Shoji[3], Takefumi Mitani[4], Takeshi Takashima[4], Yoichi Kazama[7], Bo-Jhou Wang[7], Shiang-Yu Wang[7], Chae-Woo Jun[3], Tzu-Fang Chang[8], Sunny W. Y. Tam[8], Satoshi Kasahara[9], Shoichiro Yokota[10], Kunihiro Keika[9], Tomoaki Hori[3], Ayako Matsuoka[4] (1.University of Science and Technology of China, Hefei, China, 2.Harbin Institute of Technology, Shenzhen, China, 3.Nagoya University, Nagoya, Japan, 4.Japan Aerospace Exploration Agency, Kanagawa, Japan, 5.Kanazawa University, Kanazawa, Japan, 6.Tohoku University, Sendai, Japan, 7.Academia Sinica Institute of Astronomy and Astrophysics, Taiwan, 8.National Cheng Kung University, Taiwan, 9.University of Tokyo, Tokyo, Japan, 10.Osaka University, Osaka, Japan)

[PEM19-15] Propagation characteristics of whistler-mode chorus waves in the outer radiation belt deduced from the Arase PWE observation

*Satoshi Kurita[1], Yoshizumi Miyoshi[1], Yoshiya Kasahara[2], Hirotsugu Kojima[3], Shoya Matsuda[4], Ayako Matsuoka[4], Iku Shinohara[4] (1.Institute for Space-Earth Environmental Research, Nagoya University, 2.Information Media Center, Kanazawa University, 3.Research Institute for Sustainable Humanosphere, Kyoto University, 4.ISAS/JAXA)

[PEM19-16] **EMIC (ElectroMagnetic Ion Cyclotron) waves during the Van Allen Probes and ERG era: EMIC wave properties depending on geomagnetic conditions**

*Chae-Woo Jun[1], Yoshizumi Miyoshi[1], Chao Yue[2], Jacob Bortnik[3], Larry Lyons[3], Toshi Nishimura[5], Craig Kletzing[4], Satoshi Kasahara[6], Yasumasa Kasaba[7], Shoya Matsuda[8], Masafumi Shoji[1], Fuminori Tsuchiya[6], Atsushi Kumamoto[6], Ayako Matsuoka[8], Iku Shinohara[8] (1.Institute for Space-Earth Environmental Research, Nagoya University, Nagoya, Japan, 2.Department of Earth and Space Science, Peking University, Beijing, China, 3.Atmospheric and Oceanic Sciences, University of California Los Angeles, Los Angeles, USA, 4.Department of Physics and Astronomy, University of Iowa, Iowa City, USA, 5.Boston University, Boston, USA, 6.Kanazawa University, Kakuma, Japan., 7.Tohoku University, Sendai, Japan. , 8.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Sagamihara, Japan.)

[PEM19-17] Statistical error estimation of the WPIA method and its application for nonlinear EMIC-proton interactions

*Masafumi Shoji[1], Yoshizumi Miyoshi[1], Kazushi Asamura[2], Atsushi Miyazaki[1], Yasumasa Kasaba[3], Yoshiya Kasahara[4], Shoya Matsuda[2], Ayako Matsuoka[2], Lynn M Kistler[5,1] (1.Institute for Space-Earth Environmental Research, Nagoya University, 2.ISAS, 3.Tohoku University, 4.Kanazawa University, 5.The University of New Hampshire)

An Empirical Model of Electron Flux from the Seven-Year Van Allen Probe Mission

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The near-Earth radiation environment is a force to contend with when designing satellites and their instruments. Solar storms can accelerate and transport energetic particles closer to Earth, populating Earth’ s radiation belts and increasing a satellite’ s radiation dosage. A major application to the field of space weather is therefore knowing and understanding the near-Earth radiation environment. We use Van Allen Probe MagEIS and REPT data throughout mission lifetime to look at electron fluxes at different energies, pitch angles, and L shells, creating a daily average flux model that can be used to deduce what fluences were observed by any satellite that flew within Van Allen Probe’ s seven-year mission. We supplement Van Allen Probe fluxes with THEMIS statistical fluxes at higher L shells. This model can be applied to better understand satellite degradation issues related to the radiation environment. It is an improvement from previous empirical models in this regard by virtue of the fact that actual fluxes from a specific storm (or storms) can be deduced and compared to real satellite degradation data.

Keywords: electron flux, Van Allen Probes, empirical model, space weather

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Comparison of storm-time electron dynamics observed by Arase/ERG and POES missions

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Precipitation of energetic electrons from the outer radiation belt (ORB) affects significantly the ionosphere and the upper atmosphere at middle to high latitudes. The precipitations result from effective acceleration and scattering of ORB electrons due to intense substorm and wave activity. The dynamics of electrons during magnetic storms on the late declining phase of the current 24th solar cycle (the years 2017 –2019) was investigated using experimental data acquired from joint Taiwan-Japan Arase/ERG mission, the high-apogee spacecraft of low inclination, and by a fleet of low-Earth’ s orbit sun-synchronous NOAA POES satellites. The fluxes of precipitating electrons measured by POES at low heights and high latitudes are compared with those measured in the heart of ORB by Arase/ERG satellite in order to determine the electron sources and losses at different stages of magnetic storms.

Keywords: radiation belt, magnetic storms, ionosphere

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Comprehensive Observations of Substorm-Enhanced Plasmaspheric Hiss Generation, Propagation, and Dissipation

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Plasmaspheric hiss is an important whistler-mode emission shaping the Van Allen radiation belt environment. How the plasmaspheric hiss waves are generated, propagate, and dissipate remains under intense debate. With the five spacecraft of Van Allen Probes, Exploration of energization and Radiation in Geospace (Arase), and Geostationary Operational Environmental Satellites missions at widely spaced locations, we present here the first comprehensive observations of hiss waves growing from the substorm-injected electron instability, spreading within the plasmasphere, and dissipating over a large spatial scale. During substorms, hot electrons were injected energy-dispersively into the plasmasphere near the dawnside and, probably through a combination of linear and nonlinear cyclotron resonances, generated whistler-mode waves with globally drifting frequencies. These waves were able to propagate from the dawnside to the noonside, with the frequency-drifting feature retained. Approximately 5 hr of magnetic local time away from the source region in the dayside sector, the wave power was dissipated to e^{-4} of its original level.

Keywords: Plasmaspheric Hiss, Radiation Belt, Plasmasphere, Wave Generation, Wave Propagation, Wave Dissipation

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Propagation characteristics of whistler-mode chorus waves in the outer radiation belt deduced from the Arase PWE observation

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Whistler-mode chorus is electromagnetic waves in nature observed in the frequency range from 0.1 to 0.8 times of electron gyrofrequency, fce, and they frequently appear in the dawn and noon side magnetosphere. Chorus waves often have a gap of wave power at 0.5 fce, and the waves below and above 0.5 fce are called lower-band (LBC) and upper-band chorus (UBC), respectively. These waves has been considered as the primary driver of the electron dynamics in the Earth’ s inner magnetosphere, since they can resonate with electrons in the wide energy range and cause the acceleration and loss of the electrons. Characteristics of the waves such as the wave normal angle, wave power, and their latitudinal distributions are of interest since these parameters strongly control the time scale for acceleration and loss of electrons. The characteristics of LBC was investigated by using the 11 year Cluster measurements [Santolik et al., 2014], while those of UBC has not been well clarified yet. In this study, we investigate characteristics of both LBC and UBC observed by the Arase satellite using the data processed by Onboard Frequency Analyzer (OFA), which is one of the receivers of the Plasma Wave Experiment (PWE). OFA computes power spectral density of wave electric and magnetic fields in the frequency range from 64 Hz to 20 kHz, and spectral matrices of the electric and magnetic fields are also provided. Applying the singular value decomposition technique [Santolik et al., 2003] to the magnetic spectral matrix computed by OFA, we derive occurrence frequency distributions of wave normal angle and wave magnetic field power as a function of magnetic latitudes. The parameters of LBC and UBC are separately analyzed, and we also classify the magnetic local time of the wave observations into dayside and night side. In the presentation, we will show the latitudinal distributions of wave normal angle of LBC and UBC and discuss the different propagation characteristics between LBC and UBC. We also represent latitudinal wave magnetic field power distributions to discuss the propagation effect on the wave power, that is, convective growth and damping of LBC and UBC. We will also discuss day/night difference of the parameters between LBC and UBC.

Keywords: Arase, chorus, PWE

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EMIC (ElectroMagnetic Ion Cyclotron) waves during the Van Allen Probes and ERG era: EMIC wave properties depending on geomagnetic conditions

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To understand the global characteristics of electromagnetic ion cyclotron (EMIC) waves in the magnetosphere, we performed a statistical study of EMIC wave properties waves based on the Van Allen Probes (RBSP) and Exploration of energization and Radiation in Geospace (ERG) observations in 2017-2018. Our previous study found significant dependencies of EMIC wave distributions on geomagnetic conditions. H-band EMIC waves outside the plasmasphere had two peak occurrence regions at 10-14 MLT at L˜7-8 during the recovery phase and at 4-8 MLT at L>8 during the non-storm intervals. He-band EMIC waves inside the plasmasphere were dominantly observed at 10-20 MLT during the main phase. In this study, we focus on EMIC wave properties and discuss possible drivers of EMIC wave excitation depending on geomagnetic conditions. In preliminary results by RBSP, we found that the wave powers of He-band EMIC waves are strongly enhanced during the disturbed intervals, while H-band EMIC waves have no significant wave power variations under different conditions. The other two properties (polarization and wave normal angle) showed no clear tendencies among geomagnetic activities. He-band EMIC waves were predominantly observed with left-hand polarization and higher wave normal angles, while H-band EMIC waves showed a mixture of left-hand and linear polarizations with lower wave normal angles. From these observations, we suggest that energetic particle input is the major free energy source of intense He-band EMIC waves at which the cold and dense plasma dominates. Under this condition, the growth rate of EMIC waves can have a maximum at lower frequency regions and they easily excite with strong wave power. We will combine ERG observations to extend spatial coverage up to L=12 and higher magnetic latitudes, in order to understand the generation and propagation effects on EMIC wave properties in the magnetosphere.

Keywords: Wave properties of EMIC waves, Geomagnetic conditions, Multi-space missions

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Statistical error estimation of the WPIA method and its application for nonlinear EMIC-proton interactions

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Theoretical and simulation studies suggest that the EMIC waves with various frequency changes are generated through the nonlinear wave particle interaction with the energetic protons. The nonlinear EMIC emissions with are studied by the Arase satellite data analysis in the Earth’ s inner magnetosphere. Wave-particle interaction analysis (WPIA) method which calculate the inner product between the electromagnetic fields and the particle velocities and their phase differences has been developed to show the direct evidence of the energy transfer between the plasma waves and particles. We apply the WPIA method for the EMIC rising tone emissions observed by Arase satellite on 11th Dec. 2017. We perform parametric analyses on the energy and pitch angle of the particles to identify the region causing the efficient energy transfer with the EMIC waves in the proton distribution function. We also show statistical errors which come from the ion particle detector (LEP-i). The errors from the counting statistics and the ambiguity of the looking direction of the ion detectors are estimated. We estimate the minimum integral time in the WPIA method with which we can neglect the counting statistics. The bootstrap method, one of the Monte-Carlo method, is employed to estimate the random sampling errors in the looking direction considering the azimuthal and elevation angle response obtained in laboratory experiments. We discuss significance of the energy transfer by calculating the confidence interval of the WPIA results.

Keywords: WPIA, EMIC wave, Arase observation

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM19] Dynamics of the Inner Magnetospheric System

convener:Kunihiro Keika(Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo), Aleksandr Y Ukhorskiy(Johns Hopkins University Applied Physics Laboratory), Yoshizumi Miyoshi(Institute for Space-Earth Environmental Research, Nagoya University), Lynn M Kistler(University of New Hampshire Main Campus)

The inner magnetosphere is highly variable because dynamical
variations of incoming energy from the solar wind, magnetospheric tail,
and the ionosphere. Cross-regional/cross-scale/cross-energy couplings
are key processes to understand this dynamical system, and coordinated
observations by multi-satellites and ground-based observations are
very essential to reveal these processes. In the 24th solar cycle,
a number of satellites such as Van Allen Probes, MMS, THEMIS, DSX and
Arase, coordinated ground-based observations (THEMIS-GBO, SuperDARN,
EISCAT, magnetometers, riometer, etc), and numerical simulations
(global kinetic model, MHD model, micro PIC, hybrid simulations) have
successfully investigated the inner magnetosphere system. Papers on recent results
on the inner magnetosphere and/or its coupling with the other regions,
including the ionosphere and the outer magnetosphere are invited. And
presentations on new projects for the inner magnetosphere are also
welcome.

[PEM19-18] Comprehensive Study of the Response of Outer Radiation Belt and Inner Magnetosphere to Sheath Regions of Coronal Mass Ejections

*Milla Kalliokoski[1], Emilia Kilpua[1], Drew Turner[2], Allison Jaynes[3], Adnane Osmane[1], Lucile Turc[1], Harriet George[1], Minna Palmroth[1,4] (1.University of Helsinki, 2.Johns Hopkins University Applied Physics Laboratory, 3.University of Iowa, 4.Finnish Meteorological Institute)

[PEM19-19] Electron fluxes interacting with localized oblique whistler mode waves in the Earth's outer radiation belt

*Yikai Hsieh[1], Yuko Kubota[1], Yoshiharu Omura[1] (1.Reserach Institute for Sustainable Humanosphere, Kyoto University)

[PEM19-20] Deformation of electron pitch angle distributions by Upper Band Chorus: Numerical verification for Arase observations

*Shinji Saito[1], Satoshi Kurita[2], Yoshizumi Miyoshi[2] (1.National Institute of Information and Communications Technology, 2.ISEE, Nagoya Univ.)

[PEM19-21] Relative contribution of ULF and whistler-mode chorus waves to the radiation belt variation

*Naoko Takahashi[1], Kanako Seki[1], Mei-Ching Fok[2], Yihua Zheng[2], Yoshizumi Miyoshi[3], Satoshi Kasahara[1], Kunihiro Keika[1], David Hartley[4], Yoshiya Kasahara[5], Yasumasa Kasaba[6], Nana Higashio[1], Ayako Matsuoka[7], Shoichiro Yokota[8], Tomoaki Hori[3], Iku Shinohara[7] (1.Graduate School of Science, The University of Tokyo, 2.NASA Goddard Space Flight Center, 3.Institute for Space-Earth Environmental Research, Nagoya University, 4.The University of Iowa, 5.Information Media Center, Kanazawa University, 6.Planetary Plasma and Atmospheric Research Center, Tohoku University, 7.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 8.Graduate School of Science, Osaka University)

[PEM19-22] Energetic electron variations during magnetic storms: Comparative study between Arase observations and code coupling simulations

*Yoshizumi Miyoshi[1], Vania Jordanova[2], Yuto Katoh[3], Shinji Saito[4], Satoshi Kurita[5], Sandeep Kumar[1], Yoshiya Kasahara[6], Shoya Matsuda[7], Masafumi Shoji[1], Fuminori Tsuchiya[3], Atsushi Kumamoto[3], Ayako Matsuoka[5], Satoshi Kasahara[8], Shoichiro Yokota[9], Tomoaki Hori[1], Kunihiro Keika[8], Yoichi Kazama[10], Shiang-Yu Wang[10], Chae-Woo Jun[1], Takefumi Mitani[7], Takeshi Takashima[7], Nana Higashio[7], Iku

Shinohara[7] (1.Institute for Space-Earth Environmental Research, Nagoya University, 2.Los Alamos National Laboratory, 3.Tohoku University, 4.NICT, 5.Kyoto University, 6.Kanazawa University, 7.JAXA, 8.The University of Tokyo, 9.Osaka University, 10.ASIAA)

[PEM19-23] Electric Field Effect on Proton Flux Response in South Atlantic Anomaly during Geomagnetic Storms

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Comprehensive Study of the Response of Outer Radiation Belt and Inner Magnetosphere to Sheath Regions of Coronal Mass Ejections

*Milla Kalliokoski[1], Emilia Kilpua[1], Drew Turner[2], Allison Jaynes[3], Adnane Osmane[1], Lucile Turc[1], Harriet George[1], Minna Palmroth[1,4]

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The energetic electron content in the Van Allen radiation belts surrounding the Earth can vary dramatically on timescales from minutes to days, and these strong electron fluxes present a hazard for spacecraft traversing the belts. Electron dynamics in the belts is governed by various competing acceleration, transport and loss processes in which wave-particle interactions play an important role. The response of the belts to solar wind driving is yet largely unpredictable. We investigate here the response of outer radiation belt electron fluxes to driving by sheath regions preceding interplanetary coronal mass ejections and the associated wave activity in the inner magnetosphere. To employ the energy and radial distance resolved electron flux measurements of the Van Allen Probes, we consider events from 2012 to 2018. We perform a statistical study of the events using superposed epoch analysis, where the sheaths are superposed separately from the ejecta and are resampled to the same average duration. Our results show that the ULF wave power in the Pc5 and EMIC range, as measured by geostationary GOES satellites, peaks in the sheath and declines during the ejecta. On the other hand, chorus wave power (measured by Van Allen Probes) stays at about the same level during the sheath and ejecta despite on average stronger geomagnetic activity during the ejecta. The electron fluxes are primarily enhanced at source (tens of keV) and seed (hundreds of keV) energies throughout the outer belt, whereas depletion events are more common at MeV energies at larger radial distances. Depletion progresses to lower energies with increasing radial distance from the Earth. Geoeffective events, defined by the SYM-H index, result in enhancement and depletion of the outer belt electron fluxes more often than events that do not drive strong geomagnetic activity. Additionally, case studies of electron phase space density shed light on the dominating belt processes during sheath events.

Keywords: Radiation belt, ICME sheath region, energetic electrons, phase space density

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Electron fluxes interacting with localized oblique whistler mode waves in the Earth’s outer radiation belt

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Oblique whistler mode waves are observed frequently in dayside and dawnside of the Earth’s magnetosphere around the outer radiation belt. Through the nonlinear trapping, by coherent chorus waves, energetic resonant electrons (tens keV) can be accelerated rapidly and become relativistic electrons (a few MeV). Electron acceleration of velocity perpendicular to the background magnetic field of resonant electrons plays an important role in both cyclotron and Landau resonances. Green’s functions are treated as the results of wave-particle interactions between the target waves and the given electrons. We build up a database of Green’s functions for a large number of electrons interacting with oblique whistler mode chorus emissions. The formation processes of the outer radiation belt electron fluxes interacting with consecutive chorus emissions are traced by applying the convolution integrals for the Green’s functions. We trace the evolution of the radiation belt electron fluxes for a few minutes and find that MeV electrons are generated promptly due to the combination of cyclotron resonance and Landau resonance with oblique chorus waves. We compare the formation processes among waves with different wave normal angles, and the results show that chorus waves with larger wave normal angles can accelerate 10-30 keV electrons to MeV faster. We further trace the formation processes of MeV electron fluxes for oblique chorus emissions localized in longitude for an hour, and then compare the results among several different longitudinal ranges. The acceleration rate of electrons is highly related to the longitudinal range of chorus occurrence.

Keywords: Oblique whistler mode wave, Radiation belts, Wave particle interaction

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Deformation of electron pitch angle distributions by Upper Band Chorus: Numerical verification for Arase observations

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Arase satellite observed deformation of electron pitch angle distributions associated with upper band whistler chorus waves. The observation showed that time scale of the deformation is too fast to be described by quasi-linear theory. It suggests that assumption applied to quasi-linear theory, which is broad wave spectrum with random phase and linear correlation of diffusion coefficients with wave power, is not a dominant process in the electron scattering. To study the deformation of electron pitch angle distributions by observed upper band whistlers, we have done GEMSIS-RBW simulations with realistic physical parameters observed by Arase satellite during the event (2017/4/8 19:20:17 - 19:20:49). We compare simulation results with data obtained from Medium Energy Particle experiment-electron analyzer (MEP-e) on Arase satellite during the time interval. We will show numerical results of electron scattering process by upper band whistlers, and discuss contribution of non-diffusive electron scattering process to the deformation of electron pitch angle distributions.

Keywords: radiation belts, electron scattering, test-particle simulation

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Relative contribution of ULF and whistler-mode chorus waves to the radiation belt variation

*Naoko Takahashi[1], Kanako Seki[1], Mei-Ching Fok[2], Yihua Zheng[2], Yoshizumi Miyoshi[3], Satoshi Kasahara[1], Kunihiro Keika[1], David Hartley[4], Yoshiya Kasahara[5], Yasumasa Kasaba[6], Nana Higashio[1], Ayako Matsuoka[7], Shoichiro Yokota[8], Tomoaki Hori[3], Iku Shinohara[7]

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The Earth's radiation belt exhibits a dramatic variation during the active condition of the magnetosphere such as magnetic storms. The dynamic variation of the radiation belt is, in part, contributed by various wave-particle interactions, including: (1) the radial diffusion of electrons driven by ultra-low-frequency (ULF) waves in Pc5 frequency ranges (1.6-6.7 mHz) and (2) the local acceleration caused by wave-particle interactions between whistler-mode chorus waves and radiation belt particles. Over the past decade, multi-point observations have separately shown the evidence for the contribution of ULF and whistler-mode chorus waves to the relativistic electron flux enhancement. However, the relative contribution of ULF and whistler-mode chorus waves has not been extensively studied yet. In this study, we aim to address (1) when and where ULF and whistler-mode chorus waves contribute to the radiation belt dynamics and (2) what affects the wave growth.

We first investigate the temporal contribution of both waves to the relativistic electron flux enhancement during a specific magnetic storm. The target event is 27 May 2017 storm, which is triggered by coronal mass ejections. Both Arase (post-midnight) and Van Allen Probe (RBSP)-B (dusk) show global enhancement of ULF waves during the early recovery phase, which corresponds to the global increase of relativistic electron fluxes. Observed whistler-mode chorus waves are also enhanced, but their activity is small than the ULF wave activity. On the other hand, observed whistler-mode chorus waves are enhanced later on, during the late recovery phase when relativistic electron fluxes significantly increase around L~3.5–4, while ULF wave activity is weak. The large electron anisotropy at an energy level of ~20–50 keV is seen only during the late recovery phase.

To understand the spatial contribution of ULF and whistler-mode chorus waves, we perform Comprehensive Ring Current Model (CRCM) coupled with Block-Adaptive-Tree Solar-Wind Roe-Type Upwind Scheme (BATS-R-US) simulation. The simulation qualitatively reproduces the global evolution of ULF waves during the May 2017 storm. The estimated electron anisotropy is large at the energy of 10–40 keV, which is consistent with observations. The global distribution shows that the electron anisotropy is large in the dawn sector during the main phase. We find that the area where the electron anisotropy is large shifts toward dusk during the early and late recovery phases. Comparison between the simulation and observations indicates that eastward-drifting electrons excite whistler-mode chorus waves in the dusk sector. We will further discuss what affects the wave growth, i.e., the effect of magnetic field curvature.

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Energetic electron variations during magnetic storms: Comparative study between Arase observations and code coupling simulations

*Yoshizumi Miyoshi[1], Vania Jordanova[2], Yuto Katoh[3], Shinji Saito[4], Satoshi Kurita[5], Sandeep Kumar[1], Yoshiya Kasahara[6], Shoya Matsuda[7], Masafumi Shoji[1], Fuminori Tsuchiya[3], Atsushi Kumamoto[3], Ayako Matsuoka[5], Satoshi Kasahara[8], Shoichiro Yokota[9], Tomoaki Hori[1], Kunihiro Keika[8], Yoichi Kazama[10], Shiang-Yu Wang[10], Chae-Woo Jun[1], Takefumi Mitani[7], Takeshi Takashima[7], Nana Higashio[7], Iku Shinohara[7]

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We simulate dynamics of the energetic electron distributions and the plasmasphere with the RAM-SCB simulation during magnetic storms, which calculates evolution of the electron distribution function and density of the thermal plasma with a self-consistent magnetic field. In the simulation of the March 2017 and September 2017 storms, we compare the simulated electron flux and thermal plasma density with the data from LEPe/MEPe/HEP/XEP and PWE/HFA. The RAM-SCB simulation reproduces successfully the observed variations of energetic electrons, such as, injections and subsequent energy dispersion spectra of electrons. Using the simulated distribution functions and the ambient density and magnetic field, we also calculate the linear-growth rate of whistler mode waves and compare them with the plasma wave observation data obtained by Arase. We also conduct a code-coupling simulation that consists of RAM-SCB and the self-consistent electron hybrid simulation as well as GEMSIS-RBW test particle simulations for wave-particle interactions.

Keywords: modeling, wave-particle interactions

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Electric Field Effect on Proton Flux Response in South Atlantic Anomaly during Geomagnetic Storms

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In this research, we are studying proton flux variations in the inside the South Atlantic Anomaly (SAA) due to the inductive electric field computed by the time-varying background magnetic field provided by Tsyganenko model (TS05) during geomagnetic storm event of May 15, 2005. We have developed a 3D relativistic test particle simulation code using a guiding center theory, where the Tao-Chan-Brizard model was implemented. It is well-known that the South Atlantic Anomaly (SAA) is considered as a source of hazardousness for Low-Earth Orbit (LEO) environment. The objective of this investigation is to compute the proton flux variations in this critical zone to be able to estimate the corresponding radiation doses on spacecraft bodies, due to their passage inside the anomaly, and precisely, during intense geomagnetic storms. So far, it was found that during the main storm phase, the proton flux in the SAA varied greatly with respect to altitude and the protons could penetrate deeper toward the atmosphere by about 100 km. Numerical results were compared with satellite observations.

Keywords: South Atlantic Anomaly, Geomagnetic storm, Tsyganenko model, Inductive electric field, Proton flux, Test particle simulations

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM20] Recent Advances in Ionosphere Observation and Modeling through New Observation Opportunities

convener:CHIYEN LIN(Center for Astronautical Physics and Engineering, National Central University, TAIWAN), Yen-Jung Wu(Space Sciences Laboratory, University of California, Berkeley), Yang-Yi Sun(China University of Geosciences), Charles Lin(Department of Earth Sciences, National Cheng Kung University)

Rapid developments in space technology are advancing our understanding of ionospheric space weather by increasing a great number of ground- and space-based observations over the recent decades. In the ground segment, the dense ground-based GNSS networks, radars, and airglow instruments have greatly extended the observational coverages. In the space segment, the extraordinary satellite missions, such as FORMOSAT-7/COSMIC-2, ESA-SWARM NASA-ICON and -GOLD, providing a variety of observations all over the world such as airglow, temperature, neutral winds, current, ion drifts, plasma density that contribute to the understanding of middle and upper atmospheric dynamics. Increasing ground based observations are also important for coordinations with these satellite missions.
With the large amount and diversity of datasets, theoretical and empirical models can be validated, and implemented for inclusion of new thermosphere and ionosphere phenomena. Furthermore, remarkable breakthrough of data assimilation techniques advances the ionosphere monitoring and forecast.
The purpose of this session is to solicit studies providing observations, theoretical and empirical modeling and data assimilation on the multiple scales of ionospheric phenomena, from global morphology to small-scale irregularities and traveling ionospheric disturbances. Studies from magnetically quiescent to storm conditions as well as influences from lower atmosphere will also be solicited.

[PEM20-01] Ionospheric Variability during the September 2019 Southern Hemisphere Sudden Stratospheric Warming

★Invited Papers

*Yosuke Yamazaki[1], Vivien Matthias[2], Yasunobu Miyoshi[3], Claudia Stolle[1,4], Tarique Siddiqui[1], Guram Kervalishvili[1], Jan Laštovička[5], Michal Kozubek[5], William Ward[6], David Themens[6], Samuel Kristoffersen[6], Patrick Alken[7,8] (1.GFZ Potsdam, 2.PIK Potsdam, 3.Kyushu Univ., 4.Univ. of Potsdam, 5.CAS Prague, 6.Univ. of New Brunswick, 7.Colorado Univ., 8.NOAA)

[PEM20-02] Recent Insights into the Thermosphere-Ionosphere Response to External Forcing from the Global-scale Observations of the Limb and Disk (GOLD) Mission

★Invited Papers

*Richard Eastes[1] (1.Laboratory for Atmospheric and Space Physics)

[PEM20-03] Comparing Equatorial Plasma Irregularities across Scale Sizes with GOLD and COSMIC

*Jeffrey Klenzing[1], Alexa Jean Halford[1], Jonathon Smith[1,2], Carlos Martinis[3] (1.NASA Goddard Space Flight Center, 2.Catholic University of America, 3.Boston University)

[PEM20-04] Multi-scale Ion Composition and Plasma Density Irregularities: Swarm-E Observations in the Topside Ionosphere

*Andrew W Yau[1] (1.University of Calgary)

[PEM20-05] The variation of the ionospheric electron density associated with active lightning

Yu-Cheng Lin[1], *Alfred Bing-Chih Chen[1], Chiawen Chuang[1] (1.National Cheng Kung University)

[PEM20-06] Global distribution of persistence of total electron content anomaly

*Yang-Yi Sun[1], Chieh-Hung Chen[1], JANN-YENQ Liu[2] (1.China University of Geosciences (Wuhan), 2.National Central University)

Ionospheric Variability during the September 2019 Southern Hemisphere Sudden Stratospheric Warming

*Yosuke Yamazaki[1], Vivien Matthias[2], Yasunobu Miyoshi[3], Claudia Stolle[1,4], Tarique Siddiqui[1], Guram Kervalishvili[1], Jan Laštovička[5], Michal Kozubek[5], William Ward[6], David Themens[6], Samuel Kristoffersen[6], Patrick Alken[7,8]

1. GFZ Potsdam, 2. PIK Potsdam, 3. Kyushu Univ., 4. Univ. of Potsdam, 5. CAS Prague, 6. Univ. of New Brunswick, 7. Colorado Univ., 8. NOAA

A sudden stratospheric warming (SSW) is an extreme wintertime meteorological phenomenon occurring mostly over the Arctic region. Studies have shown that an Arctic SSW can influence the whole atmosphere including the ionosphere. In September 2019, a rare SSW event occurred in the Antarctic region, following strong wave-1 planetary wave activity (see attached figure). The event provides an opportunity to investigate its broader impact on the upper atmosphere, which has been largely unexplored in previous studies. Ionospheric data from ESA's Swarm satellite constellation mission show prominent 6-day variations in the dayside low-latitude region during the SSW, including 20-70% variations in the equatorial zonal electric field, 20-40% variations in the electron density, and 5-10% variations in the top-side total electron content. These ionospheric variations have characteristics of a westward-propagating wave with zonal wavenumber 1, and can be attributed to forcing from the middle atmosphere by the Rossby normal mode “quasi-6-day wave” (Q6DW). Geopotential height measurements by the Microwave Limb Sounder aboard NASA's Aura satellite reveal a burst of global Q6DW activity in the mesosphere and lower thermosphere at this time, which is one of the strongest in the record. These results suggest that an Antarctic SSW can lead to ionospheric variability by altering middle atmosphere dynamics and propagation characteristics of large-scale waves from the middle atmosphere to the upper atmosphere.

Keywords: sudden stratospheric warming, quasi-6-day wave, Swarm

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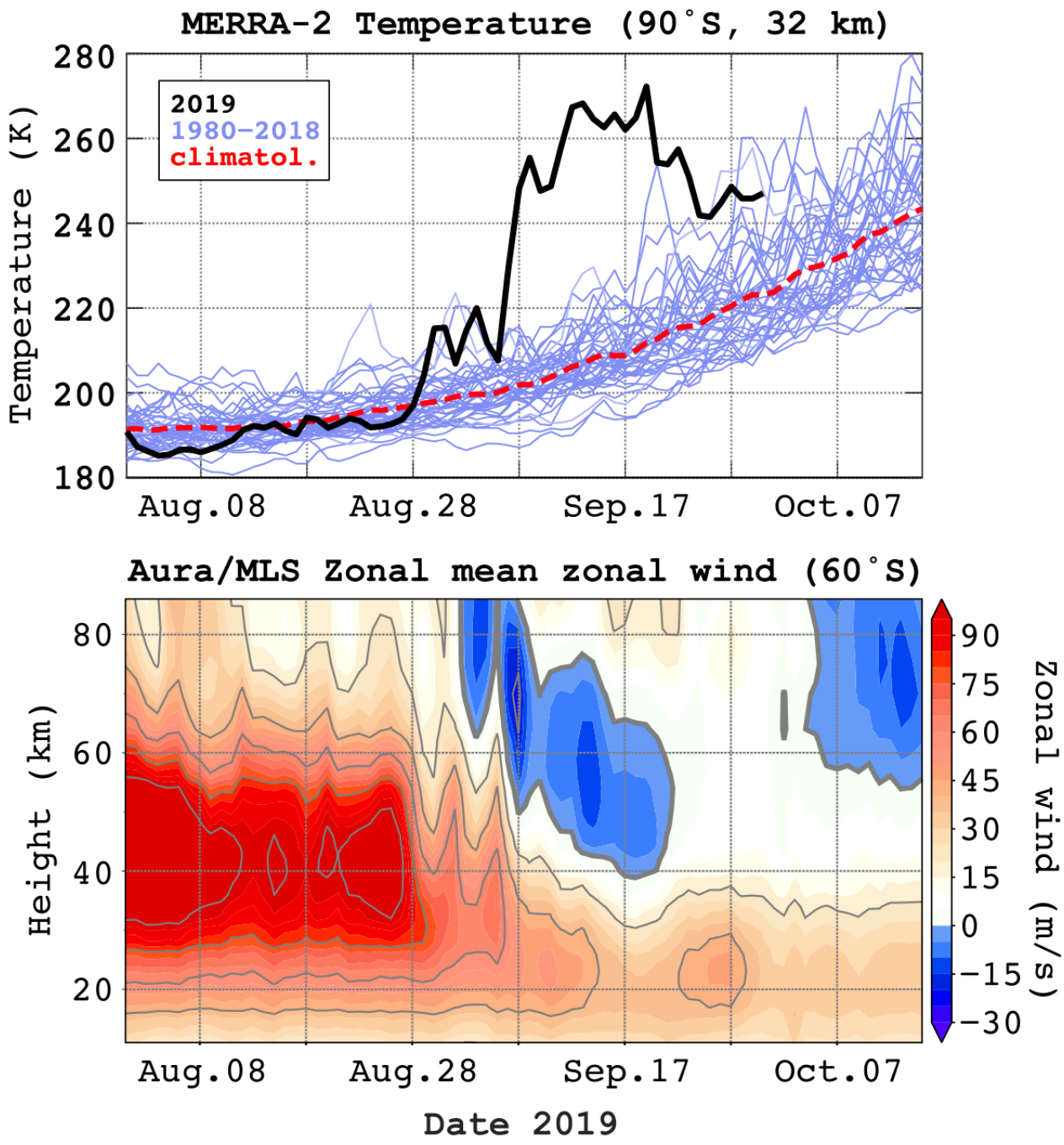

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Recent Insights into the Thermosphere-Ionosphere Response to External Forcing from the Global-scale Observations of the Limb and Disk (GOLD) Mission

*Richard Eastes[1]

1. Laboratory for Atmospheric and Space Physics

Observations by the GOLD mission are able to follow spatial and temporal changes in the composition, density and temperature of Earth’ s thermosphere, providing fundamental information for understanding the Thermosphere-Ionosphere system. GOLD images the Earth from geostationary orbit at 47.5 degrees W longitude, observing on a 30-minute cadence from 06:10 to 0:40 UT (03:00-21:3 LT at the satellite). The observations performed include limb scans; stellar occultations; and images the sunlit and nightside disk. These data provide simultaneous, synoptic daytime imaging of the composition and temperature near 160 km for the first time. Repeated observations of peak densities in the low-latitude, nighttime equatorial ionization anomaly (EIA) and the depletions within it also provide a new perspective on that region. These observations are providing significant tests of current models, tests that may lead to advances in the capabilities of global-scale models of the thermosphere and ionosphere system. Observations also clearly indicate the presence of waves in the thermosphere. There are also clear indications of waves and tides propagating from lower altitudes. Examples of these observations, as well as their potential for advancing models of the thermosphere-ionosphere system, will be presented and discussed.

Keywords: ionosphere, thermosphere, equatorial ionization anomaly, coupling, forcing

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Comparing Equatorial Plasma Irregularities across Scale Sizes with GOLD and COSMIC

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1. NASA Goddard Space Flight Center, 2. Catholic University of America, 3. Boston University

Near the geomagnetic equator, large depleted plumes of plasma (whimsically referred to as “bubbles”) can form when bottomside ionospheric plasma is lifted up hundreds of kilometers, piercing through the ionospheric layer. This uplift is caused by a Rayleigh-Taylor instability in the bottomside ionosphere, which can grow over the course of several hours. These meso-scale structures (10s to 100s of km) can lead to the formation of fine-scale (10s to 100s of m) plasma irregularities in the vicinity of large plasma density gradients. These smaller scale structures are important because they are of the right scale size to interfere with GPS signals. This study will compare the formation times of the meso-scale bubbles from space-borne airglow images from GOLD with the fine-scale S4 measurements from the COSMIC spacecraft.

Keywords: plasma irregularities, plasma bubbles, scintillation

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Multi-scale Ion Composition and Plasma Density Irregularities: Swarm-E Observations in the Topside Ionosphere

*Andrew W Yau[1]

1. University of Calgary

We present new simultaneous observations of both ion composition and plasma density variations in the topside ionosphere (325-1500 km altitude) using high sampling-resolution measurements from the Swarm-E (e-POP) ion mass spectrometer in the first 6 years of the mission (2013-2019). A statistical study of these observations reveals the frequent occurrences of multi-scale enhancements of heavy and minor ion composition in the topside auroral ionosphere during magnetic storms and substorms, as well as the corresponding occurrences of small-scale plasma density irregularities down to spatial scales of tens of meters. We compare and correlate the occurrence distributions and morphological characteristics between the two (composition enhancement and irregularities), and discuss the implications of the observed distributions on ionosphere-magnetosphere coupling.

Keywords: ionosphere, ion composition, plasma density irregularities

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The variation of the ionospheric electron density associated with active lightning

Yu-Cheng Lin[1], *Alfred Bing-Chih Chen[1], Chiawen Chuang[1]

1. National Cheng Kung University

Existing literature studies show that the thunderstorm generated in the troposphere is capable to disturb the ionospheric electron density by gravity waves generated in deep convections, or the change of the quasi-electrostatic field associated with sprites, or the direct heating of the electromagnetic pulses. The contribution of the above processes can be investigated by the variation of the ionospheric electron density above the thunderstorm regions at or after the lightning active time above thunderstorms. Unfortunately, the occurrence of lightning is unpredictable and irregular. Hence, it is difficult to study this variation by a direct and programmed measurement on the electron density above thunderstorms.

In this work, the long-term lightning activity monitored by the world-wide lightning location network (WWLLN) and the electron density profiles observed by COSMIC are employed to explore the electron density variation above the thunderstorms at their active time. The lightning active periods and regions were identified from 2006 to 2017 globally. Furthermore, the corresponding electron density profiles were extracted from the COSMIC database to exams the discrepancy respected to the density profiles at quiet time. Therefore, the variations of the ionospheric electron density caused by lightning can be assessed quantitatively in time, space and height. The results of this study indicate the elevation of the electron density by dense lightning activity is statistically significant, and the response time is less than 30 minutes. The diurnal vibration of the lightning and electron density elevation is also investigated and presented in this paper.

Keywords: Lightning, ionosphere, FORMOSAT-3/COSMIC

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Global distribution of persistence of total electron content anomaly

*Yang-Yi Sun[1], Chieh-Hung Chen[1], JANN-YENQ Liu[2]

1. China University of Geosciences (Wuhan), 2. National Central University

Solar activities can disturb the ionosphere globally and induce ionospheric weather phenomena that transit rapidly through a large area. By contrast, sometimes the ionospheric plasma density can remain high or low over a certain location for a few days, which are difficult to be attributed to solar activities. This study shows the location preference of the positive and negative total electron content (TEC) anomalies persisting continuously longer than 24 hours (cross the two terminators) at middle and low latitudes (within ±60ºN geomagnetic latitudes). The TEC is obtained from the global ionospheric map (GIM) of the Center for Orbit Determination in Europe (CODE) under the geomagnetic quiet condition of Kp less than 3o during the period of 2005–2018. There are a few (less than 4%) TEC anomalies that can persist over 24 hours. The persistence of the positive TEC anomaly along the ring of fire on the western edge of the Pacific Ocean. The high persistence of the TEC anomalies at midlatitudes suggests that thermospheric neutral wind contributes to the anomaly formation. The temporal and spatial anomalies of the ionospheric electric field, atmospheric electric field (flash), atmospheric gravity wave, and neutral wind over the ring of fire should be further examined for explaining whether the persistence of the TEC anomalies associates with lithospheric activities.

Keywords: GNSS TEC, TEC persistence, ring of fire

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM20] Recent Advances in Ionosphere Observation and Modeling through New Observation Opportunities

convener:CHIYEN LIN(Center for Astronautical Physics and Engineering, National Central University, TAIWAN), Yen-Jung Wu(Space Sciences Laboratory, University of California, Berkeley), Yang-Yi Sun(China University of Geosciences), Charles Lin(Department of Earth Sciences, National Cheng Kung University)

Rapid developments in space technology are advancing our understanding of ionospheric space weather by increasing a great number of ground- and space-based observations over the recent decades. In the ground segment, the dense ground-based GNSS networks, radars, and airglow instruments have greatly extended the observational coverages. In the space segment, the extraordinary satellite missions, such as FORMOSAT-7/COSMIC-2, ESA-SWARM NASA-ICON and -GOLD, providing a variety of observations all over the world such as airglow, temperature, neutral winds, current, ion drifts, plasma density that contribute to the understanding of middle and upper atmospheric dynamics. Increasing ground based observations are also important for coordinations with these satellite missions.
With the large amount and diversity of datasets, theoretical and empirical models can be validated, and implemented for inclusion of new thermosphere and ionosphere phenomena. Furthermore, remarkable breakthrough of data assimilation techniques advances the ionosphere monitoring and forecast.
The purpose of this session is to solicit studies providing observations, theoretical and empirical modeling and data assimilation on the multiple scales of ionospheric phenomena, from global morphology to small-scale irregularities and traveling ionospheric disturbances. Studies from magnetically quiescent to storm conditions as well as influences from lower atmosphere will also be solicited.

[PEM20-07] Assimilation of Ground- and Space-Based Ionosphere Observations in WACCMX+DART

★Invited Papers

*Nicholas M Pedatella[1], Jeffrey Anderson[1], Chia-Hung Chen[2], Charles Lin[2], Jing Liu[1], Hanli Liu[1], Kevin Raeder[1] (1.National Center for Atmospheric Research, 2.National Cheng Kung University)

[PEM20-08] COSMIC 2 Observation of Topside Ionosphere and Plasmasphere During A Substorm Event

*Qian Wu[1], William Schreiner[2], John Braun[2], Iurii Cherniak[2], Irina Zakharenkova[2], Nick Pedatella[1,2], Min-yang Chou[2] (1.National Center for Atmospheric Research, 2.COSMIC Program/UCP)

[PEM20-09] **Extreme Ionospheric Response to a Minor Magnetic Storm in Deep Solar Minimum Revealed by Data Assimilation Results of FORMOSAT-7/COSMIC-2 and GNSS Total Electron Content**

*Charles Lin[1], P. K. Rajesh[1], CHIYEN LIN[2], JANN-YENQ Liu[3], Chia-Hung Chen[1] (1.Department of Earth Sciences, National Cheng Kung University, 2.Center for Astronautical Physics and Engineering, National Central University, 3.Graduate Institute of Space Science and Engineering, National Central University)

[PEM20-10] Near real-time plasma irregularity monitoring by FORMOSAT-7/COSMIC-2

*Shih-Ping Chen[1], Charles Lin[1], Rajesh Panthalingal Krishnanunni[1], Richard Eastes[2], Jong-Min Choi[1] (1.Department of Earth Sciences, National Cheng-Kung University, 2.Laboratory for Atmospheric and Space Physics, University of Colorado)

[PEM20-11] **Behavior of the low-latitude ionospheric plasma observed by FORMOSAT-7/COSMIC-2**

*FU-YUAN CHANG[1,2], JANN-YENQ Liu[1,2,3], CHI-YEN LIN[1,2], Charles Lin[4] (1.Center for Astronautical Physics and Engineering, National Central University, Taoyuan City, Taiwan, 2.Institute of Space Science, National Central University, Taoyuan City, Taiwan, 3.Center for Space and Remote Sensing Research, National

Central University, Taoyuan City, Taiwan, 4.Department of Earth Sciences, National Cheng Kung University, Tainan City, Taiwan)

[PEM20-12] Space Weather Products of FORMOSAT-7/COSMIC-2: Global Ionospheric Specification and Aided Abel Electron Density Profile

*CHIYEN LIN[1,2], Charles Lin[3], JANN-YENQ Liu[1,2], P. K. Rajesh[3], MINYANG CHOU[4], Ho-Fang Tsai[3] (1.Center for Astronautical Physics and Engineering, National Central University, 2.Institute of Space Science and Engineering, National Central University, 3.Department of Earth Sciences, National Cheng Kung University, 4.University Corporation for Atmospheric Research)

Assimilation of Ground- and Space-Based Ionosphere Observations in WACCMX+DART

*Nicholas M Pedatella[1], Jeffrey Anderson[1], Chia-Hung Chen[2], Charles Lin[2], Jing Liu[1], Hanli Liu[1], Kevin Raeder[1]

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The ability to perform whole atmosphere data assimilation in the Whole Atmosphere Community Climate Model with thermosphere-ionosphere eXtension (WACCMX) is implemented using the Data Assimilation Research Testbed (DART) ensemble adjustment Kalman filter. This presentation primarily focuses on the recent implementation of the assimilation of ground-based Global Navigation Satellite System (GNSS) total electron content (TEC), and Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) radio occultation (RO) observations. The effectiveness of assimilating ground-based GNSS TEC and COSMIC RO observations in constraining the ionosphere is first demonstrated through a set of Observation System Experiments (OSEs). The OSE results demonstrate that the assimilation of the ionosphere observations results in a reduction of the bias in the ionosphere in both the analysis fields and short-term forecasts. Using the 2009 sudden stratospheric warming (SSW) as a case study, results are also presented that demonstrate the value of simultaneously assimilating observations in the lower-middle atmosphere (0-100 km) and the ionosphere.

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COSMIC 2 Observation of Topside Ionosphere and Plasmasphere During A Substorm Event

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The recently launched US-Taiwan joint COSMIC 2 mission offers an opportunity to view the topside the ionosphere at more local times in the equatorial region. Past observations of plasmasphere and topside ionosphere TEC are mostly from sun-synchronous satellites with fixed local times, which limited their coverages. In the early stage of the COSMIC 2 mission, satellites are at 750 km altitude with low inclination orbital angles (~ 24 deg). The mission was able to capture a substorm event and made plasmasphere observations. We observed a decrease of topside TEC, which is likely a result of plasmaspheric density depletion associated with the substorm. We will compare COSMIC 2 observed TEC to plasmapause model simulations. The model can simulate how the plasmaspheric depletion is related to the high Kp index. We will examine how the simulated Kp dependence at different local times compared to the COSMIC 2 observations. At the same time, we will show, how the ionospheric density profiles vary during the substorm

Keywords: COSMIC 2, Topside TEC, plasmasphere

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Extreme Ionospheric Response to a Minor Magnetic Storm in Deep Solar Minimum Revealed by Data Assimilation Results of FORMOSAT-7/COSMIC-2 and GNSS Total Electron Content

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Global ionosphere specification (GIS) analysis results, wherein radio occultation total electron content (TEC) measurements of recently launched FORMOSAT-7/COSMIC-2 (F7/C2) constellation and ground-based global navigation satellite system TEC are assimilated, are used to examine ionospheric responses to a minor magnetic storm on 5 August 2019. The GIS gives three-dimensional global electron density specification at the top of every hour, assimilating these TEC data hourly by the Gauss-Markov Kalman filter with the initial state specified by the international reference ionosphere model. The assimilation analysis results reveal more than 300% electron density enhancements within the equatorial ionization anomaly crest, mostly appearing in the 200–300 km altitude range. Localized density enhancements are also seen to develop over the European longitude sector. The GIS outputs generated with the new low-latitude measurements by F7/C2 satellites show unexpected extreme ionosphere variations in response to a minor magnetic storm during deep solar minimum conditions when the background electron density is very low. During solar active periods, it normally requires larger geomagnetic storms to elevate the ionospheric electron density by more than 200%. The vertical ionospheric structures given by the GIS indicate the role of an enhanced fountain effect and storm-induced equatorward circulations in producing the observed positive storm responses.

Keywords: FORMOSAT-7/COSMIC-2, Ionosphere, Magnetic Storm

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Near real-time plasma irregularity monitoring by FORMOSAT-7/COSMIC-2

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The global map of radio occultation scintillations is constructed by using the S4 index profiles of radio occultation (RO) observations onboard FORMOSAT-7/COSMIC-2 (F7/C2). This study provides comparisons between the RO S4 and the rate of TEC index(ROTI) in Brazil region, coherent scatter radar observation of the Jicamarca Unattended Long-term Investigations of the Ionosphere and Atmosphere(JULIA), and the airglow monitoring of Global-scale Observations of the Limb and Disk(GOLD). Result shows that the geographic location of the RO S4 and ground-based observed irregularities are highly correlated, and the bottom side boundary of the EPBs is the major source of strong occultation scintillations in F-region.

Keywords: FORMOSAT-7/COSMIC-2, scintillation, irregularity

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Behavior of the low-latitude ionospheric plasma observed by FORMOSAT-7/COSMIC-2

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FORMOSAT-7/COSMIC-2 (FS-7/C-2), with the mission orbit of 550 km altitude, 24-deg inclination, and a period of 97 minutes, was launched on June 25, 2019. Tri-GNSS Radio occultation (RO) Receiver System (TGRS), Ion Velocity Meter (IVM), and RF Beacon (RFB) onboard FS-7/C-2 six small satellites allow scientists to observe the plasma structure and dynamics in the mid-latitude, low-latitude, and equatorial ionosphere. Measurements of FS-7/C-2 RO and IVM, as well as those of global ground-based GNSS receivers and other satellites, such as FORMOSAT-5/AIP, DMSP, etc. are used to study and have a better understanding of wavenumber-4 (Wave-4) and plasma depletion bays (PDBs).

Keywords: FORMOSAT-7/COSMIC-2, wave-4, plasma depletion bay, plasma drift

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Space Weather Products of FORMOSAT-7/COSMIC-2: Global Ionospheric Specification and Aided Abel Electron Density Profile

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FORMOSAT-7/COSMIC-2 (F7/C2) satellite mission was launched on 25 June 2019 and 6 satellites will deploy to the different operational orbital planes with an inclination of 24 degree and 550 km altitude height. Six satellites can provide thousands radio occultation (RO) observation events per day to observes the ionosphere. This study demonstrates two space weather data products based on F7/C2 RO sounding: Global Ionospheric Specification (GIS) electron density structure and Ne-Aided Abel electron density profile. GIS is the ionospheric data assimilation product based on the Gauss-Markov Kalman filter to assimilate the slant total electron content observed from ground-based GPS receiving stations and space-based RO instrumentations into background model to provide the continuity ionospheric three-dimensional electron density distribution. With horizontal and vertical ionospheric information obtained from ground- and space-based measurement, this data product can study large-scale ionospheric structural variation. On the other hand, the Ne-aided Abel inversion implement three-dimensional time-dependent electron density based on the climatological maps constructed from previous RO observations, which has an advantage of providing altitudinal information on the horizontal asymmetry, can reduce the error of spherical symmetry assumption in Abel inversion. In this study, observing simulation system experiment is conducted to estimate the accuracy and validation with ionosonde observation is applied to proof reliability. Comparing with typical Abel electron density profile, the Ne-aided Abel inversion can mitigate the artificial plasma caves in the daytime E-region. Moreover, GIS is also used to reconstruct the ionospheric variation during the September 27, 2019 minor geomagnetic storm.

Keywords: FORMOSAT-7/COSMIC-2, Space Weather, Radio Occultation, Data Assimilation

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM20] Recent Advances in Ionosphere Observation and Modeling through New Observation Opportunities

convener:CHIYEN LIN(Center for Astronautical Physics and Engineering, National Central University, TAIWAN), Yen-Jung Wu(Space Sciences Laboratory, University of California, Berkeley), Yang-Yi Sun(China University of Geosciences), Charles Lin(Department of Earth Sciences, National Cheng Kung University)

[PEM20-13] First Results from the NASA Ionospheric Connection Explorer Mission

★Invited Papers

*Thomas J Immel[1], Scott L. England[4], Roderick A. Heelis[3], Christoph R. Englert[2], Stephen B. Mende[1], Jerry E. Edelstein[1] (1.University of California Berkeley, 2.U.S. Naval Research Laboratory, 3.University of Texas at Dallas, 4.Virginia Institute of Technology)

[PEM20-14] First results from the ICON Far-Ultra-Violet (FUV) Instrument

*Harald U Frey[1], Stephen B Mende[1], Scott L England[5], Robert R Meier[2], Andrew W Stephan[3], Farzad Kamalabadi[4], Ulas Kamaci[4], Thomas J Immel[1] (1.University of California Berkeley, 2.George Mason University, 3.Naval Research Laboratory, 4.University of Illionois, 5.Virgina Technical University)

[PEM20-15] Spatial-structure of mid-latitude sporadic-E episodes revealed by L-band ALOS/PALSAR InSAR observations

*Masato Furuya[1], Natsu Takaki (1.Department of Earth and Planetary Sciences Hokkaido University)

[PEM20-16] Global Rate of TEC Index (ROTI) Observed by Ground-Based GPS TEC in 2009 and 2013

*Shih An Wu[1], JANN-YENQ Liu[1] (1.Institute of Space Science, National Central University, Taiwan)

[PEM20-17] Design and Preliminary Results for Ionosphere Photometer on FengYun-3(D) Meteorological Satellite

*Liping Fu[1], Fang Jiang[1], Tian Mao[2], Nan Jia[1], Tianfang Wang[1], Ruyi Peng[1] (1.National Space Science Center,Chinese Academy of Sciences, 2.National Satellite Meteorological Centre)

[PEM20-18] Errors from asymmetric emission rate in spaceborne, limb sounding Doppler interferometry: A correction algorithm with application to ICON/MIGHTI

*Yen-Jung Wu[1], Brian J. Harding[1], Colin C. Triplett[1], Jonathan J. Makela[2], Kenneth D. Marr[3], Christoph R. Englert[3], John M. Harlander[4], Thomas J. Immel[1] (1.Space Sciences Laboratory, University of California, Berkeley, CA, USA, 2.Department of Electrical and Computer Engineering, University of Illinois, Urbana-Champaign, IL, USA, 3.Space Science Division, U.S. Naval Research Laboratory, Washington, DC, USA, 4.Space Systems Research Corporation, Alexandria, VA, USA)

First Results from the NASA Ionospheric Connection Explorer Mission

*Thomas J Immel[1], Scott L. England[4], Roderick A. Heelis[3], Christoph R. Englert[2], Stephen B. Mende[1], Jerry E. Edelstein[1]

1. University of California Berkeley, 2. U.S. Naval Research Laboratory, 3. University of Texas at Dallas, 4. Virginia Institute of Technology

The NASA Ionospheric Connection Explorer (ICON) mission carries a complement of 3 remote sensing instruments and an in-situ plasma instrument to explore the interaction of Earth’ s atmosphere with its plasma environment, with coverage from the boundary of space at 95 km to the altitude of maximum ionospheric plasma density. Launched in October of 2019 into a 27º 600-km circular orbit, it is now possible to report the first results from the mission. All of the instruments are working as planned, providing all of the expected calibrated data to support 6 retrieved products: cardinal neutral winds, neutral temperatures, daytime neutral composition, daytime and nighttime ionospheric density profiles, and in-situ plasma drifts and density. Intercomparison of these measurements show the varying physical connections between the atmosphere and the ionosphere, and allow researchers to understand the causes of the large day-to-day variability in the conditions in near-Earth space.

Keywords: ionosphere, thermosphere, electrodynamics, atmospheric waves, atmospheric tides, space weather

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First results from the ICON Far-Ultra-Violet (FUV) Instrument

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The NASA Ionospheric Connection Explorer (ICON) was launched in October 2019 to study the connection between terrestrial weather and space weather. One of the four science instruments is the Far-Ultra-Violet (FUV) Instrument. This Spectrographic Imager collects (altitude) limb view vertical profiles of the 135.6 nm emission from atomic oxygen and part of the molecular nitrogen Lyman-Birge-Hopfield band emission around 157 nm. These measurements are used to constrain models of the atomic oxygen to molecular nitrogen altitude profiles, their mixing ratio and the ionospheric density at the dayside, along with the ionospheric density on the nightside. We will present first results of the investigation into the variability of dayside ionospheric composition and night side density that have been obtained during the first half year of the ICON science mission.

Keywords: NASA ICON mission, FUV instrument, ionospheric composition, ionospheric density, ionosphere variability

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Spatial-structure of mid-latitude sporadic-E episodes revealed by L-band ALOS/PALSAR InSAR observations

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1. Department of Earth and Planetary Sciences Hokkaido University

Maeda et al (2016, GRL) reported the detection of mid-latitude sporadic E event in Japan, using both GNSS TEC and L-band InSAR observations. Subsequently, Furuya et al (2017, EPS) applied split-spectrum method to the InSAR data, which allowed to virtually perform dual-frequency radar observations and to separate the signals into ionospheric dispersive and (tropospheric) non-dispersive components. Based on the small-scale non-dispersive phases that were spatially correlated with the dispersive phases, Furuya et al (2017) interpreted that the correlations might indicate the presence of nitric oxide (NO) generated by the reactions of metals, Mg and Fe, with nitric oxide ion (NO+).
The sporadic E events reported in the two reports were rather large in terms of their enhanced TEC as well as spatial scale. As such, they could be detected by Japanese nationwide GNSS network (GEONET). Meanwhile, moderate- to smaller-sized sporadic E episodes are even more difficult to detect by traditional ionosonde and GNSS/TEC observations, because the spatial scales are expected to be smaller. Here we report our detetion of moderate-sized sporadic-E episodes, using Japanese L-band ALOS/PALSAR InSAR observations that enable us to examine the fine spatial structure with spatial resolutions on the order to less than 100 meters. Also, applying the split-spectrum method to the InSAR images, we have again found the presence of dispersive and non-dispersive phases that are spatially correlated with each other.

Keywords: Sporadic-E, InSAR, ALOS/PALSAR

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Global Rate of TEC Index (ROTI) Observed by Ground-Based GPS TEC in 2009 and 2013

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Routine observations of the ionospherically imposed propagation effects upon GPS satellite signals are available online from Scripps Orbit and Permanent Array Center (SOPAC). With over 1500 ground-based stations now reporting data, ionospheric studies ranging from the analysis of single-site observations to the full global network have demonstrated the geophysical science yield possible from this remarkable resource. This study examines the standard deviation of TEC (total electron content) variations in a 10-minute interval to find the rate of TEC index (ROTI) around the receiving station on the ground. Results show that prominent ROTIs appear in the low-latitude ionosphere, plus and minus 30-degree dip, which begin at 1900 LT, reach their maximum at 2000-2100 LT, and vanish by about 2400 LT, especially in spring and autumn. A comparison shows that variations of ROTI well agree with S4 scintillations observed by FORMOSAT-3/COSMIC.

Keywords: GPS TEC, scintillation, Rate of TEC Index

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Design and Preliminary Results for Ionosphere Photometer on FengYun-3(D) Meteorological Satellite

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1. National Space Science Center,Chinese Academy of Sciences, 2. National Satellite Meteorological Centre

Far Ultraviolet Ionospheric PhotoMeter (IPM) is a innovation optical payload on Fenyun-3(D) meteorological satellite which was launched in Nov.15,2017. IPM contributes to the space weather science objectives by providing far ultraviolet remote sensing measurements of the daytime and nighttime atmosphere/ionosphere with high sensitivity. During sunlit atmospheric conditions, IPM measure the nadir irradiation at 135.6 nm and the N2 Lyman-Birge-Hopfield(LBH) Bands to retrieve the atmospheric O/N2 ratio. In conditions of atmospheric darkness, IPM measures the 135.6 nm recombination emission of O+ ions used to compute the nighttime ionosphere F layer peak electron density (NmF2) and integrated electron content (IEC). IPM is a high sensitivity photometer with 5-channel on the filer wheel, and the incidence light pass through the channels sequentially into the photomultiplier tube (PMT). Detecting ultraviolet emissions in the presence of bright visible light is one of the most difficult challenges for Earth pointing ultraviolet instrument, the integrated visible-to-IR albedo is on the order of 10^11R , the long wavelength continuum must be reduced by at least a factor of 10^9, IPM use an innovation technology to depress and measure the stray light. In this paper, we introduce the design of the IPM and the preliminary result on orbit.

Keywords: Far Ultraviolet , ionosphere, innovation photometer, NmF2, O/N2

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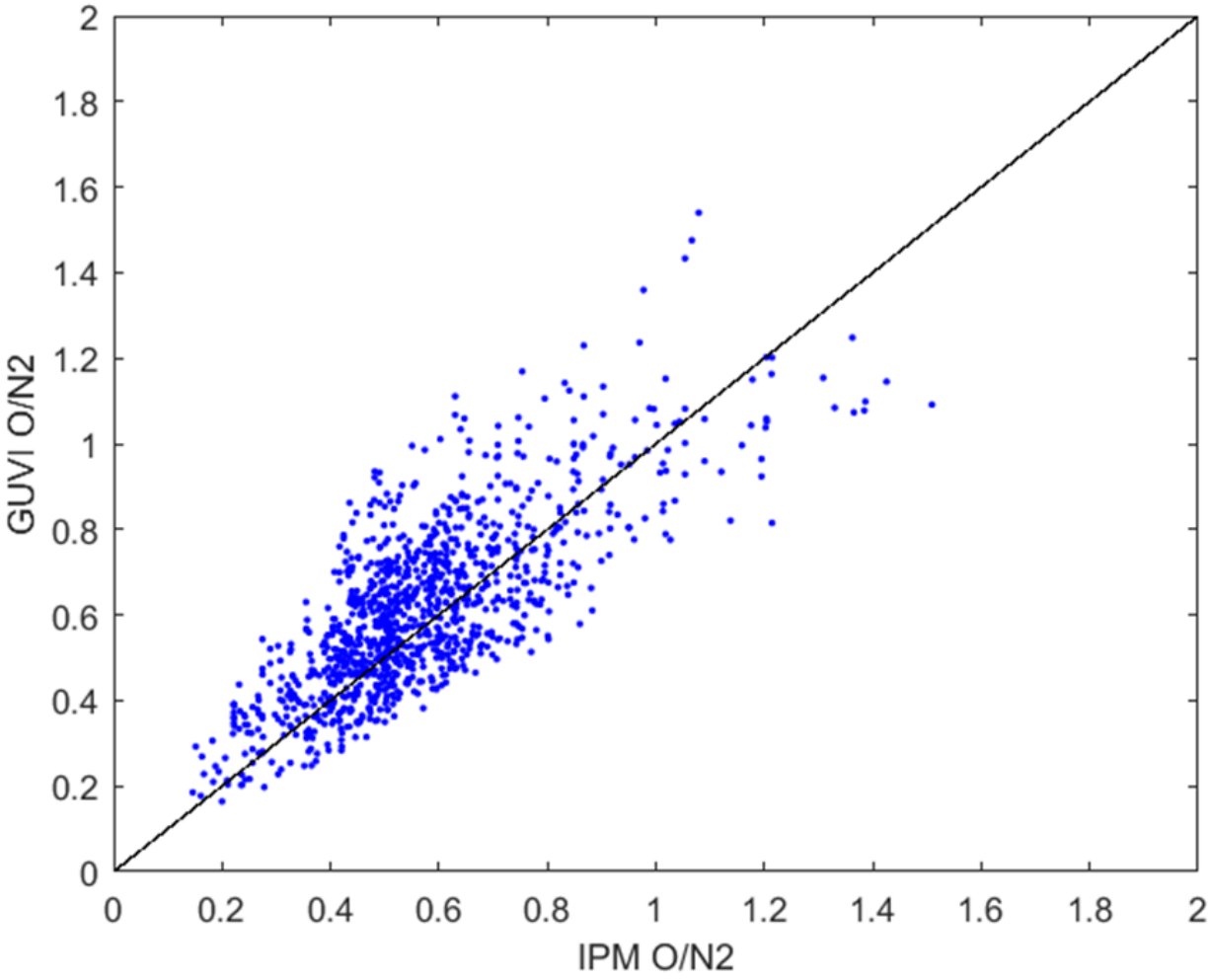

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Errors from asymmetric emission rate in spaceborne, limb sounding Doppler interferometry: A correction algorithm with application to ICON/MIGHTI

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The Michelson Interferometer for Global High-resolution Thermospheric Imaging (MIGHTI) on NASA's Ionospheric Connection Explorer (ICON) mission is designed to measure the neutral wind and temperature between 90 km and ~300 km altitude. Using the Doppler Asymmetric Spatial Heterodyne (DASH) spectroscopy technique, observations from MIGHTI can be used to derive thermospheric winds by measuring Doppler shifts of the atomic oxygen red line (630.0 nm) and green line (557.7 nm). Harding et al. (2017) describe the wind retrieval algorithm in detail, and point out the large uncertainties that result near the terminators and equatorial arcs, regions of large spatial gradients in airglow volume emission rates (VER). The uncertainties originate from the assumption of a constant VER at every given altitude, resulting in errors where the assumption is not valid when limb sounders, such as MIGHTI, observe regions with significant VER gradients. In this work, we introduce a new wind retrieval algorithm with the ability to account for VER that is asymmetric along the line of sight with respect to the tangent point. Using the predicted ICON orbit and simulated global VER variation, the greatest impact of the symmetric airglow assumption to the ICON vector wind product is found within 30 degrees from the terminator when the spacecraft is in the dayside, causing an error of at least 10 m/s. The new algorithm developed in this study reduces the error near the terminator by a factor of 10.

Keywords: Ionospheric Connection Explorer, Doppler shift sounding, Neutral wind retrieval

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[E] Oral | P (Space and Planetary Sciences)：P-EM Solar-Terrestrial Sciences, Space Electromagnetism & Space Environment

[P-EM21] Surprises from the Subauroral Zone: Synthesizing Ground and Space-Based Observations and Theory

convener:Connors Martin G(Athabasca University), Kazuo Shiokawa(Institute for Space-Earth Environmental Research, Nagoya University)

Recent studies, including some facilitated by citizen science, have shown the subauroral ionosphere to be more active than previously suspected. Unusual emissions, from SAR arcs to STEVE, indicate previously little studied physical processes in this region. Some arise from conjugacy to the radiation belts, while others have origins which remain unclear. This session attempts to stimulate synthesis of observations from different domains to address phenomena which appear difficult to explain when examined from only one of the many new sources of information about the subauroral zone. Optical observations have expanded to include those with the very high resolution of amateur DSLR cameras, yet this sporadic source is well complemented by continuous observation from the few comprehensive subauroral observatories. As ever, conjugacy with spacecraft plays an important role in assessing possible sources of precipitation or waves that may stimulate the subauroral ionosphere, and there are indeed now many space assets (RBSP, Arase, THEMIS, MMS) with footprints at least sometimes in that region. Various polar-orbiting low-altitude satellites traverse it regularly. The installation of low-latitude poleward-looking incoherent scatter radars, with large fields of view in the subauroral zone, also provides context and the ability to extract physical parameters continuously. The sometimes-extreme conditions now known to exist in the subauroral region have stimulated theory to expand the parameter range needed to explain ionospheric phenomena. We welcome contributions integrating multiple sources of observation and theoretical approaches to hopefully transform what is initially surprising into a new view of an unsuspectedly active region.

[PEM21-01] Magnetospheric-ionosphere dynamics associated with STEVE

★Invited Papers

*Toshi Nishimura[1], Jian Yang[2], Eric Donovan[3], Vassilis Angelopoulos[4], Nozomu Nishitani[5] (1.Boston University, 2.Southern University of Science and Technology, 3.University of Calgary, 4.University of California, Los Angeles, 5.Nagoya University)

[PEM21-02] Magnetosphere-Ionosphere Coupling by Alfvén Waves at Sub-Auroral Latitudes

★Invited Papers

*Robert L Lysak[1], Yan Song[1], Colin L Waters[2], Murray D Sciffer[2], Yuki Obana[3] (1.University of Minnesota, 2.University of Newcastle, 3.Osaka Electrocommunication University)

[PEM21-03] Multi-wavelength imaging observations of STEVE at Athabasca, Canada

*Sneha Yadav[1,2], Kazuo Shiokawa[1], Yuichi Otsuka[1], Martin G Connors[3], Jean-Pierre St. Maurice[4,5] (1.Institute for Space-Earth Environmental Research, 2.Space Physics Laboratory, Vikram Sarabhai Space Centre, Trivandrum, India, 3.Athabasca University Observatories, Athabasca University, Athabasca, Alberta, Canada, 4.Department of Physics and Engineering Physics, University of Saskatchewan, Saskatoon, Saskatchewan, Canada, 5.Department of Physics and Astronomy, University of Western Ontario, London, Ontario, Canada)

[PEM21-04] Pi2 ULF modulation of energetic electron precipitations observed by using VLF/LF transmitter signals

*Hiroyo Ohya[1], Miyashita Takuya[1], Fuminori Tsuchiya[2], Asuka Hirai[2], Mitsunori Ozaki[3], Kazuo Shiokawa[4], Yoshizumi Miyoshi[4], Nozomu Nishitani[4], Tomoaki Hori[4], Mariko Teramoto[5], Martin G Connors[6], Simon G Shepherd[7], Yoshiya Kasahara[3], Atsushi Kumamoto[2], Masafumi Shoji[4], Iku Shinohara[8], Hiroyuki Nakata[1], Toshiaki Takano[1] (1.Graduate School of Engineering, Chiba University, 2.Tohoku University, 3.Kanazawa University, 4.Nagoya University, 5.Kyushu Institute of Technology, 6.Athabasca University, 7.Dartmouth College, 8.Japan Aerospace Exploration Agency)

[PEM21-05] Subauroral GPS TEC and phase variations during geomagnetic storms

*Paul Prikryl[1,2], James M. Weygand[3], Reza Ghoddousi-Fard[4], Bharat S. R. Kunduri[5], P. T. Jayachandran[1], Knut S. Jacobsen[6], Yngvild L. Andalsvik[6], Tibor Durgonics[7], Kjerrmar Oksavik[8,9] (1.Physics Department University of New Brunswick, Canada, 2. Geomagnetic Laboratory Natural Resources Canada, 3.Earth Planetary and Space Sciences, University of California, USA, 4.Canadian Geodetic Survey Natural Resources Canada , 5.Bradley Dept. of Electrical and Computer Engineering, Virginia Tech, USA, 6.Norwegian Mapping Authority, Norway, 7.National Space Institute, Technical University of Denmark, Denmark, 8.Department of Physics and Technology, University of Bergen, Norway, 9.Arctic Geophysics, University Centre in Svalbard, Norway)

Discussion

Magnetospheric-ionosphere dynamics associated with STEVE

*Toshi Nishimura[1], Jian Yang[2], Eric Donovan[3], Vassilis Angelopoulos[4], Nozomu Nishitani[5]

1. Boston University, 2. Southern University of Science and Technology, 3. University of Calgary, 4. University of California, Los Angeles, 5. Nagoya University

We present three STEVE (strong thermal emission velocity enhancement) events in conjunction with THEMIS in the magnetosphere, and DMSP and Swarm in the ionosphere, for determining equatorial and inter-hemispheric signatures of the STEVE purple/mauve arc and picket fence. Both types of STEVE emissions are associated with SAID (subauroral ion drifts), electron heating, and plasma waves. The magnetosphere observations show structured electrons and flows, and waves just outside the plasmasphere. Interestingly, the event with the picket fence had a >keV electron structure detached from the electron plasma sheet, while the event with only the mauve arc did not have precipitation or ultra-violet emission. We suggest that the electron precipitation drives the picket fence, and heating drives the mauve emission. We further present particle transport processes in the magnetosphere and discuss how magnetosphere conditions that are favorable to STEVE occur.

Keywords: STEVE, SAID

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Magnetosphere-Ionosphere Coupling by Alfvén Waves at Sub-Auroral Latitudes

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Most investigations of magnetosphere-ionosphere coupling have focused on the auroral zone where strong field-aligned currents flow. The sub-auroral region, however, is a region of very low ionospheric conductivity, leading to strong plasma flows often called sub-auroral polarization streams (SAPS). This suggests that the interaction of Alfvén waves in this region may have different characteristics than this interaction in the high conductivity auroral zone. The ionospheric conductivity profile is critically important for ground observations of ultra-low-frequency (ULF) waves. At very low conductivity, Alfvén waves will be strongly damped, indicating that the ground magnetic field will be very weak. On the other hand, at high conductivity, the ionosphere can shield field-aligned currents, again producing only weak ground magnetic fields. Such behavior has been seen in statistical studies of the ground fields on the dayside (Obana et al., 2005). Simple models of this process (e.g., Yoshikawa et al., 2002; Sciffer et al., 2004) have shown that the ratio of the ground magnetic field to the incident magnetic field in the ionosphere rises to a peak as the Pedersen conductance is enhanced, but then decreases as the Pedersen conductance is increased further. This question is investigated using a three-dimensional numerical model of ULF wave propagation in the magnetosphere. These results are relevant to the relationship between ground magnetic fields and the magnetic fields measured by low-altitude orbiting spacecraft, and may assist in the understanding of magnetosphere-ionosphere coupling during the sub-auroral emission called STEVE (Strong Thermal Emission from Velocity Enhancement).

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Keywords: Magnetosphere-Ionosphere Coupling, ULF Waves, Sub-Auroral Ionosphere

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Multi-wavelength imaging observations of STEVE at Athabasca, Canada

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STEVE (Strong Thermal Emission Velocity Enhancement) is a relatively new phenomenon in the area of auroral physics. Although STEVE has been recognized by amateur night sky watchers for about a decade, it is only recently that it has drawn attention of the space physics community. STEVE is distinctly different from traditional aurora and appears as a violet and green narrow band structure spreading over thousands of kilometers in the east-west direction. The purple STEVE emission is also accompanied usually by "Picket Fence" structure which are the distinct structures of green color. In this paper, we present the first multi-wavelength observations of STEVE using an all-sky imager at Athabasca (magnetic latitude = 61.7°N), Canada. This study is based on three STEVE events which were accompanied by picket fence structures in the green-line. Although the STEVE arc was dominant in 630.0 nm, weak emissions were also found in other wavelengths including OI at 844.6 nm, Hβ, and background continuum emission at 572.5 nm. The investigation on the evolutionary characteristics of the STEVE arc in 630.0 nm reveal that it detached from the auroral oval as a faint structure and moved equatorward. Similar to the arc in 630.0 nm, the arc in the 557.7 nm also detached from the auroral oval. In addition the 557.7 arc exhibited picket fence structure at later times. The picket fence was sometimes found to persist even after the 630.0 nm arc had disappeared. Based on the horizontal component of the geomagnetic field at Fort Smith (magnetic latitude 67.28°N), we find that the STEVE arc detachment, its equatorward motion, and its brightness coincided with additional magnetic activity in the recovery phase of a substorm. One of the distinctive features of our results is the appearance of dark bands at the poleward edge of the 557.7 nm arc. These dark bands might represent the so-called "black aurora". These results indicate that STEVE is not a sole consequence of F-region heating, but particle precipitation from the inner magnetosphere and associated field-aligned currents might play an important role to trigger STEVE.

Keywords: STEVE, Airglow, Aurora, subauroral ionosphere

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Pi2 ULF modulation of energetic electron precipitations observed by using VLF/LF transmitter signals

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It has been expected that ULF (ultra low frequency, 1 mHz –1 Hz) magnetic pulsations modulate the precipitation of electrons in the magnetosphere [Coroniti and Kennell, 1970]. In this process, periodic change in the local magnetic field strength due to the ULF pulsations modulates the growth rate of whistler mode chorus waves and resultant pitch angle scattering rate. That is, flux of the precipitating electrons may depend on the strength of pitch angle diffusion coefficient at the same frequency as the ULF pulsations. There have been several studies of Pc5 (1.67–6.67 mHz, the periods: 150–600 s) ULF modulation of energetic electron precipitations (EEP) in the D-region ionosphere based on ground-based riometers and X-ray observations [e.g., Brito et al., 2012]. The EEPs associated with Pi2 pulsations (40-150 s) were reported [Asnes et al., 2004]. Auroral precipitations and energetic particle flux near the equator in nightside magnetosphere occur due to Pi2 modulation [Saka et al., 1999]. Precipitation of low energy electrons below 300 eV was reported when a Pi2 pulsation with short periods (less than 40 s) occurred [Tsunomura et al., 1990]. However, there have been few reports for the ULF modulation of high energy electrons that modulate the D-region ionosphere. In this study, we investigate the D-region signatures of the modulation due to the ULF waves using a network of VLF/LF transmitter signals in North America. The transmitter signals from NLK (USA, 24.8 kHz, L = 2.88), NDK (USA, 25.2 kHz, L = 2.98) and WWVB (USA, 60.0 kHz, L = 2.26) were observed by a receiver at ATHA (Athabasca, Canada, L = 4.31). We show the first observations of oscillations in intensities and phases on the NDK-ATH and WWVB-ATH paths with periods of 3-4 minutes during a small substorm at 05:25-05:50 UT on 4 June, 2017 (AE index = 140 nT). Based on ground-based magnetic observations, there were pulsations with the same periods with the VLF/LF oscillations both at high- and low-latitudes. The ground-based H-component magnetic field variations and Doppler velocity observed by the SuperDARN (Super Dual Auroral Radar Network) HF (high frequency, 8-20 MHz here) radars showed the same periodic changes as seen in the VLF/LF oscillations, suggesting that energetic electron precipitation over the WWVB-ATHA and NDK-ATHA paths was modulated by the ULF waves. Based on the ground-based magnetic field data, we conclude that the ULF wave was the Pi2 pulsations associated with the substorm, because propagation direction of the wave was westward (66.4 km/s) from the pre-midnight sector, the magnetic variations at low latitudes were in-phase over wide longitudes, and the magnetic variations at ATHA slightly preceded those at low latitudes. Rising-tone chorus emission was observed in the frequency range of 5-6 kHz at ATHA during the VLF/LF oscillations. Pitch angle scattering by the whistler-mode chorus wave is one of possible mechanism that accounts for the energetic electron precipitation. In this presentation, we will discuss possible causes of these VLF/LF oscillations.

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Subauroral GPS TEC and phase variations during geomagnetic storms

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High-latitude ionospheric structure caused by precipitation of energetic particles, strong ionospheric currents and convection results in changes of the GPS total electron content (TEC) and rapid variations of GPS signal amplitude and phase. The phase variations, called phase scintillation, are typically observed in the ionospheric cusp, polar cap and auroral zone. They are particularly intense during geomagnetic storms when the aurora and ionospheric convection expand further equatorward. The ionospheric structure is also affected at subauroral latitudes resulting in the GPS TEC changes and phase scintillation. The focus of this paper will be the subauroral GPS TEC and phase variations that are caused by storm-enhanced plasma density (SED) on the dayside, and subauroral polarization streams (SAPS) on the nightside. Phase scintillation index is computed for specialized GPS scintillation receivers in Canada and Norway, at sampling rate of 50 Hz. A proxy scintillation index is obtained from dual frequency measurements of geodetic-quality GPS receivers sampling at 1 Hz, which include receivers operated by the Norwegian Mapping Authority (NMA), Greenland GPS Network (GNET) and globally distributed receivers of RT-IGS network that are monitored by the Canadian Geodetic Survey in near-real-time.

Keywords: Polar, auroral and subauroral ionosphere, Ionospheric irregularities, GPS TEC and phase scintillation

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[E] Oral | P (Space and Planetary Sciences)：P-AE Astronomy & Extrasolar Bodies

[P-AE22] Exoplanets

convener:Masahiro Ikoma(Department of Earth and Planetary Science, The University of Tokyo), Norio Narita(The University of Tokyo), Yuka Fujii(National Astronomical Observatory of Japan)

Exoplanetary science, which began with the discovery of a hot Jupiter in 1995, reached a significant turning point by the detection of countless super-Earths by the Kepler space telescope. In 2018, the new space telescope TESS was launched to conduct an extensive survey of exoplanets orbiting nearby bright stars, opening a new era of characterization of exoplanet atmospheres. Moreover, recent observations have identified a growing number of terrestrial planets in the so-called habitable zone. While exoplanets have been targeted mainly for astronomy until recently, it would be fair to say that Earth and planetary science is finally becoming a research field to make a central contribution. This session aims at allowing participants to share their research results and new ideas regarding exoplanets and also inform the current status of their projects. Exoplanet science is a growing, interdisciplinary research field. We welcome participants from various fields.

[PAE22-01] Population studies of exoplanetary atmospheres with next generation of space and ground telescopes

*Giovanna Tinetti[1] (1.UCL)

[PAE22-02] Solving atmospheric retrievals with deep learning.

★Invited Papers

*Ingo Waldmann[1] (1.University College London)

[PAE22-03] Condensates and Clouds in Exoplanetary Atmospheres: Some Lessons from our Solar System

★Invited Papers

*Tristan Guillot[1,2] (1.Observatoire de la Cote d Azur, 2.JSPS/University of Tokyo)

[PAE22-04] **Twinkle: a visible and near-infrared space-based observatory for exoplanet and solar system spectroscopy**

*Billy Nelson Edwards[1,2], Giovanna Tinetti[1,2], Marcell Tessenyi[2,1], Giorgio Savini[1,2], Jonathan Tennyson[1,2], Richard Archer[2], Ian Stotesbury[2], Max Joshua[2], Benjamin Wilcock[2] (1.University College London , 2.Blue Skies Space Ltd)

[PAE22-05] Detecting molecular lines in thermal emission spectra of temperate planets with SPICA/SMI

*Yuka Fujii[1], Taro Matsuo[2], Yui Kawashima[3], Kazumasa Ohno[4], Ayaka Okuya[4], Teruyuki Hirano[4] (1.Earth-Life Science Institute, Tokyo Institute of Technology, 2.Nagoya University, 3.Netherlands Institute for Space Research, 4.Tokyo Institute of Technology)

[PAE22-06] FUV-driven atmospheric escape from hot Jupiters

*Hiroto Mitani[1], Riouhei Nakatani[2], Naoki Yoshida[1] (1.The University of Tokyo, 2.RIKEN)

Population studies of exoplanetary atmospheres with next generation of space and ground telescopes

*Giovanna Tinetti[1]

1. UCL

In most fields of astronomy (supernovae, brown dwarfs, black holes), revolutions in our understanding of the main processes often came from the study of statistical behaviour using large samples as opposed to individual studies. As the next generation of space and ground-based telescopes come online, we are potentially reaching this important step in the study of exoplanet atmospheres. It is therefore paramount to prepare for the new wealth of information and challenges associated with future large scale studies. In this paper I will briefly review the instruments coming online in the next decade and present state of art models and tools to analyse and interpret observations of exoplanetary atmospheres.

Keywords: Exoplanets, Atmospheres, Spectroscopy

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Solving atmospheric retrievals with deep learning.

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1. University College London

The field of exoplanetary spectroscopy is as fast moving as it is new. Analysing currently available observations of exoplanetary atmospheres often invoke large and correlated parameter spaces that can be difficult to map or constrain. This is true for both: the data analysis of observations as well as the theoretical modelling of their atmospheres. In many aspects, data mining and non-linearity challenges encountered in other data intensive fields are directly transferable to the field of extrasolar planets as well as planetary sciences. In this talk, I will discuss the use of machine learning and in particular deep learning to help solve for complex likelihood spaces in the analysis of atmospheres. By efficiently exploiting the information content and sparsity of the data, we can gain significant new insights into atmospheric retrieval algorithms and how to optimally analyse low to mid-resolution spectra.

Keywords: exoplanets, machine learning, radiative transfer, atmospheric retrievals, bayesian techniques

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Condensates and Clouds in Exoplanetary Atmospheres: Some Lessons from our Solar System

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We will soon enter a new era for exoplanetary research: That of the characterization of exoplanetary atmospheres. With instruments such as JWST, Ariel and a growing number of instruments on ground-based observatories of different sizes, we can expect to learn much about the composition, structure and atmospheric dynamics of these planets. Before we can attempt to identify potentially habitable worlds, we must first make sense of these observations and understand their implications in terms of structure, dynamics and formation mechanisms. The lesson from our Solar System is that planets and planetary atmospheres are complex systems, full of surprises and far from being fully understood. Proper caution should be exercised when analyzing spatially unresolved observations of exoplanets often at a single epoch.

Most of the complexity can be tied to the presence of condensating species and the formation of clouds. The case of water in Jupiter is a particularly striking example: While water should be entirely in vapor form below about 5 to 7 bars, the Galileo probe has found its abundance to be extremely low down to 22 bars into the planet. Juno microwave observations indicate that ammonia is depleted relatively globally except near Jupiter's equator and the analysis of the mechanisms behind this indicates that water should follow suit: Thus the low abundance of water measured in hot spots but also throughout the north equatorial belt in Jupiter is probably not an indication of a low water abundance in the planet but instead of its settling to deeper regions than anticipated by classical models. In this case, the high molecular weight of water compared to hydrogen is a key factor to consider. This mechanism should be prevalent in exoplanets and brown dwarfs with hydrogen atmospheres, as long as they are cool enough to contain abundant condensing species.

On the other hand, exoplanets may be considered as unique laboratories to learn about the compositions and structure of planets in general. For example, water does not condense in hot Jupiters - measurements of its abundance may therefore provide a more reliable estimate of a global, bulk value in the deep interior. The observation of water clouds and atmospheric dynamics in temperate hydrogen planets will be invaluable to further understand the physics of planetary atmospheres in general.

Keywords: Exoplanets, Giant planets, Planetary Atmospheres, Composition, Clouds

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Twinkle: a visible and near-infrared space-based observatory for exoplanet and solar system spectroscopy

*Billy Nelson Edwards[1,2], Giovanna Tinetti[1,2], Marcell Tessenyi[2,1], Giorgio Savini[1,2], Jonathan Tennyson[1,2], Richard Archer[2], Ian Stotesbury[2], Max Joshua[2], Benjamin Wilcock[2]

1. University College London , 2. Blue Skies Space Ltd

The Twinkle Space Mission is a space-based observatory that has been conceived to measure the atmospheric composition of exoplanets, study bright stars and brown dwarfs, and reveal the surface mineralogy of solar system objects. The satellite is based on a high-heritage platform and will carry a 0.45 m telescope with a visible and near-infrared spectrograph providing simultaneous wavelength coverage from 0.5 - 4.5 μm. The spacecraft will be launched into a Sun-synchronous low-Earth polar orbit and will operate for a baseline lifetime of seven years.

Twinkle will have the capability to provide high-quality infrared spectroscopic characterisation of the atmospheres of hundreds of bright exoplanets, covering a wide range of planetary types. It will also be capable of providing phase curves for hot, short-period planets around bright stars and of providing ultra-precise photometric light curves to accurately constrain orbital parameters, including ephemerides and TTVs/TDVs present in multi-planet systems.

Twinkle is available for researchers around the globe in two ways:

1) joining its collaborative multi-year survey programme, which will observe hundreds of exoplanets and solar system objects; and

2) accessing dedicated telescope time on the spacecraft, which can be freely scheduled for any combination of science cases.

I will present an overview of Twinkle’s capabilities and discuss some example exoplanet surveys to highlight the broad range of targets the mission could observe, demonstrating the huge scientific potential of the spacecraft.

Keywords: Exoplanet Atmospheres, Visible and near-infrared spectroscopy

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Detecting molecular lines in thermal emission spectra of temperate planets with SPICA/SMI

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1. Earth-Life Science Institute, Tokyo Institute of Technology, 2. Nagoya University, 3. Netherlands Institute for Space Research, 4. Tokyo Institute of Technology

We examine the utility of SPICA/SMI for characterizing the thermal emission spectra of exoplanets. The sensitivity at $> 10\ \mu$m is useful for the observations of relatively warm/cool planets (around 300K) as their planet-to-star contrast significantly improves at these wavelengths. We modeled the thermal emission spectra of temperate Jupiter-like planets and found that the prominent features of NH_3 and H_2O would be expected at the wavelengths of SPICA/SMI. Their high-frequency features are detectable with a reasonable amount of integration time. We found that combining the data at various orbital phases is critical to suppress the correlated photon noise due to the spectral features of the stellar light. The high-resolution spectroscopy with SPICA/SMI is also able to measure their line-of-sight velocities, which allows us not only to measure the orbital inclination (and thus the true mass) but also to search for large moons or the binary planet system (Ochiai et al., 2014). This is relevant for warm/cool planets as the companions are dynamically more stable around them than around hot Jupiters. We also examine the detectability of the atmospheric features of terrestrial planets around nearby low-mass stars, e.g., Proxima Centauri b. The high-resolution spectroscopy (12-18μm) and mid-resolution spectroscopy (18-40μm) of SMI would be useful to probe CO_2, N_2O, and H_2O, while the required integration time is much longer. We discuss the range of accessible targets and the requirements for the stability of the pre-processed data.

Keywords: Exoplanets, Planetary Atmospheres, Spectroscopy

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FUV-driven atmospheric escape from hot Jupiters

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1. The University of Tokyo, 2. RIKEN

Since the first discovery in 1995, many hot Jupiters have been detected. For some hot Jupiters, it is thought that the atmosphere escapes due to the radiation from the central star. Such processes can change the evolution of close-in giant planets. A light close-in giant planet can lose a significant amount of mass because of its weak gravity. Thus, atmospheric escape can possibly explain the small number of light planets near the central star (so-called sub-Jupiter desert).

Recent theoretical studies of atmospheric escape from hot Jupiters incorporate the Extreme-UV (EUV; >13.6 eV) heating. EUV heats the gas through photoionization of hydrogen. It does not yield any metallicity-dependent trend. On the hand, some recent observations suggest that sub-Jupiter desert depends on the metallicity of the central star. There can be other heating processes which depends on metallicity.

In this study, we show that Far-UV (FUV; <13.6eV) drives atmospheric escape, using hydrodynamical simulation including radiative transfer and non-equilibrium chemistry. FUV can heat gas through the photoelectric effect of dust grains. The process is well known in the study of inter-stellar medium, but not considered in the atmospheric escape studies.

We find that FUV can drive atmospheric escape if the central star is hot (>6000K), and close-in giant planets around the hot stars can evaporate in ~100Myr. We also find that FUV-driven atmospheric escape depends on the metallicity of the planetary atmosphere and the central star. The heating rate and the mass loss rate increase in the case of metal-rich planets. However, both the rates decrease for the case of metal-rich central stars because FUV fluxes decrease in the metal-rich stars. We discuss the FUV-driven atmospheric escape and its dependence on the metallicity of planets and stars.

Keywords: Hot Jupiter, Atmospheric Escape

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[E] Oral | P (Space and Planetary Sciences)：P-AE Astronomy & Extrasolar Bodies

[P-AE22] Exoplanets

convener:Masahiro Ikoma(Department of Earth and Planetary Science, The University of Tokyo), Norio Narita(The University of Tokyo), Yuka Fujii(National Astronomical Observatory of Japan)

Exoplanetary science, which began with the discovery of a hot Jupiter in 1995, reached a significant turning point by the detection of countless super-Earths by the Kepler space telescope. In 2018, the new space telescope TESS was launched to conduct an extensive survey of exoplanets orbiting nearby bright stars, opening a new era of characterization of exoplanet atmospheres. Moreover, recent observations have identified a growing number of terrestrial planets in the so-called habitable zone. While exoplanets have been targeted mainly for astronomy until recently, it would be fair to say that Earth and planetary science is finally becoming a research field to make a central contribution. This session aims at allowing participants to share their research results and new ideas regarding exoplanets and also inform the current status of their projects. Exoplanet science is a growing, interdisciplinary research field. We welcome participants from various fields.

[PAE22-07] Pebble Accretion by Planets on Eccentric Orbits and the Mass Ratios of Exoplanets

*Steven J Desch[1], Alan Jackson[1], Chuhong Mai[1], Jessica Noviello[1] (1.Arizona State University, School of Earth and Space Exploration)

[PAE22-08] Theoretical prediction of water contents of terrestrial planets with effects of water production in primordial atmospheres

*Tadahiro Kimura[1], Masahiro Ikoma[1] (1.The University of Tokyo)

[PAE22-09] Water Storage Capacity of Rocky Exoplanet Interiors

*Christine Houser[1], Cayman T Unterborn[2], Jun Tsuchiya[3] (1.Earth-Life Science Institute, Tokyo Institute of Technology, 2.Arizona State University, 3.Geodynamics Research Center, Ehime University)

[PAE22-10] Thermal and magnetic evolution of exoplanetary cores

*Irene Bonati[1], Marine Lasbleis[2,1], Lena Noack[3] (1.Earth-Life Science Institute, Tokyo Institute of Technology, 2.Laboratoire de Planétologie et Géodynamique, Université de Nantes, 3.Freie Universität Berlin)

[PAE22-11] The Coupled Roles of Host Star Age, Exoplanet Radiogenic Heat Budget and Climatic Evolution

*Cayman T Unterborn[1], Steven Desch[1], Patrick Young[1], Greg Vance[1], Lee Chieffle[1], Bradford Foley[2] (1.Arizona State University, 2.Pennsylvania State University)

[PAE22-12] Impact of Stellar Superflares on Planetary Habitability

*Yosuke Alexandre Yamashiki[1], Hiroyuki Maehara[2], Vladimir Airapetian[3,4], Yuta Notsu[5], Tatsuhiko Sato[7], Takanori Sasaki[6] (1.Earth & Planetary Water Resources Assessment Laboratory Graduate School of Advanced Integrated Studies in Human Survivability Kyoto University, 2.Okayama Branch Office, Subaru Telescope, National Astronomical Observatory of Japan, 3.NASA/GSFC/SEEC, 4.American University, 5.Laboratory for Atmospheric and Space Physics, University of Colorado Boulder, 6.Department of Astronomy, Kyoto University, 7.Nuclear Science and Engineering Center, Japan Atomic Energy Agency (JAEA))

Pebble Accretion by Planets on Eccentric Orbits and the Mass Ratios of Exoplanets

*Steven J Desch[1], Alan Jackson[1], Chuhong Mai[1], Jessica Noviello[1]

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Introduction: Planets in our solar system and others grew remarkably fast. Super-Earth exoplanets have thick H_2/He atmospheres [1,2], requiring growth to several M_E within < 3-10 Myr [3]. Hf-W dating of Mars shows it mostly formed between 1 and 3 Myr [4]. Low-D/H hydrogen reservoirs in Earth [5,6] and Theia [7,8] and solar He, Ne [9] demand ingassing of solar nebula gas into the magma oceans of the planetary embryos comprising them; these must have grown to ~0.4 M_E in < 3 Myr [3]. Pebble accretion [10], an aerodynamic process allowing a planet to capture most particles with Stokes numbers St ~0.01–0.1 in its Hill sphere of radius R_H, best explains this growth.

Super-Earths in multi-exoplanet Kepler systems appear similar in orbital period ratios and in size and mass, like "peas in a pod" [11]. Likewise proto-Earth and Theia were probably similarly sized embryos. But most pebble accretion models predict that planets grow at rates $dM_p/dt \sim M_p^{2/3}$ [10] and the mass ratios should decrease with time only slowly, unlike the peas-in-a-pod result. We propose that planet growth may be dominated by the short intervals of time spent by a planet on an eccentric orbit following a scattering event, and that this would produce similar masses.

Circular vs. eccentric orbits: A planet on a circular orbit sees its mass M_p increases at a rate $dM_p/dt = 2 R_H^2 \Sigma_p \Omega$, where Σ_p is the surface density of pebbles (St~0.01–0.1 solids), yielding $dM_p/dt \sim 47 (\Sigma_p / 1 \text{ g cm}^{-2}) (M_p / 1 M_E)^{2/3} M_E \text{ Myr}^{-1}$ at a=1 AU. Assuming $\Sigma_p = 1$ g cm^{-2} at 1 AU, in 10^5 yr a 0.5 M_E planet would grow to 13.2 M_E, but a 2.0 M_E planet to 22.6 M_E. The mass ratio would decrease from 4.0 to 1.7. Planets on orbits with eccentricity e grow faster: in a co-rotating frame, the planet makes epicyclic orbits with radial excursions $\pm ae$, moving relative to the gas at speeds $\sim e a \Omega$, several km/s. We can show that if $e > 2\pi \text{St} \sim 10^{-1}$, then $dM_p/dt = ae \Sigma_p \eta V_K$, where $V_K = a\Omega$ and $\eta = -(C^2/V_K^2) d\ln P / d\ln r \sim 10^{-3}$ [12]. This generally exceeds the circular orbit pebble accretion rate, because the embryo can sweep up pebbles from a larger area, and because pebbles are swept up with greater efficiency.

If scattered onto an eccentric orbit, planets accrete faster, until their orbits damp on timescales $\tau = 0.1 (M_p/ 0.5 M_E)^{-1}$ Myr due to disk torques [13]. The growth rate dM_p/dt is proportional to e, but e is damped at rates $de/dt = -e/\tau$ proportional to M_p. Integrating the coupled differential equations, we find that being scattered onto an orbit with eccentricity e will cause a 0.5 M_E embryo to reach mass $M_p = 3.80 (\Sigma_p / 1 \text{ g cm}^{-2})^{1/2} (e / 0.1)^{1/2} M_E$, and a 2.0 M_E embryo to reach mass $M_p = 4.26 (\Sigma_p / 1 \text{ g cm}^{-2})^{1/2} (e / 0.1)^{1/2} M_E$, before circularizing within about ~5×10^4 yr. After a burst of rapid growth while on eccentric orbits, the mass ratio drops from 4.0 to 1.12, much closer to 1. Growth primarily while on eccentric orbits may explain why exoplanets in a system have similar masses [11].

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Keywords: exoplanets, Theia, pebble accretion

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Theoretical prediction of water contents of terrestrial planets with effects of water production in primordial atmospheres

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Because of a growing number of detected exoplanets with Earth-like insolation, it is now important to predict how common Earth-like aqua planets are beyond the solar system. Theoretical predictions so far consider only water delivery from icy or water-rich planetesimals and conclude that planets with Earth-like water contents are rare around M dwarfs, which are the main target of ongoing and near-future observations. On the other hand, a primordial atmosphere of nebular origin itself is capable of producing water through oxidation of the atmospheric hydrogen with oxides in rocky materials from incoming planetesimals or the magma ocean. Thermodynamically, normal oxygen buffers produce water comparable in mass to or more than hydrogen. Thus, the primordial atmosphere would likely be highly enriched with water vapor. However, the properties of such water-rich primordial atmospheres are poorly known. Here we integrate the 1D structure of such an enriched atmosphere and investigate the effects of water enrichment on the atmospheric structure and mass with focus on the water amount. We have found that the mass of the 80 wt.% H_2O atmosphere is larger by a few orders of magnitude than that for solar-abundance atmosphere, and that even a Mars-mass planet can obtain water comparable in mass to the present Earth oceans. Furthermore, by combining the atmospheric structure model and planetary population synthesis model, we have found that the produced water in the primordial atmosphere significantly affects the predicted abundance of terrestrial exoplanets with Earth-like water contents. For more precise predictions, however, detailed investigation about the water production processes such as material mixing in the atmosphere and magma ocean and ingassing of produced water into the magma ocean are required in the future.

Keywords: terrestrial planet, primordial atmosphere, water content

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Water Storage Capacity of Rocky Exoplanet Interiors

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A tectonically active planet has the capacity to transport and store water deep in its interior. The Earth transports water from the surface into the upper mantle by the subduction of cold oceanic lithosphere at subduction zones. On Earth we observe that most of the water returns to the surface, but some water may leak deeper into the planet. The minerals wadsleyite and ringwoodite are high pressure forms of olivine that comprise a majority of the mineralogy between approximately 400-700 km of Earth’ s mantle (ie. the mantle transition zone). While the upper and lower mantle minerals can host almost no water in their structure, the transition zone minerals can host hydrogen as defects in their crystal structure in the range of 1-3 wt.% water. Thus, the transition zone minerals have the greatest potential for long-term water storage in a rocky mantle. In addition, there are minor phases that can host hydrogen in their crystal structure under colder temperature and higher aluminum conditions. Here we show how the storage capacity of water in a planet's interior changes as the planet grows from Mars size to two Earth masses and how water at the surface modifies this internal storage capacity. Assuming Earth composition, as planet mass increases, the transition zone minerals shift to shallower depth creating a thinner shell that can store water. Since this shell is moving to larger radius as planet mass increases, we find the volume increases rapidly as a planet grows from Mars to Earth size and then plateaus for Earth to 2xEarth-mass planets. As oceans of water accumulate at the planet’ s surface, the interior pressure and temperature profile changes due to the change in the density profile which also shifts the transition zone minerals to shallower depth. We find that a dynamic planet can quickly saturate its transition zone if tectonics transports water into the deep interior. Once these minerals are saturated, any additional water supply will lead to flux melting, such as that which drives arc volcanism in Earth's upper mantle. Thus, tectonically active, water-rich rocky planets may likely be able to sustain volcanism although the depth and nature of the dehydration reaction changes with time.

Keywords: mantle transition zone, water worlds, mineral physics

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Thermal and magnetic evolution of exoplanetary cores

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Most of the planets located within our solar system display evidence of past and/or current magnetic activity, with the potential exception of Venus. Magnetic fields of rocky bodies are thought to be driven by thermo-chemical convection taking place in an electrically conducting fluid in their deep interior, such as the liquid outer core for Earth. The existence of a magnetic field during the history of a planet is therefore considered as a constraint for past or present internal dynamics, as well as a strong evidence for the existence of a liquid core at depth. In addition, magnetism is thought to play an important role for the development of habitable surface conditions and for the long-term stability of a planet, as it shields the upper atmosphere from mass loss induced by stellar winds and extreme space weather events. This, as well as the discovery of a large number of extrasolar bodies, motivates the search and study of magnetic fields beyond the solar system. Such a goal requires knowledge of the cores of bodies other than Earth, while current observations are limited to their radius and minimum mass.

Here, we investigate the evolution of planets having different masses and compositions, defined by their iron content and the mantle iron number. Starting out from the temperature profile right after the solidification of a global magma ocean, we determine the size and structure of the core, and model its subsequent thermal and magnetic evolution history. We calculate the buoyancy fluxes resulting from compositional and thermal convection, as well as the generated magnetic field strength and lifetime. While the planetary mass does not seem to be a determining factor, we find that iron-rich planets start out with inner cores that are substantially larger than iron-poor bodies, and can maintain an active magnetic field for longer. Depending on the initial amount of impurities in the core, the strength of the generated magnetic fields is similar or stronger than Earth’s, although they are still too weak to be observed by current instrumentation.

Keywords: Exoplanetary cores, Magnetic field

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The Coupled Roles of Host Star Age, Exoplanet Radiogenic Heat Budget and Climatic Evolution

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The ideal exoplanets on which to search for life are rocky exoplanets with temperate climates that have been stable for billions of years. Even for a planet orbiting within the host star's habitable zone, its climate is a strong function of its geochemistry and its evolution to date. The primary controls on a rocky exoplanet's climate are the rates of removal of greenhouse gases (in particular, CO_2) by weathering, the rates of release of those greenhouse gases from the planet's interior by volcanic processes, and the balance between these rates. These processes require a sufficient heat budget to power them. As a rocky planet ages, its heat budget --- a combination of heat of formation, gravitational potential energy released during core formation, and heat released by radioactive elements, especially ^{40}K, ^{232}Th, ^{238}U and ^{235}U --- dwindles, slowing the rates of mantle degassing and weathering. Having exhausted their heat budgets, it is possible, then, for certain planets to be too old to support these climate-regulating processes, and thus are more likely to be in the snowball or hot-house climate regimes. Here, we quantify this “timescale of temperateness” by performing Monte Carlo 1-D exoplanet thermal evolution simulations of exoplanets across an observationally-constrained range of stellar abundances for long-lived radionuclides (Th, K) or their proxies (Eu for U). We perform these models under the assumption of stagnant-lid convection. We find the average lifetime of degassing for an Earth-sized stagnant-lid planet is 1.6 ±0.8 Gyr, with longer lifetimes expected for those planets that formed with a higher concentration of ^{40}K. Older exoplanets, such as those in the TRAPPIST-1 (age 8 ±2 Gyr) or Kepler 444 (age 11 ±2 Gyr) systems, are unlikely to be degassing at all and thus very presumably to be in the hothouse or snowball climate regimes. That is unless these planets are additionally heated by tidal dissipation, or undergoing plate tectonics. As plate tectonics may be rare, we assert these results represent a conservative lower-limit for the “timescale of temperateness” for Earth-sized exoplanets. Should an Earth-size exoplanet older this age range be observed to be actively degassing, however, this may be an indirect observation that the planet is undergoing active plate tectonics. We argue, then, that both stellar age and host-star radionuclide abundances are therefore key observables in determining whether an exoplanet is likely to be "Earth-like," temperate and potentially habitable.

Keywords: Exoplanets, Habitability, Geodynamics, Climate

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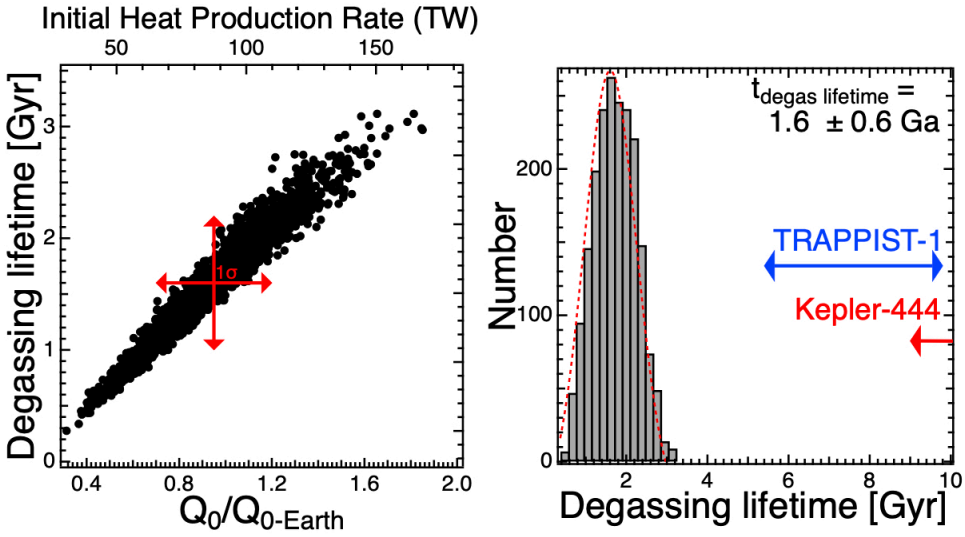

Figure 1:

LEFT: Calculated times when degassing rates fall below 10% of Earth value as function of total initial heat budget (Q_0) relative to model adopting Earth abundances of radionuclides. The one sigma range for each axis are shown as red arrows. Total heat production in TW is shown on top axis.

Right: Histogram of calculated degassing lifetimes for 2000 model runs adopting random radionuclide abundances. The reported ages ± 1σ of the star's TRAPPIST- 1 (Burgasser & Mamajek, 2017) and Kepler-444 (Mack et al., 2018) are shown for reference in blue and red, respectively.

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Impact of Stellar Superflares on Planetary Habitability

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High-energy radiation caused by exoplanetary space weather events from planet-hosting stars can play a crucial role in conditions promoting or destroying habitability in addition to the conventional factors. In this paper, we present the first quantitative impact evaluation system of stellar flares on the habitability factors with an emphasis on the impact of stellar proton events. We derive the maximum flare energy from stellar star spot sizes and examine the impacts of flare-associated ionizing radiation on CO_2, H_2, and N_2+O_2-rich atmospheres of a number of well-characterized terrestrial type exoplanets. Our simulations based on the Particle and Heavy Ion Transport code System suggest that the estimated ground-level dose for each planet in the case of terrestrial-level atmospheric pressure (1 bar) for each exoplanet does not exceed the critical dose for complex (multicellular) life to persist, even for the planetary surface of Proxima Centauri b, Ross-128 b, and TRAPPIST-1 e. However, when we take into account the effects of the possible maximum flares from those host stars, the estimated dose reaches fatal levels at the terrestrial lowest atmospheric depth on TRAPPIST-1 e and Ross-128 b. Large fluxes of coronal X-ray and ultraviolet radiation from active stars induce high atmospheric escape rates from close-in exoplanets, suggesting that the atmospheric depth can be substantially smaller than that on Earth. In a scenario with the atmospheric thickness of one-tenth of Earth's, the radiation dose from close-in planets including Proxima Centauri b and TRAPPIST-1 e reaches near fatal levels with annual frequency of flare occurrence from their host stars. The radiation dose for newly discovered planets, such as TOI-700 d, is indeed smaller as estimated upon the observation.

Keywords: Stellar flare, Ionizing radiation

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[E] Oral | P (Space and Planetary Sciences)：P-CG Complex & General

[P-CG23] Shock responses of planetary materials elucidated from meteorites and laboratory experiments

convener:Takuo Okuchi(Institute for Planetary Materials, Okayama University), Toshimori Sekine(Center for High Pressure Science and Technology Advanced Research), Naotaka Tomioka(Kochi Institute for Core Sample Research, Japan Agency for Marine-Earth Science and Technology)

Impact phenomena have been recognized to play essential roles in the processes of planetary evolution. Recent progresses in nanoscale analysis of meteorites, asteroid explorations, as well as laboratory experiments for simulating shock dynamics on planetary materials are collaboratively revealing complex effects of shock-induced processes in planetary evolution. Recently, several new metastable high-pressure phases have been identified in strongly shocked meteorites. Their occurrences indicate that the shock-induced physical states are far from thermodynamic equilibrium and contain very complicated processes. On the other hand, laboratory experiments including laser-driven shock techniques have recently been making remarkable progresses. They successfully simulate a variety of fast non-equilibrium processes at transient high-pressure conditions reaching tens to a few hundreds of gigapascals, that uniquely affect the physical and chemical properties of planetary materials upon impacts. Here we discuss how planetary materials are compressed, fractured, transformed, melted, and quenched during impact events by referring these recent studies. We welcome presentations from interdisciplinary research fields related to shock responses of planetary materials.

[PCG23-01] Shock heating origin of anomalous achondrite NWA 6704 from infrared spectroscopy and modal mineralogy

*Matthew Izawa[1], Sean Yokoyama[2], Shigeru Yamashita[1], Takuo Okuchi[1], Takuya Moriguti[1], Andrew P Jephcoat[1], Vishnu Reddy[3], Allison M McGraw[3], Lucille Le Corre[4], Edward A Cloutis[5] (1.Institute for Planetary Materials, Okayama University, 827 Yamada, Misasa, Tottori 682-0193, Japan, 2.University of Toronto, 27 King's College Cir, Toronto, ON M5S, Canada , 3.Lunar and Planetary Laboratory, University of Arizona, 1629 E University Blvd Tucson AZ 85721-0092 USA, 4.Planetary Science Institute, 1700 East Fort Lowell, Suite 106, Tucson, AZ, USA, 5.Center for Terrestrial and Planetary Exploration, University of Winnipeg, 515 Portage Avenue, Winnipeg, Manitoba, R3B 2E9 Canada)

[PCG23-02] A new Mg2SiO4 polymorph “poirierite” in shocked meteorites and its possible high-pressure synthesis conditions

*Naotaka Tomioka[1], Takuo Okuchi[2], Luca Bindi[3], Masaaki Miyahara[4], Toshiaki Iitaka[5], Zhi Li[6], Xiande Xie[7], Narangoo Purevjav[2,8], Kiyoshi Fujino[9], Tetsuo Irifune[9], Riho Tani[4,1], Yu Kodama[10] (1.Kochi Institute for Core Sample Research, Japan Agency for Marine-Earth Science and Technology, 2.Institute for Planetary Materials, Okayama University, 3.Università degli Studi di Firenze, 4.Hiroshima University, 5.RIKEN, 6.Nanjing University of Science and Technology, 7.Guangzhou Institute of Geochemistry, 8.Bayerisches Geoinstitut, University of Bayreuth, 9.Geodynamics Research Center, Ehime University, 10.Marine Works Japan Ltd)

[PCG23-03] Shock degrees of eucrites from petrographic and XRD analyses

*Rei Kanemaru[1], Naoya Imae[1,2], Akira Yamaguchi[1,2], Hirotsugu Nishido[3] (1.the Graduate University for Advanced Studies (SOKENDAI), 2.National Institute of Polar Research (NIPR), 3.Okayama University of Science (OUS))

[PCG23-04] Shock conditions for shergottites: A comparison between Asuka 12325 and other shergottites

★Invited Papers

*Atsushi Takenouchi[1], Akira Yamaguchi[1], Takashi Mikouchi[2] (1.National Institute of Polar Research, 2.The University Museum, The University of Tokyo)

[PCG23-05] Shock and recovery experiments of petrologic type 3 ordinary chondrite

*Masaaki Miyahara[1], Junnosuke Edanaga[1], Akira Yamaguchi[2], Takamichi Kobayashi[3], Toshimori Sekine[4,5] (1.Department of Earth and Planetary Systems Science, Graduate School of Science, Hiroshima University, 2.National Institute of Polar Research, 3.National Institute for Materials Science, 4.Center for High-Pressure Science and Technology Advanced Research, 5.Graduate School of Engineering, Osaka University)

[PCG23-06] An overlooked heat source in impact events and its effect on the degree of devolatilization of natural calcite carbonates

★Invited Papers

*Kosuke Kurosawa[1], Hidenori Genda[2], Shintaro Azuma[3], Keishi Okazaki[4] (1.Planetary Exploration Research Center, Chiba Institute of Technology, 2.Earth-Life Science Institute, Tokyo Institute of Technology, 3.Department of Earth and Planetary Sciences, School of Science, Tokyo Institute of Technology , 4.Kochi Institute for Core Sample Research, JAMSTEC)

Shock heating origin of anomalous achondrite NWA 6704 from infrared spectroscopy and modal mineralogy

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The anomalous achondrite Northwest Africa (NWA) 6704 has isotopic affinities with carbonaceous chondrites and shows geochemical evidence for a highly oxidized precursor and no sign of equilibration with a metallic melt. NWA 6704 and its paired samples are dominated by pyroxene with sodic plagioclase, Ni-bearing olivine, and rare chromite and awaruite (Ni_3Fe). The isotopic and geochemical link between the NWA 6704 pairing group and carbonaceous chondrites is consistent with significant hydration of the precursor materials. Both endogenic [1] and impact-melt [2] origins for NWA 6704 meteorites have been proposed. Here, we use infrared spectroscopy of pyroxene grains from NWA 6704 to show a distinct lack of hydration in the parent melt of NWA 6704, consistent with an origin as a superheated impact melt. The recent discovery of plausible parent asteroids for NWA 6704 [3] demonstrates that some apparently dry, “igneous” asteroids (including in the outer asteroid belt) may have originated as impact-melted material, possibly during catastrophic collisional disruptions.

[1] Warren et al., Geochimica et Cosmochimica Acta 107:135–154 2013 [2] Hibiya et al., Geochimica et Cosmochimica Acta 245(15) 597-627, 2018 [3] McGraw et al., in press, Astrophysical Journal 2020

Keywords: Shock melting, Anomalous achondrites, Infrared spectroscopy

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A new Mg2SiO4 polymorph “poirierite” in shocked meteorites and its possible high-pressure synthesis conditions

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A new spinelloid-structured $(Mg,Fe)_2SiO_4$ polymorph named poirierite, whose structure was theoretically predicted three decades ago [1], was discovered successively in Tenham [2], Miami, and Suizhou shocked ordinary chondrites. HRTEM observations clarified that the nano-scale lamellar poirierite in Tenham and Miami is topotactically intergrown with polycrystalline ringwoodite and wadsleyite, respectively. The topotaxy demonstrated that the ringwoodite/wadsleyite to poirierite transformations were promoted by shear mechanisms after supercooling at peak shock pressure or during a subsequent decompression process in the shock metamorphism. Single-crystal X-ray diffraction analysis of poirierite from Suizhou, as well as results of first principles calculations, confirmed that the mineral has a minimum unit-cell size with dynamical stability among all the spinel-related structures. Due to structural similarities also with olivine, the poirierite structure would be a relay point in all the shear transformations in $(Mg,Fe)_2SiO_4$, thus enhancing its kinetics.

To understand the formation conditions of poirierite, we have also performed high-pressure experiments of San Carlos olivine (Fo_{90}) powder with heterogeneous grains size (<~100 μm) at 16 GPa and 900 ˚C by using a Kawai-type multianvil apparatus. The olivine grains were partially transformed into polycrystalline ringwoodite aggregates. TEM observations clarified that the ringwoodite grains have a high density of stacking faults on {110} as well as those in heavily shocked chondrites. Some of the grains showed weak electron diffraction spots corresponding to the poirierite structure in addition to those of ringwoodite. Fe-free wadsleyite, which was formed in the rim of a single crystal olivine (300 μm) surrounded by olivine powder (10 μm) at 15.5 GPa and 1000 ˚C [3], was also examined by TEM. Some of the wadsleyite grains with pervasive stacking faults on (010) plane showed the poirierite diffraction spots. Although detailed formation conditions need to be further evaluated, poirierite would form within the stability fields of wadsleyite and ringwoodite when a large differential stress is applied at relatively low temperatures.

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Keywords: Shock metamorphism, meteorite, olivine, high-pressure phase transition

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Shock degrees of eucrites from petrographic and XRD analyses

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Shock metamorphism is one of the most important geologic processes on the surface crust of asteroids. The evaluation of shock metamorphism is indispensable for better understanding of the material evolution at the early solar system. Eucrites are believed to have derived from the outer crust of the asteroid 4 Vesta. Eucrites experienced a complex shock history [e.g., 1]. Therefore, we propose the shock degrees of eucrites combing XRD analysis with petrographic observations. We have three specific purposes in this study, 1) the determination of the shock degrees of eucrites on the basis of textures, 2) the semi-quantitative measurement of shock degrees from XRD data, and 3) the better understanding of impact history on the eucrite parent body.

We performed petrological and mineralogical studies using an optical microscope, an FE-SEM, an EPMA, a micro-Raman spectroscopy at NIPR, and a luminoscope at the Okayama University of Science. We performed XRD analyses by the in-plane rotation method of polished sections [2], using an X-ray diffractometer (SmartLab), on the conditions of Cu Kα1 (wavelength = 0.15406 nm) with 40 kV and 40 mA through the slit of 10 mm in height and 5 mm in width with the divergence angle of (1/6) ˚. The measured range of the twofold Bragg angle is 8 to 75˚. The rotation speed of the polished sections was 100 rpm. We measured 12 basaltic eucrites and 4 cumulate eucrites.

We proposed the shock degrees of eucrites from A to E, based on the petrographic textures. The textural criteria include the angles of undulatory extinction, and the relative abundance of maskelynite to plagioclase. Shock degree A represents unshocked eucrites, characterized by a sharp (< ~2º) optical extinction of plagioclase and pyroxene (e.g., Agoult and EET 90020). Shock degree B represents weakly shocked eucrites, characterized by an weak undulatory extinction (< 15º) (e.g., NWA 5356 and Y 983366). Shock degrees C, D, and E show strong undulatory extinction (>15º) and are divided by the relative abundance of maskelynite to plagioclase. Shock degree C represents the moderately shocked eucrites, characterized by the absence of maskelynite (e.g., Stannern and Y-792510). Shock degree D represents the moderately to highly shocked eucrites, characterized by small abundances of maskelynite (Msk/Msk+Pl = < 0.1) (e.g., Y-790266 and Y 980433). The maskelynite in the eucrites with the degree C located only near the shock vein. The occurrence of maskelynite may be explained by at high-temperature conditions along shock veins [3]. Shock degree E eucrites are characterized by abundant maskelynite (Msk/Msk+Pl = >> 0.5) (e.g., A-87272). The occurrence of maskelynite suggests that the A-87272 experienced near the equilibrium shock pressure of maskleynization.

The macroscopic XRD data such as averaged FWHM (full width at half maximum) values, shows the correlation for the shock degrees estimated from textures. The averaged FWHM values increase as shock degrees increases. Since the FWHM values reflect the lattice spacing, the increasing of the averaged FWHM values indicates the disturbance of the crystal lattice. Therefore, the peak broadening of the shocked eucrites is closely related to the degree of shock metamorphism.

In summary, the results of petrographic observations and XRD analyses are consistent and are a useful indicator for evaluating shock degrees of eucrites to infer the impact history on the Vestan crust.

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Keywords: Eucrite, Shock metamorphism, XRD analysis

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Shock conditions for shergottites: A comparison between Asuka 12325 and other shergottites

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Most Martian meteorites, in particular shergottites, show severe shock metamorphism, such as shock melting, complete maskelynitization of plagioclase, transformation to high-pressure phases and its back-transformation. Recently, weakly shocked shergottites (Northwest Africa (NWA) 8159 and NWA 10416) whose plagioclase is still crystalline were reported (Sharp et al. 2019; Walton et al. 2016) and we also found that Asuka 12325 (A 12325) retained birefringent plagioclase (Takenouchi et al. 2019, 2020). Such weakly shocked shergottites are rare and may have recorded specific shock conditions when shergottites were ejected from Mars. For example, NWA 8159 experienced longer shock duration (~100 ms) compared with Tissint or Zagami (Sharp et al. 2019). Revealing such differences in shock conditions between severely and weakly shocked shergottites is important to constrain shock conditions for shergottites' ejection. Therefore, in this study, we compare shock metamorphism of A 12325 with that of other shergottites and discuss the shock conditions of shergottites.

A 12325 is a poikilitic shergottite with "depleted" rare earth element pattern and general descriptions are found in Debaille et al. (2019) and Takenouchi et al. (2019). Poikilitic shergottites, in particular "intermediate" ones, commonly contain maskelynite and their shock pressures were estimated ~55 GPa (e.g., Takenouchi et al. 2018), while their shock durations are poorly constrained yet. In contrast to such poikilitic shergottites, almost of all plagioclase in A 12325 are only partly isotropic indicating its shock pressure below 26-31 GPa (Takenouchi et al. 2019), which is slightly weaker than that of Tissint (Walton et al. 2014). A shock vein in A 12325 is occupied mainly by ringwoodite (<1 μm in size) and chemically zoned majorite (~3 μm in size), which is different from shock melt veins in "intermediate" poikilitic shergottites containing abundant voids and quenched low-pressure minerals. Even in the center of the thickest vein (220 μm in width), majorite and ringwoodite are present. Ringwoodite also occurs at the rim of the host olivine adjacent to the shock melt vein. The ringwoodite rim around a 110 μm-thick shock vein is composed of a 20 μm-thick homogeneous (microcrystalline) region and a ~15 μm-thick lamella-rich region.

If we assume cooling by 1-dimensional thermal conduction (Carlsow and Jaeger 1959) with an initial temperature gradient from 2573 K to 2023 K within the vein and from 2023 K to 273 K in surrounding areas, we can reproduce the ringwoodite formation around the 110 μm-thick shock vein by calculating its growth rate (Ohtani et al. 2004), although differences such as Fe contents in ringwoodite were not taken into consideration. Then, when we calculated the cooling of the 220 μm-thick shock vein in the same way, we obtained that the cooling of the vein center from 2573 K to 2200 K and to 2000 K took 9.2 ms and 21 ms, respectively. In order to form ringwoodite at the center of the thickest shock vein, high-pressure about 13-16 GPa must have been retained when the vein temperature reached its solidus temperature. Therefore, if we adopt 2000-2200 K for solidus temperature at 13-16 GPa (Agee et al. 1995), the shock duration may be longer than at least >9.1-21 ms. The shock duration of 9-21 ms is almost the same or a little longer compared with those of Tissint and Zagami, but shorter than that of NWA 8159. This result indicates that shergottites with similar shock pressure tend to experience similar shock duration regardless of its primary igneous texture, and possibly, shock pressure and duration may be correlated among rocks that have escaped from Mars. If this is the case, "intermediate" shergottites may have experienced the shortest shock duration owing to its highest shock pressure. In addition to their high post-shock temperature, such short shock duration may contribute to the absence of high-pressure

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minerals in those severely shocked shergottites.

Keywords: shergottite, shock metamorphism, Martian meteorites

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Shock and recovery experiments of petrologic type 3 ordinary chondrite

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One of the classic structure models for an ordinary chondrite parent-body is the onion shell model [e.g., 1]. Based on the onion shell model, the parent-body consists of petrologic type 3, 4, 5, and 6 ordinary chondrites from the outside to inside. Many previous works have worked on the shock features recorded in the petrologic type 5 and 6 consisting of the inside portions of the parent-body. In contrast, few previous works worked on the shock features recorded in the petrologic type 3 and 4 consisting of the outside portions of the parent-body. Our preliminary investigations showed that several petrologic type 3 ordinary chondrites have shock-induced melting textures, deformed chondrules, and high-pressure polymorphs [2]. We expect that the deformation degree of the chondrules depends on the shock pressure. In the present study, we will try to evaluate the relationship between the ellipticity of the chondrule and shock pressure through the shock and recovery experiments.

We used Allan Hills 78084 (ALH 78084) H3.9 and Yamato 793375 (Y-793375) L3.6 ordinary chondrites for our purpose. We prepared the doubly polished disc samples (ϕ = 12 mm, thickness = 1.5 mm) from their piece samples allocated from NIPR. We put the disc samples into the stainless container. We used a propellant gun installed at NIMS for the shock and recovery experiments. We estimated the shock pressure by the impedance matching method. The shock experiments were conducted up to 42.9 GPa (6 shots for ALH 78084 H3.9 and 6 shots for Y-793375 L3.6).

We recovered all stainless containers including the disc samples successfully after each shot. We cut the stainless containers and polished the disc samples in the containers. The polished surface is almost parallel to the shockwave front. We took the back-scattered electron (BSE) images of the polished disc samples using a field-emission scanning electron microscope (FE-SEM) at NIPR. We measured the ellipticity (1 - (short axis/long axis)) of the chondrules using the BSE image and image processing application. We also measured the ellipticity of the chondrules in ALH 78084 H3.9 and Y-793375 L3.6 using their petrographic thin sections stored in NIPR.

The long and short axes of the chondrules in ALH 78084 H3.9 as a starting material are 337 μm and 277 μm (median), respectively. Those in Y-793375 L3.6 as a starting material are 596 μm and 498 μm (median), respectively. The ellipticity of ALH 78084 H3.9 and Y-793375 L3.6 as starting materials are 0.16 and 0.18 (median), respectively. The ellipticity of the chondrules in the recovered samples becomes bigger compared to those in the starting samples. The ellipticity of the chondrules in ALH 78084 H3.9 at 42.9 GPa and Y-793375 L3.6 at 42.5 GPa are 0.36 and 0.43 (median), respectively. The ellipticity of the chondrules in ALH 78084 H3.9 and Y-793375 L3.6 becomes bigger with increasing the shock pressure. The planar fracture almost parallel to the shockwave front becomes distinct in the shocked samples above ~36 GPa both in ALH 78084 H3.9 and Y-793375 L3.6. Melting textures were observed at the boundaries between the chondrule and matrix in the shocked samples above ~10 GPa.

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We could reproduce the shock-induced deformation of the chondrules and shock-induced melting by the shock and recovery experiments. We propose that we can estimate the shock pressure recorded in petrologic type 3 and 4 using the ellipticity of the chondrules.

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Keywords: ordinary chondrite, petrologic type 3, Shock experiment

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An overlooked heat source in impact events and its effect on the degree of devolatilization of natural calcite carbonates

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Mutual collisions between two small planetary bodies at the main belt region at velocities higher than several km s^{-1}cause heating of their surface materials, resulting in a variety of thermal metamorphism. Given that we have understood the relation between the degree of thermal metamorphism and impact condition accurately, analyses of thermally-metamorphic features recorded in meteorites allow us to decode the impact environment in the solar system through its history. Recently, Kurosawa and Genda (2018) found that plastic deformation of the shock-comminuted rocks during decompression from the peak shock state efficiently converts the kinetic energy in the impact-driven flow field into the thermal one, resulting in a higher degree of shock heating than previously thought. If a temperature rise due to plastic deformation is also significant in natural impact events, impact histories derived from thermal metamorphism would need to be revised. This new finding was obtained based on a modern shock physics code, which can treat elasto-plastic behavior of rocky materials. In this study, we validated the numerical results by comparing the numerically-calculated CO2 production with the experimental data pertaining to natural calcite blocks by Kurosawa et al. (2012). We simulated the seven impacts performed in the experiment by using the iSALE-2D. The “ROCK” model in the iSALE package was used to simulate pressure-temperature dependent elasto-plastic behavior of calcites. We varied the von-Mises limit Y_{lim} as a free parameter to explore the roles of material strength on the numerical results. The CO_2 production in the simulation was calculated based on temporal entropy under an assumption that the system is in a thermal equilibrium. Total 35 runs with 4 different Y_{lim} values and without material strength (i.e., purely hydrodynamic) were performed. We found that the calculated CO_2 production in the case of hydrodynamic is systematically lower than the experimental results. In contrast, if we used Y_{lim} = 1 GPa, the calculated values are close to the experimental results at impact velocities ranged from 2 to 7 km/s, strongly suggesting that the additional heating during decompression due to plastic deformation is significant in natural impact events.

Acnowledgement: We appreciate the developers of iSALE, including G. Collins, K. Wünnemann, B. Ivanov, J. Melosh, and D. Elbeshausen. We also thank Tom Davison for the development of the pySALEPlot.

Keywords: Shock-induced devolatilization, Plastic deformation, Calcites

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[E] Oral | P (Space and Planetary Sciences)：P-CG Complex & General

[P-CG23] Shock responses of planetary materials elucidated from meteorites and laboratory experiments

convener:Takuo Okuchi(Institute for Planetary Materials, Okayama University), Toshimori Sekine(Center for High Pressure Science and Technology Advanced Research), Naotaka Tomioka(Kochi Institute for Core Sample Research, Japan Agency for Marine-Earth Science and Technology)

Impact phenomena have been recognized to play essential roles in the processes of planetary evolution. Recent progresses in nanoscale analysis of meteorites, asteroid explorations, as well as laboratory experiments for simulating shock dynamics on planetary materials are collaboratively revealing complex effects of shock-induced processes in planetary evolution. Recently, several new metastable high-pressure phases have been identified in strongly shocked meteorites. Their occurrences indicate that the shock-induced physical states are far from thermodynamic equilibrium and contain very complicated processes. On the other hand, laboratory experiments including laser-driven shock techniques have recently been making remarkable progresses. They successfully simulate a variety of fast non-equilibrium processes at transient high-pressure conditions reaching tens to a few hundreds of gigapascals, that uniquely affect the physical and chemical properties of planetary materials upon impacts. Here we discuss how planetary materials are compressed, fractured, transformed, melted, and quenched during impact events by referring these recent studies. We welcome presentations from interdisciplinary research fields related to shock responses of planetary materials.

[PCG23-08] Reproducing the high-pressure metallic, oxide and silicate minerals found in meteorites using novel shock-recovery experiments

★Invited Papers

*Jinping Hu[1], Paul D. Asimow[1] (1.Division of Geological and Planetary Sciences, California Institute of Technology)

[PCG23-09] **Shock-induced melting of iron and the melting temperature at Earth's inner-core boundary revisited**

*Youjun Zhang[1], Jun Li[2], Toshimori Sekine[3] (1.Sichuan University, China, 2.Institute of Fluid Physics, China, 3.Center for High Pressure Science and Technology Advanced Research, China)

[PCG23-10] **Ramp compressed Iron at Super-Earth interior conditions**

*Liang Sun[1], Xiaoxi Duan[1], Liping Peng[1], Yulong Li[1], Youjun Zhang[2], Toshimori Sekine[3], Zhebin Wang[1], Jiamin Yang[1], Shaoen Jiang[1] (1.Laser Fusion Research Center, China Academy of Engineering Physics (CAEP), Mianyang,621900,P. R. China, 2.Sichuan University, Chengdu, P.R. China, 3.Center for High Pressure Science and Technology Advanced Research (HPSTAR), Shanghai, 201203, P. R. China.)

[PCG23-11] Experimental platform using high-power laser with X-ray free-electron laser at SACLA and its capabilities for shock experiments

*Kohei Miyanishi[1], Yuichi Inubushi[1,2], Toshinori Yabuuchi[1,2], Keiichi Sueda[1], Tadashi Togashi[1,2], Norimasa Ozaki[3], Michel Koenig[4], Yoshinori Tange[2], Kensuke Tono[1,2], Makina Yabashi[1,2] (1.RIKEN SPring-8 Center, 2.Japan Synchrotron Radiation Research Institute, 3.Osaka University, 4.LULI, CNRS, CEA, Ecole Polytechnique, UPMC, Univ Paris 06)

Discussion

Reproducing the high-pressure metallic, oxide and silicate minerals found in meteorites using novel shock-recovery experiments

*Jinping Hu[1], Paul D. Asimow[1]

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Shock metamorphism features in meteorites provide important records of the pressure-temperature-time (*P-T-t*) conditions of shock events, which in turn constrain the impact history of their parent bodies. A general scale for shock pressures can be defined on the basis of deformational shock features and was calibrated directly using shock-recovery experiments by many authors. On the other hand, shock-induced high-pressure (HP) minerals should be particularly useful because their (meta)stability fields can accurately indicate shock conditions, but there have been many difficulties in calibrating the application of HP minerals in meteorites because they are rarely recovered using shock experiments. This is because (1) a laboratory impact produces a shock pulse 5-6 orders of magnitude shorter than planetary impact, which limits the time available to drive HP reactions and (2) the post-shock temperature of millimeter-scale recovery charges can be uniformly high and last long enough for low-pressure annealing to back-transform any HP phases that may have formed. To overcome these difficulties, we designed novel shock experiments with well-defined *P-T-t* conditions that have led to successful recovery of multiple high-pressure metallic, oxide and silicate phases.

The common metallic phases in chondrites, i.e. Fe-Ni alloys, are resistant to shock deformation all the way to their melting points. In contrast, the rare Al-Cu-Fe-Ni alloys observed exclusively in two chondrites can form a number of intermetallic phases, including the first and only natural quasicrystalline phases (QC) with 5-fold (i.e. icosahedrite) and 10-fold (i.e. decagonite) forbidden rotation axes. Previous synthetic QCs all formed during superfast quenching, which is an unlikely pathway in most geological settings except a shock event. Inspired by this idea, we tried a number of shock experiments with a wide range of compositions in Al-Cu-Fe-Ni space around the narrow stability fields of QCs. Indeed, we successfully reproduced icosahedral and decagonal quasicrystals, which is definitive proof of admissible impact origin for their natural occurrences. In one such experiment, we used a starting material containing a smooth compositional gradient from Al to Cu, encompassing all intermediate Al/Cu ratios. This experiment precisely reproduced a natural phase-assemblage of stolperite + khatyrkite + hollisterite + icosahedral quasicrystal, which greatly strengthens the case for a natural impact origin of the quasicrystals in the Khatyrka CV3 meteorite.

Silicate high-pressure minerals are more difficult than metallic phases to produce by shock because of the generally sluggish diffusion of their constituents. The few successful examples of HP silicate mineral recovery reflect either displacive transformation (e.g. zircon to reidite), formation of short-range order (e.g. stishovite), or growth from fast-quenched shock melt (e.g. wadsleyite). In light of these examples, we design our experiments to achieve either higher shock temperature (to enhance the reaction kinetics) or lower post-shock temperature (to limit annealing). To increase shock temperature, we use the known Hugoiots of basalt, dunite, silica and feldspar to design non-reverberating experiments that reach the peak shock pressure in a single step. This setup creates much higher shock temperature at any given shock pressure than the multiple reflected shock path used in most previous studies. To decrease recovered temperature and annealing, we used graded density impactors to create quasi-isentropic loading paths with lower shock temperature and nearly ambient release temperature. With these setups, we recovered, for example, a zagamiite-like hexagonal phase from shocked labradorite and produced

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olivine disproportionation to spinel phases by dunite-steel reaction.

Keywords: Shock experiment, high-pressure minerals, meteorite

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Shock-induced melting of iron and the melting temperature at Earth's inner-core boundary revisited

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Iron is the main constituent of Earth’ s core. Its melting temperature at ultrahigh pressures is of fundamental importance for understanding the thermal structure and energetics of the core. In spite of extensive works on the determination of melting temperature by static and shock experiments, it is still debated, especially at the inner-core boundary conditions (~330 GPa). We remeasured the shock temperature of iron by an improved pyrometer up to ~260 GPa, where it was completely melted. The measured temperature in our study is above a thousand kelvins lower than previous measurements [1,2]. The melting temperatures at Hugoniot and partially released states were obtained based on our experiments. Our determined temperature at Earth’ s inner-core boundary is consistent with the extrapolations from the laser-heated diamond anvil cells and theoretical computations by ab initio free energy and thermodynamic model [3,4]. Our results support a young inner core.

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Keywords: Earth's core, iron, melting temperature, shock compression

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Ramp compressed Iron at Super-Earth interior conditions

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Recent investigations of the mass-radius relationship of solid exoplanets indicate they consist of iron, silicates, water, and carbon compounds. The accurate equation of state (EOS) at Super-Earth interior conditions is fundamental to evaluate the composition and interior structure. The conditions in these rocky Super-Earths interiors reach 1-4 TPa and ~10^4K and cannot be easily achieved by a single shock or quasi-isentropic compression in laboratory experiments.
Here we developed laser shock and ramp compression techniques to perform a series of experiments on Fe-LiF targets initially shocked and then ramped using shaped laser pulses in the high-powered laser facility of China. In the present experiments, the initial shock pressure was nearly 300 GPa to provide high temperature for achieving interiors conditions. The peak ramp pressures were more than 1 TPa, comparable to that predicted at the center of Super-Earths. By the Lagrangian sound-speed analysis for the measured VISAR data, we determined pressure, density and sound speed along the isentropic path at these extreme condition. Our EOS data were also compared with the previous ones to know the effects of the initial shock pressure and temperature. Finally, our results provide directly-measured key physical properties of iron at the extreme high pressure and temperature, which can be used to model the physics and chemistry of iron and to understand the structures and dynamics of the cores of Super-Earths.

Keywords: Iron, High Pressure, Laser shock compression, Super-Earth interior, Equation of State

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Experimental platform using high-power laser with X-ray free-electron laser at SACLA and its capabilities for shock experiments

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Thanks to its brilliance and short pulse duration, X-ray free-electron lasers (XFELs) provide revolutionary capabilities to capture dynamics of materials on the timescales of atomic motion. On the other hand, laser-driven dynamic compression can easily generate high pressures relevant to inside planets and planetary impact phenomena. The combination of laser-driven dynamic compression pump and XFEL probe enables probing ultrafast lattice-level dynamical phenomena and transient states associated with dynamic compressions such as phase transitions, shock formation, and dynamic fractures. Recently, we have developed a new experimental platform for combinative use of an XFEL and a 100-J class laser at the SPring-8 Angstrom Compact free-electron LAser (SACLA), designed for exploring matters in extreme conditions. The platform has capabilities for X-ray diffraction (XRD) measurement, small-angle X-ray scattering (SAXS) measurement, and X-ray imaging along with auxiliary optical measurements such as velocity interferometry for any reflector (VISAR) and streaked optical pyrometer (SOP).
In this presentation, we present an overview of the newly developed platform, its current capabilities, and commissioning results.

Keywords: X-ray free-electron laser, dynamic compression, high-power laser

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[E] Oral | P (Space and Planetary Sciences)：P-CG Complex & General

[P-CG24] Future missions and instrumentation for space and planetary science

convener:Kazuo Yoshioka(Graduate School of frontier Science, The University of Tokyo), Satoshi Kasahara(The university of Tokyo), Kazunori Ogawa(Japan Aerospace Exploration Agency), Mitsunori Ozaki(Faculty of Electrical and Computer Engineering, Institute of Science and Engineering, Kanazawa University)

Not only national space agencies but some universities and even companies in the world are now leading a number of space science and exploration missions and also energetically initiating new research activities for satellite and rocket developments and international collaborations in these days because the Earth observations from the space and the space explorations could be achieved much easier than a few decades ago (e.g. ultra-small satellite). The deployment to the space, which itself is not purely a scientific purpose but one of methods for better sciences, is vigorously motivating the technical innovation and the educational development. For successful space missions, it is also crucial to research and develop aim-oriented on-board instruments, and the fundamental research and development of observational instrumentation with future perspectives could totally lead space missions in some case. Detailed investigation and evaluation on various on-board instruments are needed during their proposals, selections, and fabrications in order to promote the missions, and inevitably we have to make multi-sided arrangements and evolution at every process and aspect of any type of space missions, independently of their mission sizes. In this session, we focus on these comprehensive research activities in the space and astronomy missions, including the mission integrations and the individual instrumental developments, and we also call many presentations showing the uniqueness and renovation regarding the mission strategy and methodology, and the status and latest results in the related state-of-the-art researches and developments, which would provide all of researchers and developers with invaluable opportunities for active discussion, information sharing, and collaboration toward the realization of more missions for more fruitful space sciences and explorations in nearer future.

[PCG24-01] Overview of Smart Lander for Investigating Moon and Scientific Instrument

★Invited Papers

*Makiko Ohtake[1] (1.Department of Planetary Science, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency)

[PCG24-03] Development of an Ion Source for Future Solar System Explorations

*Naho yanase[1], Satoshi Kasahara[1], Yoshifumi Saito[2], Shoichiro Yokota[3], Masafumi Hirahara[4], Oya Kawashima[1] (1.The University of Tokyo, 2.ISAS/JAXA, 3.Osaka University, 4.Nagoya University)

[PCG24-04] Overview of DESTINY$^+$ mission

★Invited Papers

*Takeshi Takashima[1], Kazutaka Nishiyama[1], Hiroyuki Toyota[1], Tomoko Arai[2], Takayuki Yamamoto[1] (1.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 2.Chiba Inst. of Technology)

[PCG24-05] Breadboard model of asteroid tracking system for DESTINY$^+$ mission: concept design and initial performance test

*Peng Hong[1], Ko Ishibashi[1], Shunsuke Sato[2], Kotaro Fujiwara[3], Kanako Machii[4], Hiroyuki Toyota[2], Kazutaka Nishiyama[2], Masatsugu Otsuki[2], Osamu Okudaira[1], Takeshi Takashima[2] (1.Planetary Exploration Research Center, Chiba Institute of Technology, 2.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 3.Division of Mechanical and Space Engineering, Graduate School of Engineering, Hokkaido University, 4.Department of Mechanical Engineering and Intelligent Systems, Faculty of Informatics and Engineering, The University of Electro-Communications)

[PCG24-06] Development of gravity gradiometer for the interior investigation of the solar system small body

*Reiko Nomura[1], Akito Araya[2], Noriyuki Namiki[1], Koji Matsumoto[1], Hiroshi Araki[1], Kazuyoshi Asari[1], Kazushi Asamura[3], Hiroaki Shiraishi[3] (1.National Astronomical Observatory of Japan, 2.Earthquake Research Institute, the University of Tokyo, 3.Insititute of Space and Astronautical Science, JAXA)

Overview of Smart Lander for Investigating Moon and Scientific Instrument

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Smart Lander for Investigating Moon(SLIM) is a technology demonstration mission to be launched in FY2021 aimed at precise landing(within a 100 m radius) of a small and lightweight lander. To achieve safe landing on steeper sloped areas such as its observation target, the SLIM adopts a unique two-stagelanding procedure. Lunar mantle constitutes more than 90% of the lunar volume. Ascertaining the mantle composition is therefore crucially important to estimate the bulk composition of the Moon. Such knowledge will enable us to understandlunarformation and evolution processes. However, no samples, which are believed to be directly derived from the mantle are available among lunar samples. Although olivineis believed to be a major mineral component oflunar mantle, its composition remains unclear. Recent remote-sensingdata obtained using the SELENE (Kaguya) Spectral Profiler(SP) revealed exposures with olivine-rich spectral features, distributed throughout the lunar surface. Surrounding largebasins, their spectral characteristics indicate an olivine-rich, pyroxene-poor composition. Distributions of olivine-rich materials at recent crater walls and ejecta suggestthat these olivine-rich exposures originated from mantleexcavated from depths bybasin-forming impacts. To investigate the olivine-rich lithology revealed by SELENE (Kaguya), SLIMcarries one scientific instrument: a MultiBand camera(MBC).For direct investigation of this unexplored lithology, onesmall (approximately 200 m)fresh crater justoutside of the Theophilus crater was selectedas a SLIM landing site, designated as Shioli. The MBC, a compact visible and near-infrared camera, has an imaging sensor (InGaAs), a filter wheel with 10 band-pass filters, a telephoto optical system, and a movable mirror for azimuth and elevation scanning. The MBC will observe boulders on the lunar surface with high spatial resolution of 1.3 mm/pixel at 10 m. It will investigate the mineralogy and composition of the olivine-rich lithology.To achieve high spatial resolution, the camera has afocusing mechanism that will operate automatically.It has four driving motors withinits small and lightweight body. It is approximately 4 kg, includingelectronics. The MBC technology is useful not only for optical instruments in future exploration missions, but for allinstrumentsthat require scanning.Afterthe SLIM mission, JAXA is planning a lunar polar exploration mission to investigate the abundance and distribution of water in the polar region for evaluation of the possibility of using wateras a resource, possibly asfuel. The precise landing technology demonstrated bySLIM is expected to be extremely important for polar missions and for future landing missions, includingMars missions, because targeted landing sites in these missions are likely to be verysmall to fulfill their intended scientific interest.

Keywords: Moon, mantle, SLIM

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Development of an Ion Source for Future Solar System Explorations

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Observations by recent lunar explorations have suggested the existence of volatile ice including water in permanently shadowed craters of the moon. However, estimates of volatile constituents have uncertainties depending on the measurement method. Although neutron spectroscopy has been used to indicate water ice on/around the lunar surface, it is not possible to confirm the presence of water since this method detects hydrogen atoms, rather than water molecules. In order to quantify the water ice in the lunar polar region, it is necessary to make direct observations that can identify water molecules. Japan Aerospace Exploration Agency (JAXA) is planning a landing exploration of the lunar polar region in order to elucidate the concentration process and origin of lunar polar water ice and to investigate its availability as resources for the future human lunar activities. In this mission, it is planned to use a rover that carries out in-situ mass spectrometry for water detection. The mass spectrometer is designed to be comprised of an ionization section and a time-of-flight mass analysis section. In this study, we develop an ion source with the reasonable power consumption and high sensitivity for this mission. The dimensions and applied voltages of the ion source have been optimized using numerical calculations. We report the results of the verification test in the laboratory.

Keywords: Solar System Explorations, ion source, mass spectrometer

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Overview of DESTINY$^+$ mission

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DESTINY$^+$ that stands for Demonstration and Experiment of Space Technology for INterplanetary voYage, Phaethon fLyby and dUst Science is small mission program using Epsilon rocket in ISAS/JAXA. The mission of DESTINY$^+$ is to validate key technologies for our future deep space exploration.
DESTINY$^+$ will demonstrate the high performance electric propelled vehicle technology and execute the flyby exploration of asteroid 3200 Phaethon. DESTINY$^+$ starts its voyage from a low elliptic orbit, spirals up the orbits, fly-by the Moon, escapes from the Earth, and depart for the asteroid 3200 Phaethon. DESTINY$^+$ will make flyby at about 500 km from 3200 Phaethon.
The scientific objective is to understand where and how sources of organic compounds are transported to Earth. It will detect and analyze interplanetary and interstellar dust particles during deep space cruise. Dusts will be detected from the 3200 Phaethon with the dust analyzers and its surface will be observed with two cameras to make clear mechanisms of dust ejection from 3200 Phaethon. This paper will introduce an overview of the DESTINY$^+$ mission.

Keywords: dust, deep space mission, small body

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Breadboard model of asteroid tracking system for DESTINY$^+$ mission: concept design and initial performance test

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DESTINY$^+$ (Demonstration and Experiment of Space Technology for INterplanetary voYage, Phaethon fLyby and dUst Science) mission plans to conduct high-resolution imaging during close flyby of asteroid (3200) Phaethon, which is considered as a parent body of Geminid meteor shower. The Telescopic CAmera for Phaethon (TCAP) is planned to perform high-resolution imaging of the surface of Phaethon with an imaging rate of more than 1 frame per second and with a spatial resolution down to 3.5 m/px at closest approach. Since the relative flyby speed and closest distance to Phaethon are expected to be 30 to 40 km/s and about 500 km, it is significantly difficult to track the asteroid only by the rotation of the spacecraft itself. Therefore, an asteroid tracking system is required for TCAP to obtain unblurred high-resolution images. The tracking system is also required to operate autonomously during the high-speed flyby. We have conducted conceptual studies of the tracking mirror as well as the control algorithms to properly navigate the mirror based on feedforward and/or feedback loop. To realize the designed concept, we have developed a simple breadboard model focusing on the rotating mechanism which is the most important part of the tracking mirror. The breadboard model consists of a rotating mirror, a 2-phase stepping motor and its driver, a motor reducer, and a FPGA board to control the driver. The most important performances required for the tracking system are pointing accuracy and tracking accuracy of the mirror. We report the current development status of the breadboard model of the asteroid tracking system and show that the pointing and tracking accuracy of the breadboard model generally satisfy the required performance.

Keywords: flyby, small body, tracking mirror, DESTINY+

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Development of gravity gradiometer for the interior investigation of the solar system small body

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In order to elucidate the processes of water transport in the early solar system, the interior structure of the solar system small body need to be resolved. The gravity field investigation is an effective measure for the interior structure exploration, because the gravity depends not only on the surface topography but also the internal density variation.
For this purpose, we are developing a new type of spaceborne gravity gradiometer (GGM) which enables fine spatial resolution of the microgravity measurement. We take advantages of previously developed accelerometer for the observation at LEO by Araya of Earthquake Research Institute of the University of Tokyo (ERI). On the basis of design of terrestrial GGM to be used at ocean bottoms, Araya's accelerometer adopts magnetic actuators, not electrostatic actuators which are commonly used for the gravity measurement by Earth orbiting satellites. To test and evaluate our new instrument and basic technology, we plan a drop tower experiment by GGM at the end of FY2020.
In this presentation, we show the performance evaluation results of the test model for translation and rotation acceleration measurements and its feasibility of the microgravity measurement in the future space mission.

Keywords: gravity gradiometer, solar system small body, internal structure exploration

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[E] Oral | P (Space and Planetary Sciences)：P-CG Complex & General

[P-CG24] Future missions and instrumentation for space and planetary science

convener:Kazuo Yoshioka(Graduate School of frontier Science, The University of Tokyo), Satoshi Kasahara(The university of Tokyo), Kazunori Ogawa(Japan Aerospace Exploration Agency), Mitsunori Ozaki(Faculty of Electrical and Computer Engineering, Institute of Science and Engineering, Kanazawa University)

Not only national space agencies but some universities and even companies in the world are now leading a number of space science and exploration missions and also energetically initiating new research activities for satellite and rocket developments and international collaborations in these days because the Earth observations from the space and the space explorations could be achieved much easier than a few decades ago (e.g. ultra-small satellite). The deployment to the space, which itself is not purely a scientific purpose but one of methods for better sciences, is vigorously motivating the technical innovation and the educational development. For successful space missions, it is also crucial to research and develop aim-oriented on-board instruments, and the fundamental research and development of observational instrumentation with future perspectives could totally lead space missions in some case. Detailed investigation and evaluation on various on-board instruments are needed during their proposals, selections, and fabrications in order to promote the missions, and inevitably we have to make multi-sided arrangements and evolution at every process and aspect of any type of space missions, independently of their mission sizes. In this session, we focus on these comprehensive research activities in the space and astronomy missions, including the mission integrations and the individual instrumental developments, and we also call many presentations showing the uniqueness and renovation regarding the mission strategy and methodology, and the status and latest results in the related state-of-the-art researches and developments, which would provide all of researchers and developers with invaluable opportunities for active discussion, information sharing, and collaboration toward the realization of more missions for more fruitful space sciences and explorations in nearer future.

[PCG24-07] Updated status and future plans of BepiColombo

★Invited Papers

*Go Murakami[1], Johannes Benkhoff[2] (1.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 2.European Space Agency)

[PCG24-08] Current Status of Japanese Participation in JUICE (Jupiter Icy Moons Explorer)

★Invited Papers

*Yoshifumi Saito[1], Yasuhito Sekine[2], Yasumasa Kasaba[3], Keigo Enya[1], Kazushi Asamura[1], YASUKO KASAI[4], Junichi Haruyama[1], Ayako Matsuoka[1], Shoya Matsuda[1] (1.Solar System Science Division, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 2.Earth-Life Science Insitute, Tokyo Institute of Technology, 3.Planetary Plasma and Atmospheric Research Center, Tohoku University, 4.National Institute of Information and Communications Technology (NICT))

[PCG24-09] Scientific Instruments on Martian Moons eXploration (MMX)

★Invited Papers

*Shingo Kameda[1], Jean-Pierre Bibring[2], David Lawrence[3], Hiroki Senshu[4], Shoichiro Yokota[5], Masanori Kobayashi[4], Patrick Michel[6], Stephan Ulamec[7], Hirotaka Sawada[8], Kiyoshi Kuramoto[9], Kazunori Ogawa[8], Koji Wada[4], Tomohiro Usui[8], Tomoki Nakamura[10], Masaki Fujimoto[8], Hidenori Genda[11], Jörn Helbert[7], Naru Hirata[12], Takeshi Imamura[13], Yasuhiro Kawakatsu[8], Hiroki Kusano[14], Koji Matsumoto[15], Hideaki Miyamoto[13], Hiromu Nakagawa[10], Hisashi Otake[8], Sara Russell[16], Sho Sasaki[5], Naoki Terada[10], Sei-ichiro WATANABE[17] (1.School of Science, Rikkyo University, 2.Université de Paris-Sud, 3.The Johns Hopkins University, 4.Chiba Institute of Technology, 5.Osaka University, 6.Observatoire de la Côte d'Azur, 7.Deutschen Zentrums für Luft- und Raumfahrt, 8.Japan Aerospace Exploration Agency, 9.Hokkaido University, 10.Tohoku University, 11.Tokyo Institute of Technology, 12.Aizu University, 13.The University of Tokyo, 14.National Institutes for Quantum and Radiological Science and Technology, 15.National Astronomical Observatory of Japan, 16.Natural History Museum, 17.Nagoya University)

[PCG24-10] Development of the Raman Spectrometer for Martian Moon Exploration (RAX) for the MMX rover

*Yuichiro Cho[1], Koki Yumoto[1], Shingo Kameda[2], Tomohiro Usui[5], Conor Ryan[3], Till Hagelschuer[3], Selene Routley[3], Maximilian Buder[3], Enrico Dietz[3], Ute Böttger[3], Heinz-Wilhelm Hübers[3], Andoni Moral[4], Tomás Belenguer[4], Pablo Rodríguez[4], Fernando Rull[6] (1.Department of Earth and Planetary Science, University of Tokyo, 2.Rikkyo University, 3.German Aerospace Center (DLR), 4. Instituto National de Técnica Aerospacial (INTA), 5.Japan Aerospace Exploration Agency (JAXA), 6.Universidad de Valladolid)

[PCG24-11] Development of a new method for in situ cosmic-ray exposure age measurements using laser ablation

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[PCG24-12] Examination of the Magnetic Field Experiment for the OKEANOS Mission

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Updated status and future plans of BepiColombo

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The ESA-JAXA joint mission BepiColombo is now on the track to Mercury. BepiColombo will achieve a comprehensive exploration at Mercury with two spacecraft: "Mio" (Mercury Magnetospheric Orbiter: MMO) and "Bepi" (Mercury Planetary Orbiter: MPO). They were successfully launched by Ariane-5 launch vehicle from Kourou in French Guiana on 20 October 2018. Mio is fully dedicated to investigating Mercury’ s environment with a complete package of plasma instruments (particles, electric fields, and magnetic fields), a spectral imager of sodium exosphere, and a dust monitor. During the cruise to Mercury, in addition to two spacecraft MMO Sunshield and Interface Structure (MOSIF) and Mercury Transfer Module (MTM) are all integrated together. After the commissioning operations of spacecraft, we are focusing on preparing science operations for interplanetary cruise and planetary flybys. Some science instruments can be used even in the composite spacecraft configuration. The first and second flybys will happen at the Earth in April 2020 and at Venus in October 2020, respectively. Here we report the updated status of BepiColombo mission, initial results of the commissioning operations and Earth flyby observations, and the future plans for interplanetary cruise and planetary flybys.

Keywords: Mercury, BepiColombo, Planetary exploration

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Current Status of Japanese Participation in JUICE (Jupiter Icy Moons Explorer)

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JUICE (Jupiter Icy Moons Explorer) is ESA's L-class mission during COSMIC VISION 2015–2025 to Explore Jupiter Icy Moons. JUICE will be launched by Arian-5 in May 2022. After 7.5 years of interplanetary transfer and Earth-Venus-Earth-Mars-Earth gravity assists, JUICE will be inserted into an orbit around Jupiter in January 2030. JUICE will make observation of the three Jupiter icy Moons, Europa, Ganymede, and Callisto that potentially have subsurface ocean under the icy crust. JUICE will be the world first Icy Moon Orbiter when JUICE is inserted into Ganymede orbit in 2032. JUICE will make detailed observation of the largest Icy Moon in the solar system: Ganymede.

Four Japanese groups were selected to provide part of the four different science instruments on JUICE: RPWI (Radio and Plasma Wave Investigation), GALA (Ganymede Laser Altimeter), PEP (Particle Environment Package)/JNA (Jupiter Neutrals Analyzer) and SWI (Submillimeter Wave Instrument). Two Japanese groups were also selected as science Co-Is of two instrument groups JANUS (Jupiter Camera) and J-MAG (Jupiter Magnetometer). ISAS/JAXA is responsible for RPWI, GALA, PEP/JNA, JANUS, J-MAG, and NICT is responsible for SWI.

The science objectives of Japanese participation in JUICE is to understand (1) How Jupiter system was Formed, (2) What is the habitable worlds around gas giants, and (3) The strongest accelerator in our solar system: Jupiter. Taking into account the data to be obtained by 5 instruments that JUICE-JAPAN will participate, Japanese team will be able to contribute to most of the major science objectives relating with Jupiter system (JANUS, SWI and PEP/JNA), Jupiter/Ganymede magnetosphere (PEP/JNA, RPWI, and J-MAG), and sub-surface water in icy moons (GALA, J-MAG, and JANUS).

Japanese participation in JUCE was initiated by collaboration between ISAS/JAXA and ESA on BepiColombo mission to Mercury. The close collaboration between BepiColmbo science instrument teams in Europe and Japan has lead to the further collaboration on JUICE. RPWI-Japan has completed CDR in July 2018 and has finished FM delivery to IRF-Uppsala, Sweden in January 2020. PEP-Japan completed CDR in June 2019 and FM will be delivered to IRF-Kiruna, Sweden in February 2020. GALA-Japan will complete CDR in March 2020 and FM will be delivered to DLR, Germany in May 2020. SWI has completed CDR in June 2019. SWI PFM and FS plan to be delivered to MPS, Germany by March 2020. Although a number of small problems are occurring, Japanese teams are participating in JUICE without significant delay. All the Japanese teams will finish delivering FM and FS (Flight Spare) to Europe by April 2021.

Keywords: JUICE, Jupiter, Ganymede, Icy Moon, Europa, Calisto

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Scientific Instruments on Martian Moons eXploration (MMX)

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Mars has two satellites, Phobos and Deimos, and the origin of these satellites are still controversial. The Japan Aerospace Exploration Agency (JAXA) is planning the Martian Moon eXploration (MMX) mission, which is a sample-return mission for Phobos or Deimos to reveal the origins of these two satellites. The scientific instruments onboard the MMX spacecraft are a telescopic camera (TENGOO), a multiband wide-angle camera (OROCHI), an infrared spectral imager (MacrOmega), a gamma-ray spectrometer (MEGANE), a laser altimeter (LIDAR), an ion mass spectrum analyzer (MSA) and a sampler. MMX will enter a quasi-satellite orbit around a moon after the arrival at the Martian sphere We spend ~1 year to investigate the moon’ s surface using the scientific instruments at the quasi-satellite orbit to select the landing sites. The global observation of the moon is also important for characterization of the returned sample. In the landing phase, we will use the scientific instruments to observe the area near the sampling site. The MMX Rover, which is a small rover for investigating the surface of the moon, has visible cameras, thermal infrared sensors and a Raman spectrometer. This rover will give us the information of the surface of the moon. In this presentation, we introduce the current status of the scientific instruments onboard the MMX spacecraft and the operation plan.

Keywords: Phobos, Mars, Sample return

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Development of the Raman Spectrometer for Martian Moon Exploration (RAX) for the MMX rover

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The Raman Spectrometer for MMX (RAX) is one of the instruments on board the MMX rover. RAX will conduct Raman spectroscopy on the surface of Phobos to analyze the surface mineralogy. This instrument is composed of laser module, spectrometer module, and autofocusing subsystem (AFS). The entire RAX instrument weights ~1.4 kg and its size is only 81 x 98 x 125 mm^3, excluding the externally mounted laser module. The RAX instrument is developed through an international collaboration among Japan (Univ. Tokyo/Rikkyo Univ/JAXA), DLR from Germany, and INTA/Univ Valladolid from Spain.

The Japanese team provides the autofocusing subsystem (AFS). The aim of AFS is to focus the collimated laser beam onto the surface of Phobos and to transmit the Raman signal generated at the laser spot back to the spectrometer module in the form of collimated light. To obtain optimized Raman signals from samples of various size, the distance between the bottom end of the optics and a sample can be adjusted within a range of ±7.5 mm from the nominal working distance of 80 mm. Because of the highly limited volume inside the rover, the volume allocated for the autofocusing subsystem is only approximately 65 x 65 x 50 mm^3, giving a challenge in designing and manufacturing the system. The mass of AFS will be less than 250 g.

The AFS is composed of the objective lens, stepping motor, linear guide, lead screw, photo-interrupter, electronics, and mechanical parts that connect them. The rotations of the stepping motor are converted to the linear motion of the objective lens, with a combination of nut, lead screw, and linear guide. To protect the motor axis from any shock/vibration load, the lead-screw shaft is separated from the motor axis and connected with it by a pair of gears. The AFS has its own printed circuit board to activate the stepping motor. Although the AFS will not have an encoder, the photo-interrupter will be used as an end-stop sensor. Its end-to-end performance is being evaluated with a breadboard model, while the preliminary design of the AFS is established in the international RAX team.

Keywords: Raman spectroscopy, MMX, Phobos

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Development of a new method for in situ cosmic-ray exposure age measurements using laser ablation

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On the surface of planets without thick atmosphere and magnetic field, including Mars, biosignatures and organic materials are degraded by cosmic and ultraviolet rays at a timescale of a few million years [1]. Thus, during lander missions, we should search for organic matters at places that had been buried and shielded from cosmic and ultraviolet rays until very recently. However, evaluating when a certain place/rock was exposed to the surface just by observing with a camera is challenging. Cosmic-ray exposure (CRE) ages can be an indicator of the duration for which the sample is subject to the severe environment. Thus, developing a method for in situ CRE age measurement would be important. In situ CRE age measurements are also useful for choosing samples that should be brought back to the Earth.

On Mars, K–Ar and CRE ages of powdered rocks were measured by the NASA’ s Curiosity rover using APXS to derive the elemental composition and thus production rates, quadrupole mass spectrometer, and onboard furnace to derive the concentrations of noble gases [2]. Their method, however, had uncertainties in ages because (1) the production rates of cosmogenic nuclei were uncertain between the measured aliquots due to the heterogeneity of the samples and (2) the extraction of noble gases was incomplete due to insufficient heating temperature and duration [5]. Drilling rocks and keeping the onboard furnace at 900℃ for 30 minutes were among the technical challenges for the rover operation.

To resolve these problems and measure the cosmic-ray exposure ages of rocks, we develop a new method that combines laser-induced breakdown spectroscopy (LIBS) and quadrupole mass spectroscopy (QMS). The LIBS-MS approach potentially yields the spot-by-spot CRE ages by measuring cosmic-ray production rates with LIBS and concentrations of noble gases with MS. In this study, we assess the feasibility of measuring very small amount of cosmogenic noble gases (~10^{-15} mol) in a meteorite, as well as to investigate the accuracy of the CRE ages obtained with this method. This study focuses on the noble gas analysis with QMS because LIBS measurements for major target elements are more straightforward.

The CRE ages were measured in the following procedures: 5000 laser pulses (266 nm, 20 mJ, spot size 350 μm) were applied to a slab sample of the Camel Donga meteorite. Camel Donga is a eucrite that exhibits CRE ages of 11.9 ±1.3, 27.3 ±1.4, and 28.8 ±1.9 Ma for ^{3}He, ^{21}Ne, and ^{38}Ar, respectively [3]. The gases extracted by the laser were processed with a Ti-Zr getter and a charcoal trap before being introduced to the QMS. The abundances of noble gases, ^{3}He, ^{21}Ne and ^{38}Ar, were determined after correcting procedural blank and isobaric interferences. The volume of laser-ablation spots was measured with a microscope and was converted to ablated mass with the bulk density of the sample of 3.16 g/cm^{3} [4]. The CRE ages were calculated from the concentrations of the cosmogenic noble gases (^{3}He, ^{21}Ne and ^{38}Ar) and published production rates [3].

In our preliminary CRE age measurements, noble gases of ~10^{-16} mol were detected although the signal-to-blank ratios were small (<5). The ablated mass was 5e-5 g. Isotopic ratios of noble gases, e.g., ^{38}Ar/^{36}Ar = 1.13 ±0.07, were more consistent with their cosmogenic origin (1.55) rather than the trap of the terrestrial air. By assuming the typical shielding factor (^{22}Ne/^{21}Ne = 1.14), we obtained the CRE ages of

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148 ±8 Ma for ^{3}He, 21.8 ±7.0 Ma for ^{21}Ne, and 60.4 ±91.7 Ma for ^{38}Ar. The CRE ages for ^{21}Ne and ^{38}Ar are consistent with those reported in the previous study, suggesting the validity of this approach. The much longer CRE age obtained with ^{3}He is most likely because of the isobaric interference by HD^{+} released from the meteorite. To obtain accurate ^{3}He-ages, HD^{+} should be removed more efficiently by adding a second getter near the QMS. We found that the reliable age for the Camel Donga meteorite is the ^{21}Ne-age under the assumption that the shielding indicator ^{22}Ne/^{21}Ne is 1.14, but otherwise the ^{38}Ar-age. Our noble gas analyses demonstrate that even very small amounts of cosmogenic noble gases can be measured with this method, suggesting the capability of in situ CRE age measurement based on laser ablation.

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Keywords: astrobiology, cosmic-ray exposure age, LIBS, QMS

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Examination of the Magnetic Field Experiment for the OKEANOS Mission

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Magnetic field is a key parameter to study the natural phenomena in the space. Magnetometers have been boarded on a lot of spacecraft launched for the exploration of new area and novel interpretation of the physical process. Meanwhile, in the future space and solar-system exploration missions, very often the available mass and power are limited and there are various restrictions in the system design. We are developing small-size and low power consumption magnetometers for such difficult space missions. One of the specific ones our development is targeting is OKEANOS.
To avoid the interference with the spacecraft, the sensor is very often mounted on the deployment boom and connected with the electronics installed in the spacecraft body. For example, the Voyager spacecraft had one of the longest (13-m) boom to measure the weak magnetic field at the heliopause. We are now breaking that record by OKEANOS; we will put a pair of magnetometer on the tip mass at the corners of the solar power sail, which is at about 30 m distance from the spacecraft body. That configuration provides us an ideal condition to measure very faint magnetic field in the space.
OKEANOS is a project to explore the Trojan asteroid. In view of the space magnetism, the objectives are the measurements of the intrinsic magnetic field of the target asteroid and the disturbances of the interplanetary magnetic field. We will use magnetic field data at the OKEANOS mother spacecraft and data at the lander to determine the magnetic moment of the Trojan asteroid. We need to detect the difference of the magnetic fields at two positions very accurately because the magnetic moment is estimated to be small.
OKEANOS will make the 13-years journey to the asteroid after the launch. That period is very good opportunity to investigate the interplanetary magnetic field at different distances from the sun. One of the subjects we try to solve is the heating process of the solar wind on the way spreading in the solar system. Whistler waves in the interplanetary shocks are the candidate for the providing heats to the solar-wind plasma. We will measure the magnetic disturbances in the interplanetary shock with high resolution and investigate the contribution to the plasma heating.
We are investigating to mount the magnetometer sensors and electronics together on the tip mass at the corners of the solar power sail. We need to develop small-size and low power consumption magnetometers for the OKEANOS mission. We have two development strategies; one is the small-size fluxgate sensor, and the other is ASIC of the electronics. The detail about the development of the sensor is shown in the separated presentation by Murata and Matsuoka. The ASIC is developed based on the heritage of the magnetometers designed for BepiColombo MMO and Arase (ERG). It was firstly manufactured for the SS-520-3 sounding rocket project. The development is now in progress to modify it to measure the small intensity magnetic field and secure the high reliability in the space environment.

Keywords: Magnetic field, Magnetometer, OKEANOS, Trojan asteroid, Interplanetary shock

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[E] Oral | P (Space and Planetary Sciences)：P-CG Complex & General

[P-CG24] Future missions and instrumentation for space and planetary science

convener:Kazuo Yoshioka(Graduate School of frontier Science, The University of Tokyo), Satoshi Kasahara(The university of Tokyo), Kazunori Ogawa(Japan Aerospace Exploration Agency), Mitsunori Ozaki(Faculty of Electrical and Computer Engineering, Institute of Science and Engineering, Kanazawa University)

Not only national space agencies but some universities and even companies in the world are now leading a number of space science and exploration missions and also energetically initiating new research activities for satellite and rocket developments and international collaborations in these days because the Earth observations from the space and the space explorations could be achieved much easier than a few decades ago (e.g. ultra-small satellite). The deployment to the space, which itself is not purely a scientific purpose but one of methods for better sciences, is vigorously motivating the technical innovation and the educational development. For successful space missions, it is also crucial to research and develop aim-oriented on-board instruments, and the fundamental research and development of observational instrumentation with future perspectives could totally lead space missions in some case. Detailed investigation and evaluation on various on-board instruments are needed during their proposals, selections, and fabrications in order to promote the missions, and inevitably we have to make multi-sided arrangements and evolution at every process and aspect of any type of space missions, independently of their mission sizes. In this session, we focus on these comprehensive research activities in the space and astronomy missions, including the mission integrations and the individual instrumental developments, and we also call many presentations showing the uniqueness and renovation regarding the mission strategy and methodology, and the status and latest results in the related state-of-the-art researches and developments, which would provide all of researchers and developers with invaluable opportunities for active discussion, information sharing, and collaboration toward the realization of more missions for more fruitful space sciences and explorations in nearer future.

[PCG24-13] Sounding rocket missions (LAMP and SS520-3) for ionospheric and magnetospheric explorations

★Invited Papers

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[PCG24-14] Computer Simulation of Electric Field Sensor in Space Plasma

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[PCG24-15] Development of the analog integrated circuit for the new plasma wave receiver

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[PCG24-16] Development of Geant4 application for particle detector design

*PARK INCHUN[1], Yoshizumi Miyoshi[1], Takefumi Mitani[2], Takane Hori[1], Mariko Teramoto[4], Satoshi Kurita[1], Satoshi Kasahara[3], Nana Higashio[5], Fajardo Taipia Isai[4], Keiichi Okuyama[4] (1.Nagoya University Institute for Space-Earth Environmental Research, 2.Japan Aerospace Exploration Agency, Institute of Space and Astronautical Science, 3.The University of Tokyo, 4.Kyushu Institute of Technology, 5.Japan Aerospace Exploration Agency)

[PCG24-17] Development of a miniature Ion-trap Fourier-transform mass spectrometer for future space missions

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[PCG24-18] Signal and Noise Separation from Satellite Magnetic Field Data Using Independent Component Analysis: Prospect of Magnetic Measurements without Mast and Noise Source Information

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Sounding rocket missions (LAMP and SS520-3) for ionospheric and magnetospheric explorations

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We are participating into two sounding rocket missions, both of which will be launched in the coming winter. LAMP (Loss through Auroral Microburst Pulsations) is NASA's sounding rocket mission which will provide the first simultaneous measurements of the micrburst precipitations of high-energy electrons into the auroral ionosphere and optical emissions of pulsating auroras with high-time resolution. LAMP is one of approaches to quantify the magnetospheric / radiation belt electron loss through auroral activities. For LAMP, we will provide four scientific instruments onboard: a high-energy electron detector, two auroral imagers, and a magnetometer, and ground support observations as well. They have not only the scientific purposes, but also aspects of technological demonstration for future space missions.

SS520-3 is led by JAXA. It carries plasma wave instruments, a sensor package measuring supra-thermal to low-energy plasma particles, Langmuir probes, and a magnetometer, in order to reveal the generating mechanisms of ion outflows from the polar ionosphere, where the many of the instruments also contain state-of-art techniques as technological demonstration including wave-particle interaction analysis.

Using the sounding rocket, we can exlore the low-altitude regions which is difficult for satellites. Moreover, interface requirements are usually quite milder with a lot of aspects when we compare them to those of spacecraft, which saves time and resources for development/verification to meet the requirements. We will report the status of LAMP and SS520-3, and benefits from usage of the sounding rocket platform.

Keywords: sounding rocket, LAMP, SS520-3

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Computer Simulation of Electric Field Sensor in Space Plasma

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A dipole antenna has been commonly used for electric-field sensors in plasma wave observations via scientific satellites in space.

Electric field sensors in plasmas are characterized by their effective lengths and antenna impedances.

The effective lengths and antenna impedances depend on target waves and plasma parameters around a satellite.

We have been using approximation values under the assumption that wavelengths are much longer than antenna lengths.

However, it is not true, because wavelengths of electrostatic waves are much shorter than those of electromagnetic waves and their wavelengths can be in the same order of antenna lengths.

Hence knowing the characteristics of electric field sensors over plasma waves with shorter wavelengths is significant in evaluating intensities and phases of targeted electrostatic waves.

In this research, we simulated the antenna impedances of electric field sensors in magnetized plasmas over electromagnetic waves with short wavelengths.

We conducted Particle-In-Cell simulations with electric field sensors as inner boundaries.

The results were evaluated considering the linear dispersion relations in magnetized plasmas.

According to the calculation results, when the wave number of the antenna resonance is large enough, it is estimated that the resonances are seen at the frequencies of the electron cyclotron harmonics, which are frequently observed in the magnetized plasmas.

When the wave number is small enough, the resonances frequencies are shifted to slightly high.

As results of the PIC simulations, the resonances were seen at harmonics of the electron cyclotron frequency when their wave numbers were large.

When the wave number was small, no resonance was observed.

We also performed simulations to examine effects of a satellite body to characteristics of electric field sensors.

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When the length of the satellite parallel to the antenna was about the same as the sensor length, the resonance of the antenna impedance at the second harmonic disappeared, and the resonance at the third harmonic became prominent.

In the present paper, we discuss the characteristics of electric field sensors in plasmas over plasma waves with short wavelengths that are comparable with lengths of electric field sensors.

Keywords: antenna impedance, computer simulation, electric field measurement, Particle-in-cell

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Development of the analog integrated circuit for the new plasma wave receiver

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Recently, the miniaturization of the instruments onboard scientific satellites is required. We have been working on the integration of analog circuits to reduce the size of the plasma wave instruments. Recent scientific missions use Fast-Fourier Transform (FFT) based plasma wave instruments. This type of instrument receive waveform using wideband analog circuits, and it transfer waveform or frequency spectrum calculated by onboard digital processor depending on observation mode. The FFT based plasma wave instruments have an advantage that the size of the instrument can be reduced because it can realize waveform and spectrum receiver using the same analog circuit. On the other hand, it has a disadvantage in the difficulty of adjusting its receiver's dynamic range to the dynamic range of target signals in a wide frequency range. We propose the new receiver which overcomes this disadvantage. The new receiver uses the analog circuit whose upper and lower cutoff frequencies are selectable. These analog circuits enable that the receiver changes bandwidth depending on its observation mode. In addition, we can realize miniaturized and high-performance plasma wave receiver by developing these analog circuits using Application-Specific Integrated Circuits (ASIC).

The analog circuit developing in this study is mainly composed of band-limiting filter, main amplifier, and anti-aliasing filter. The band-limiting filter can be selected as its behavior from the band-pass filter (BPF) or the low-pass filter (LPF). The upper cutoff frequency of the BPF and LPF can be selected from 1 kHz, 10 kHz, or 100 kHz, and the lower cutoff frequency of the BPF can be selected from 1 kHz or 10 kHz. The main amplifier has selectable gain from 0 dB, 20 dB, and 40 dB. The digital part controls this analog circuit, and the receiver can realize wideband waveform type and narrowband spectrum type receiver by using one analog circuit. In the presentation, we will describe the detail design and performance of the new receiver and analog circuit.

Keywords: Plasma wave, ASIC

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Development of Geant4 application for particle detector design

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Developing particle detectors for space mission requires testing them in the actual particle environment. Although the environment cannot be reproduced on the ground facility, it can be simulated by using computer simulation, which is an essential step in designing the detectors. Geant4 is a widely used tool that simulates the high-energy particle environment, but it is difficult to use for unskilled researchers.

In this research, we developed a G-factor Analysis tool using Geant4 (GAG) simulation to make it easier to test the particle detector's characteristics. For easy operation, the GAG has two main features. The one is that GAG can be read the detector geometry from a CAD file which is difficult to adapt to Geant4 simulation. And the other is the automatic calculation of results such as detector's efficiency, G-factor, and spectral characteristics, etc. These features are based on the result of the calibration studies of the HEP instrument onboard the Arase satellite, which allows the GAG application to be used to determine the characteristics of the detectors as well as to perform the calibration.

Using these application's features, we examine the characteristics of particle detectors such as XEP and TENKOH, as well as HEP. The results of the simulation provide cross-calibration information. We report the preliminary result of these simulation results

Keywords: Geant4 simulation, Particle detector, Satellite instrument, Detector calibration

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Development of a miniature Ion-trap Fourier-transform mass spectrometer for future space missions

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In-situ high-resolution (m/Δm > 10,000) mass spectrometry is playing an important role in planetary explorations. In particular, isotopic composition is a key for understanding the evolution of planetary bodies. However, most conventional high-resolution mass spectrometers (MSs) are large in volume and heavy. Therefore, the opportunity of high-resolution mass spectrometry is limited, despite their high performance. The aim of this study is to develop a compact high-resolution MS. Our design is based on OrbitrapTM, which has recently been used in ground facilities. This is an ion trap Fourier-transform MS with a small ion trap optics (<10×10×10 cm3) to gain long time of flight. Our numerical simulations showed high mass resolution (m/Δm ~ 10,000) can be achieved with a small size. For the ion trap Fourier-transform MS, it is the key to have ions bunched before injecting into the time-of-flight region. We implemented this bunching with ion resonation. Then we examined the performance of the newly developed resonator through test model experiments. The results were consistent with expectations from numerical calculations, in terms of gas pressure dependency and storage time dependency. Furthermore, we also started integration tests to obtain high-resolution mass spectra. We are going to give a presentation about details of these experimental tests.

Keywords: High-resolution, Orbitrap, exploration, mass spectrometer, development

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Signal and Noise Separation from Satellite Magnetic Field Data Using Independent Component Analysis: Prospect of Magnetic Measurements without Mast and Noise Source Information

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We propose an application of the independent component analysis (ICA) to separate satellite-induced time-varying noises from magnetic data obtained by onboard multiple magnetometers. The ICA is a method of estimating source signals observed at multiple sites so that estimated source signals are statistically independent of each other. Since satellite noises are clearly independent of external natural variations, the ICA is expected to separate the satellite noises. We applied the ICA to the magnetic data measured by the first Quasi-Zenith Satellite (QZS-1) that has two triaxial fluxgate magnetometers without an extendable mast. First, we removed the long-period trend from the original data. Then, we applied the FastICA to the detrended data and obtained six independent components (ICs). Satellite-induced noises were successfully classified into three ICs (noise ICs). Natural signals are represented by the rest three ICs (signal ICs). Finally, we restored the observed signals from the signal ICs. We confirmed that amplitude and waveform of natural phenomena were not altered by the processing. We also proposed the method of automatic determination of noise ICs using the *D* score, which is similar to the normalized coefficient of variance of the mixing vectors. We confirmed that the three largest *D* scores, which give the noise ICs, are much larger than the three smallest *D*, which give the signal ICs. The automatic determination of noise ICs by this method was 95% identical to that by visual inspection. These results demonstrated that the ICA method can provide for mast-less magnetic observations in future satellite missions.

Keywords: satellite magnetic observations, independent component analysis, saparation of satellite-induced noises, mast-less magnetic observations, statistical signal processing

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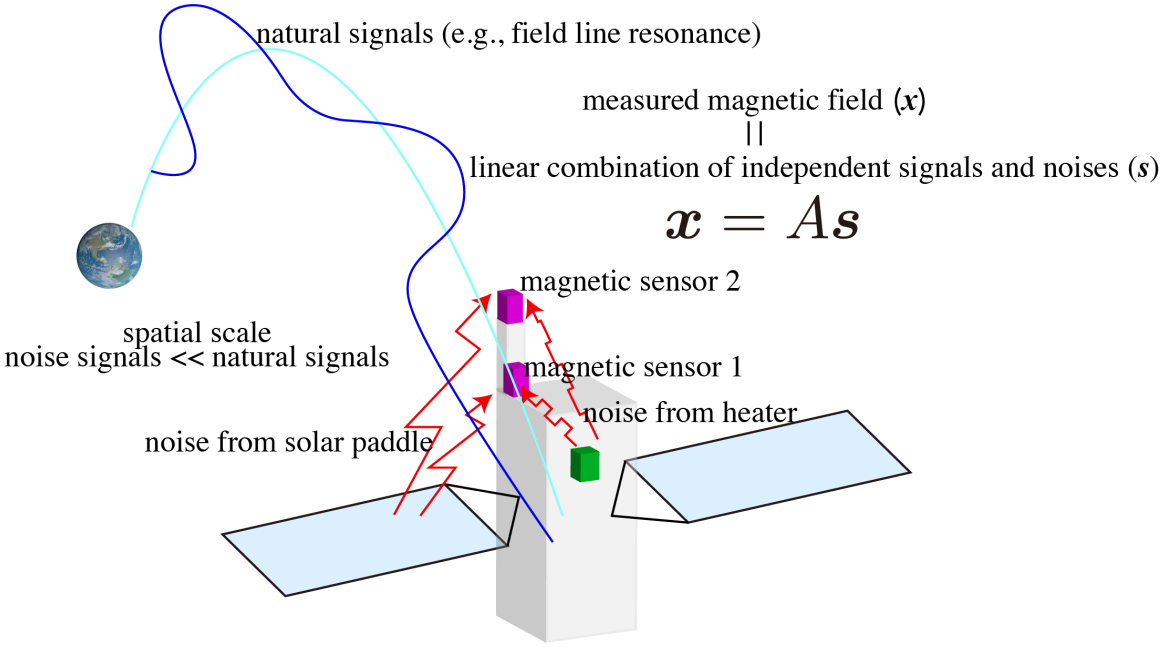

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[E] Oral | P (Space and Planetary Sciences)：P-CG Complex & General

[P-CG25] Planetary Magnetosphere, Ionosphere, and Atmosphere

convener:Kanako Seki(Graduate School of Science, University of Tokyo), Takeshi Imamura(Graduate School of Frontier Sciences, The University of Tokyo), Hiroyuki Maezawa(Department of Physical Science Osaka Prefecture University), Naoki Terada(Graduate School of Science, Tohoku University)

Exploration of Moon, Venus, Mars, Mercury, Jupiter, Saturn, and beyond together with rapid developments of numerical simulations provides us new view of planetary environment. This session collects general contributions of new findings about planetary magnetosphere, ionosphere, and atmosphere. New methodology and technology development studies for future explorations are also welcome. In order to put the common knowledge at different planets into perspective, this session aims to facilitate discussions on comparative planetary environments.

[PCG25-01] Seasonal variation of Mercury's exosphere deduced from the analysis MESSENGER data

*Yudai Suzuki[1], Kazuo Yoshioka[1], Go Murakami[2], Ichiro Yoshikawa[1] (1.University of Tokyo, 2.ISAS/JAXA)

[PCG25-03] Study of ion loss mechanisms from ancient Mars with a focus on effects of the global intrinsic magnetic field

*Ryoya Sakata[1], Kanako Seki[1], Shotaro Sakai[1], Naoki Terada[2], Hiroyuki Shinagawa[3], Takashi Tanaka[4] (1.Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, 2.Department of Geophysics, Graduate School of Science, Tohoku University, 3.National Institute of Information and Communications Technology, 4.International Center for Space Weather Science and Education, Kyushu University)

[PCG25-04] Sensitivity of the difference of cumulus convection schemes to the precipitation distributions simulated in a Paleo Mars GCM

*Takeshi Kuroda[1], Katsushige Toriumi[1], Arihiro Kamada[1], Naoki Terada[1], Yasumasa Kasaba[1,2], Isao Murata[1,3], Hiromu Nakagawa[1] (1.Department of Geophysics, Tohoku University, 2.Planetary Plasma and Atmospheric Research Center, Tohoku University, 3.Graduate School of Environmental Studies, Tohoku University)

[PCG25-05] Zonal wind acceleration in the Martian mesosphere during the global dust storm 2018 observed by IR heterodyne spectroscopy

*Akiho Miyamoto[1], Hiromu Nakagawa[1], Takeshi Kuroda[1], Kosuke Takami[1], Isao Murata[1], Nao Yoshida[1], Katsushige Toriumi[1], Shohei Aoki[2], Hideo Sagawa[3], Nicholas McCord Schneider[4], Sonal Jain[4], Yasumasa Kasaba[1], Naoki Terada[1] (1.Major in Geophysics , Graduate School of Science in Tohoku University, 2.Royal Belgian Institute for Space Aeronomy (IASB-BIRA), 3.Kyoto Sangyo University, 4.Laboratory for Atmospheric and Space Physics, Boulder, CO)

[PCG25-06] Study of proton escape from Mars based on MAVEN observations

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Seasonal variation of Mercury's exosphere deduced from the analysis MESSENGER data

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Celestial bodies with surface-bound exosphere are valuable because we can directly see the interaction between the bodies and space environment to which they are exposed. This interaction is especially expected to be clearly observed around Mercury. This research aims to clarify the generation process of neutral sodium exosphere, through the comparison between the data from MASCS onboard MESSENGER spacecraft and 3-D model calculation considering generation, transportation and dissipation processes.

First, seasonal variability of the amount of sodium exosphere is analyzed for each local time (LT) using MASCS data. Previous research has shown that the amount of sodium above LT12 reaches a maximum at aphelion, and it is found that this maximum is seen only above LT12. In addition, two hypotheses proposed by the research: the increase in the surface sodium density of the dayside due to fast rotation of terminator, and the expansion of exosphere owing to weaker radiation pressure, were turned out to be inconsistent with seasonal variability above LT06 and the results of test particle calculations.

Following these results, in order to understand the key process of the seasonal variation of the amount of sodium especially around LT12, 3-D sodium exosphere model including release from the surface, transport due to gravity and solar radiation pressure, and dissipation due to ionization caused by solar radiation is constructed. The results from numerical calculation is consistent with the observations by MASCS in terms of the vertical profile and the seasonal variability above LT06 and LT18, but the maximum at aphelion above LT12 could not be reproduced. Then, when the existence of the impact of comet dust stream is assumed as a local and short-term sodium source, the model with impact of comets per Mercury year could reproduce observations.

Using the model constructed in this study, the sodium distribution which would be observed by MSASI onboard MIO spacecraft is predicted. The comparison between the calculation and observation by MSASI will provide us new insights into the interaction between the celestial bodies and space environment.
In this presentation, we will summarize the results of comparison between observations by MASCS and 3-D Monte Carlo simulation about the seasonal variability of Mercury’ s sodium exosphere.

Keywords: Mercury, Exosphere, MESSENGER

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Study of ion loss mechanisms from ancient Mars with a focus on effects of the global intrinsic magnetic field

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Past observations on Mars suggested a warm and wet environment approximately four billion years ago. Such a warm climate requires the greenhouse effect of a thick atmosphere, but Mars has only a thin (~0.007 bar) CO_2 atmosphere today. A major problem in understanding climate evolution at Mars is determining processes that have played an important role in the removal of the atmosphere over time. Ion loss caused by interactions between the solar wind and the upper atmosphere is one of the candidate processes. Mars was exposed to intense solar X-ray and extreme ultraviolet (XUV) flux and strong solar wind during a younger, more active phase of the Sun. Intense solar activity during the early period may enhance ion loss by several orders of magnitude. The crustal remnant magnetic fields on Mars suggest existence of a global intrinsic magnetic field on ancient Mars. A global intrinsic magnetic field affects magnetic configuration around the planet and thus ion loss, but the detailed effects are still unclear.

We investigated processes and rates of ion loss from ancient Mars with a focus on effects of the existence and strength of an intrinsic magnetic field based on multispecies magnetohydrodynamics (MHD) simulations. We conducted simulations under the two different (extreme and moderate) solar conditions and the different strength of the intrinsic magnetic field. The extreme solar conditions were that the solar XUV flux was 100 times higher than the present value, and the solar wind number density, the velocity, and the interplanetary magnetic field (IMF) strength were 1000 cm^{-3}, 2000 km s^{-1}, and 60 nT, respectively. The moderate solar conditions were that the solar XUV flux was 10 times higher, and the solar wind number density, the velocity, and the IMF strength were 70 cm^{-3}, 700 km s^{-1}, and 6.58 nT, respectively. The intrinsic magnetic field was assumed to be a dipole field and northward at the equator.

Under extreme solar conditions, existence of a dipole field strongly affects molecular ion escape by the cusp outflow. The effect depends on the dipole field strength. In the overpressure cases where the solar wind dynamic pressure exceeds the dipolar magnetic pressure, the cusp outflow is enhanced, and the loss rates of molecular ions are increased by a factor of ~6. In the non-overpressure cases where the dipolar magnetic pressure is higher than the solar wind dynamic pressure, however, the loss rates are strongly suppressed by two orders of magnitude. The mass-loading of O^+ on the extended oxygen corona contributes to a certain part of the total O^+ loss. Therefore, the effects of the dipole field are less pronounced on the O^+ loss rate.

Under moderate solar conditions, the effects are similar but partly different. The loss rates of molecular ions are increased in the overpressure cases. However, only the O_2^+ loss rate is increased even in the non-overpressure case. In this case, the main escape process is the O_2^+-rich polar outflow instead of the cusp outflow. The polar outflow is driven by relatively strong pressure gradient in the polar ionosphere caused by the thinner corona and higher magnetopause. The O^+ loss rate is decreased with the dipole field strength. The mass-loading process is weaker and more sensitive to change in altitude of the magnetopause. This is because the density and the scale height of the corona is small due to the weaker

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solar XUV flux.

The study reveals that effects of an intrinsic magnetic field on ion loss depend on the pressure balance between the solar wind dynamic pressure and the magnetic pressure of the intrinsic magnetic field. The effects are also affected by properties of the oxygen corona that is mainly determined by the solar XUV flux.

Keywords: ancient Mars, atmospheric escape, multispecies MHD simulation, intrinsic magnetic field

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Sensitivity of the difference of cumulus convection schemes to the precipitation distributions simulated in a Paleo Mars GCM

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Current Mars has a lot of fluvial traces, which are supposed to have been made during the late Noachian and early Hesperian boundary (3.8-3.6 Ga). If these traces are created by the fluvial activity, the climate of early Mars should be ‘warm and wet’ enough for the long-term existence of liquid water on its surface. However, solar luminosity at that time would be weaker by 20-30 % of today’s value, which would make such the ‘warm and wet’ climate difficult (‘Faint Young Sun paradox’). Possible occasions to overcome this contradiction are the collisions of meteorites or the eruption of Tharsis which might make a temporary heating, and/or the emission of H_2 and/or CH_4 which possibly make a long term greenhouse effect by enhancing the infrared absorption.

We have newly developed a 3-dimensional Paleo Mars Global Climate Model (PMGCM) with ancient ocean on its surface below a sea level of -2.54 km, including the absorptions of CO_2 / H_2O /H_2 (0-20%) gases, CO_2 / H_2O ice clouds, thermodynamics of land / ocean, and hydrological processes [*Kamada et al.,* 2020]. This model reproduced a clement surface environment enough for liquid water on surface and could create most of fluvial channels by hydrological processes. However, the fluvial channels reproduced in our model were partly not consistent with observations on current Mars [*Hynek,* 2010].

Here we focused on the sensitivity of cumulus convection schemes to explain this inconsistency. This process could be crucial for resolving atmospheric instability and affect the distribution and the amount of precipitations on early Mars. Therefore, we have introduced two cumulus convection schemes and compared the results produced by each other. One is the Relaxed Arakawa-Schubert scheme (RAS) [*Moorthi and Suarez,* 1991] which is often used in terrestrial GCMs. RAS creates several cumulus in one grid and considers detrainment only top at the cloud top. The other is the Kain-Fritsch scheme (KF) [*Kain and Fritsch,* 1993], which creates a cumulus in one grid and considers detrainment at all height. Those two schemes use different convection triggers, which can affect the precipitation and cloud distribution on PMGCM.

At first, we did the tests of those two schemes under the present terrestrial condition (1bar, N_2 / O_2 atmosphere, 1370 W m^{-2}). In the T21L20 resolution the results of surface temperature and precipitation were almost similar in the two schemes, but the vertical distribution of cloud amount in sigma=0.8 with KF was 1.5 times thicker than RAS. That is because the characteristics of detrainment for each scheme are different, and due to the difference of convection trigger, the precipitation distribution did not match exactly between two schemes.

As the next step, we implemented those two schemes into the PMGCM for the conditions of surface pressures between 0.5-2.0 bars and H_2 mixing ratios of 0, 3, 6%. In the all conditions, the PMGCM results of surface temperature and precipitation were similar for the two schemes. However, the tendency of cloud amount and precipitation distribution was different, and in certain conditions, KF’s precipitation in the low latitudes was larger than RAS’s.

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Under the conditions in which KF had higher precipitation in low latitude than RAS (1.0bar and 6% H_2; 2.0bar and 3% H_2), the timescale of VN formation with KF would be 1.2 to 2.0 times faster than with RAS, because KF's detrainment in all altitudes resulted in more horizontal water vapor transport from the ocean than RAS. With KF, the change of precipitation area to higher latitudes, as seen in the higher temperature condition of *Kamada et al.,* [2020], tended to be smaller than with RAS because KF produced more humid atmosphere. It was difficult to generate new VNs which was not reproduced in *Kamada et al.,* [2020] with KF, i.e. the qualitative distributions of VN formations unchanged between KF and RAS in our PMGCM.

Keywords: Paleo-Mars Climate, Cumulus Convection, Precipitation Processes

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Zonal wind acceleration in the Martian mesosphere during the global dust storm 2018 observed by IR heterodyne spectroscopy

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Recent observations have revealed unexpectedly high abundance of water in the middle atmosphere (1.0 ~ 0.1 Pa), which should affect the atmospheric escape of water to space [Maltagliati et al.,2013]. Heavens et al. [2018] also found that the water vapor abundances in the middle atmosphere are further enhanced during the global dust storm (GDS). However, the detailed picture of the middle atmosphere during the GDS is not yet addressed, even though it is proposed that an intensified meridional circulation may transport water vapor to the middle and upper atmosphere effectively [Shaposhnikov et al., 2019].

On June 2018, the GDS occurred on Mars. The growth phase of the dust storm is June(solar longitude, Ls=196-202˚)and the decay phase is August(Ls=220-240˚)[Aoki et al.,2019]. It is also suggested that the dust particles were lifted to about 80 km [Fedorova et al.,2020], and equinoctial Hadley circulation reinforced by the GDS transported the water vapor to 100 km [Aoki et al.,2019].

In order to understand the mesospheric response during the dust storm, we have performed the direct measurement of mesospheric zonal winds and temperature from June to September 2018 by ground-based infrared heterodyne spectroscopy. The field of view is 4 arcsec for Martian angular diameter 20 arcsec. The observed CO_2 non-local thermodynamic-equilibrium (non-LTE) emission lines at 10 micron are originated from the mesosphere, peaking at ~ 80 km (~ 0.15 Pa) altitude [Lopez et al., 2011]. The kinetic temperature was derived from doppler width of the emission line and zonal wind velocity was directly derived from line-of-sight doppler shift of the emission line.

The observed kinetic temperature is 140 K from June (Ls=197) to September (Ls=242). Simultaneous observation by MAVEN/IUVS shows a good agreement with this study. On the other hand, zonal wind velocities derived from our observations during the GDS is retrograde 220 m/s from June to September. It is about twice as strong as a few remote sensing measurements of the mesospheric winds during a clear sky [Moreno et al., 2009; Sonnabend et al., 2012]. The uncertainty of retrieved value was roughly estimated to be 49% for kinetic temperature and 46% for zonal wind due to the fitting error, pointing error, and wavelength calibration uncertainty.

We investigate the mechanism to accelerate the zonal wind during the GDS by comparing with simulations by the Martian general circulation model (MGCM) [Medvedev et al.,2013]. MGCM suggested stronger retrograde winds around 0.1 Pa during MY25 GDS than clear sky at the equator, which agrees with this study. We concluded that one of the plausible mechanisms to accelerate the equatorial retrograde winds is intensified meridional advection from the southern hemisphere to the northern hemisphere during the GDS.

Keywords: Mars, Atmosphere, Infrared

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Study of proton escape from Mars based on MAVEN observations

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Mars is considered to have had water on surface in ancient days, while there is no surface water at present. Escape of atmospheric gases to space is considered to play an important role in this climate change. Particularly, hydrogen loss is closely related to the water content on Mars. Its main mechanism is thought to be Jeans escape of hydrogen atoms, which are dissociated from hydrogen molecules, sourced from odd-hydrogen reactions with near-surface water vapor. Since the molecular hydrogen is long-lived, the seasonal variation of hydrogen escape is predicted to be typically less than a factor of two (Krasnopolsky, 2002). However, Halekas (2017) reported unexpectedly large (about one order of magnitude) seasonal variations in the hydrogen corona. The cause of the large seasonal variation is not understood. A candidate mechanism is rapid transport of water to upper atmosphere due to the Martian dust storms. The enhancement of the hydrogen corona will increase the proton escape originated from the neutral hydrogen. In order to assess the hypothesis, we investigated proton escape from Mars based on MAVEN (Mars Atmosphere and Volatile EvolutioN) observations from November 2014 to March 2019. We also investigated if the seasonal variation depends on size of the dust storms by comparing MY32, 33 and 34, since Martian global dust storm occurred only in MY34.
For this purpose, we implemented methods to separate planetary-origin protons from solar-origin protons, which utilize characteristics of phase space density (PSD) observed in the solar wind, magnetosheath, and magnetotail wake regions, by STATIC (Supra Thermal and Thermal Ion Composition) instrument. For identification of each region, we used data from MAG (magnetometer) and SWIA (Solar Wind Ion Analyzer) onboard MAVEN. STATIC can measure ion distribution functions with energy and mass discrimination. In the magnetotail wake region, we divided the energy range in three parts: less than 20eV, between 20eV and 100eV, and greater than 100eV. The ions in the lowest energy range were identified as planetary protons. The methods to separate planetary from solar wind protons in solar wind and magnetosheath regions need to be different from that in the wake region. We removed solar wind velocity distributions by fitting in the rest frame of the solar wind/magnetosheath bulk flow, and calculated partial moments of picked up protons originated from hydrogen corona. To calculate partial moments, we identified regions where picked up protons should distribute. The regions are different between solar wind and magnetosheath regions. The obtained variations of the planetary protons are compared by using the wavelet analysis. The result shows that planetary proton density in the wake region had a seasonal variability which was more than one order, while variations in MY32, 33 and 34 were similar. Therefore, it is thought that the size of dust storm does not affect proton escape through the magnetotail wake region. The result in the solar wind region has the same seasonal variation as the result in the wake region. However, the amplitude of the variation in the solar wind region is smaller than that in the wake region. The protons in the magnetosheath region shows variation in the shorter periods. The wave period is about 200 days. It is thought that this time variation depends on the solar zenith angle.

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[E] Oral | P (Space and Planetary Sciences)：P-CG Complex & General

[P-CG25] Planetary Magnetosphere, Ionosphere, and Atmosphere

convener:Kanako Seki(Graduate School of Science, University of Tokyo), Takeshi Imamura(Graduate School of Frontier Sciences, The University of Tokyo), Hiroyuki Maezawa(Department of Physical Science Osaka Prefecture University), Naoki Terada(Graduate School of Science, Tohoku University)

Exploration of Moon, Venus, Mars, Mercury, Jupiter, Saturn, and beyond together with rapid developments of numerical simulations provides us new view of planetary environment. This session collects general contributions of new findings about planetary magnetosphere, ionosphere, and atmosphere. New methodology and technology development studies for future explorations are also welcome. In order to put the common knowledge at different planets into perspective, this session aims to facilitate discussions on comparative planetary environments.

[PCG25-07] Study of Molecular Ion Contribution to the Polar Plume from Mars Based on MAVEN Observations

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[PCG25-08] Study of the plasma distribution along a field line between Jupiter and Io related to the auroral electron acceleration process

*Koseki Saito[1], Yuto Katoh[1], Atsushi Kumamoto[1], Tomoki Kimura[1], Yohei Kawazura[1] (1.Department of Geophysics, Graduate School of Science, Tohoku University)

[PCG25-09] Characteristics of Jovian polar atmosphere derived from multispectral and polarimetric observations

*Shuntaro Yokota[1], Mitsuteru Sato[1], Yukihiro Takahashi[1], Seiko Takagi[1], Tatsuharu Ono[1], Yuuki Sato[1], Haruki Sugiyama[1] (1.Department of Cosmosciences, Graduate School of Science, Hokkaido University)

[PCG25-10] Numerical simulations of electron elastic collisions with neutral H_2O originated from Enceladus

*Hiroyasu Tadokoro[1], Yuto Katoh[2] (1.Musashino University, 2.Tohoku University)

[PCG25-11] High-contrast imaging of planetary and satellite atmospheres by the 1.8 m off-axis PLANETS telescope

*Takeshi Sakanoi[1], Masato Kagitani[1], Masahiro Hirahara[2], Mikio Kurita[3], Toshihisa Suzuki[1], Yasumasa Kasaba[1], Takahiro Obara[1], Shoichi Okano[1], Kuhn Jeff[4], Svetlana Berdyugina[5], Emilio Marcelo[6] (1.Planetary Plasma and Atmospheric Research Center, Graduate School of Science, Tohoku University, 2.Graduate School of Environmental Studies, Nagoya University, 3.Graduate School of Science, Kyoto University, 4.Institute for Astronomy, University of Hawaii, USA, 5.Kiepenheuer Institute for Solar Physics, Germany, 6.Universidade Estadual de Ponta Grossa, Brazil)

[PCG25-12] Development of Generic Plasma Irradiation System for Modeling of Space Weathering at Solar System Bodies

*Tomoki Kimura[1], Yusuke Nakauchi[4], Jun Kimura[2], Go Murakami[4], Naoki Terada[3], Hideyuki Usui[6], Masaki N Nishino[4], Shoichiro Yokota[2], Yohei Miyake[6], Kazuo Yoshioka[5] (1.Frontier Research Institute for Interdisciplinary Sciences, Tohoku University, 2.Graduate School of Science, Osaka University, 3.Graduate school of science, Tohoku University, 4.JAXA/ISAS, 5.Department of Complexity Science and Engineering, Tokyo University, 6.Kobe University)

Study of Molecular Ion Contribution to the Polar Plume from Mars Based on MAVEN Observations

*Sakakura Kotaro[1], Kanako Seki[1], Shotaro Sakai[1], David A Brain[2], James P McFadden[3], James S Halekas[4], Gina A Dibraccio[5], Bruce M Jakosky[2]

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Mars once had water on its surface about 4 billion years ago, but there is no liquid water on the surface at present. Escape of the atmosphere to space is considered as the main cause of this climate change. However, the mechanism of the large amount of atmospheric loss is far from understood. Ion escape is one of the important candidates of the loss mechanism. There are three channels of the ion escape, namely, tailward escape, pickup ion, and polar plume. Polar plume ions are accelerated by solar wind electric field and escape to positive E hemisphere of the Mars-Sun-Electric field (MSE) coordinates. It is estimated by Dong et al. [2017] that the escape rate of O^+ plume is 20-30% of the total O^+ escape depending on the solar EUV radiation. The rate is not negligible in order to understand ion escape from Mars. Molecular ions in the polar plume should also be studied since it is shown that main escape species is O_2^+ for tailward escape by Inui et al. [2019]. We recently reported a CO_2^+-rich plume event on August 28, 2015. Peak flux of CO_2^+ was 3.6×10^6 $cm^{-2}s^{-1}$, which is about one order of magnitude higher than the average flux of O^+ in the polar plume reported by Dong et al. [2017]. Such high escape flux is unexpected because CO_2^+ is minor component at high-altitude ionosphere due to its small scale height. To fully understand the mechanism of polar plume, it is important to study the composition of the plumes.

In order to investigate relationship between CO_2^+-rich plume event and solar wind conditions, we conducted a statistical study. We analyzed data obtained by STATIC (Supra Thermal and Thermal Ion Composition), MAG (magnetometer) and SWIA (Solar Wind Ion Analyzer) onboard MAVEN (Mars Atmosphere and Volatile EvolutioN) from Dec. 11, 2014 to Feb. 23, 2019. STATIC can measure ion distribution functions with mass discrimination. In order to derive CO_2^+ number density, we use the fitting method invented by Inui et al. [2018]. By fitting a log-normal distribution to O_2^+ count data, we remove O_2^+ contamination in the CO_2^+ mass range. We defined CO_2^+ plume event as the time period when the observed maximum flux of CO_2^+ in an MAVEN orbit is higher than 2.5×10^5 $cm^{-2}s^{-1}$. In order to remove false CO_2^+ plume events due to high O_2^+ counts, we set another requirement that CO_2^+ has evident peak which is at least comparable to O_2^+ contamination in the CO_2^+ mass range. The results show that the CO_2^+ plume events tend to be observed under high solar wind dynamic pressure and strong electric field conditions. This result is consistent with hypothesis that CO_2^+ plume is caused by deep penetration of the solar wind electric field due to the high solar wind dynamic pressure. On one hand, detection probability of O_2^+ plume events don't show such dependences on the solar wind parameters. This is probably because O_2^+ is abundant near the ionopause enough to create dense ($>2.5 \times 10^5$ $cm^{-2}s^{-1}$) O_2^+ plumes regardless of the solar wind conditions. On the other hand, the escape flux of O_2^+ due to the polar plume has weak positive correlation with the solar wind dynamic pressure. This result might reflect high density of O_2^+ near the ionopause under the high solar wind dynamic pressure conditions.

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Keywords: Mars, MAVEN, atmospheric escape, carbon dioxide, polar plume

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Study of the plasma distribution along a field line between Jupiter and Io related to the auroral electron acceleration process

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Observation NASA's spacecraft Juno revealed the downward electrons in the energy range from a few tens keV to hundreds keV in the Jupiter's auroral regions. The observed energy and pitch angle distributions suggested that Alfvenic acceleration process, which has been considered to be a minor acceleration mechanism on the Earth, plays significant roles in the formation of Jupiter's aurora [Mauk et al., 2017]. Despite the increasing attention to the Alfvenic acceleration process in considering the aurora formation of magnetized planets, physical process controlling the characteristic energy and pitch angle distributions have been still unclear. For the discussion of Alfvenic acceleration, the spatial distribution of multispecies ions and electrons along a field line is necessary to understand property of Alfven waves. In the present study, we have been developing a static Vlasov code [Ergun et al., 2000; Matsuda et al., 2010] for the steady state distribution of magnetospheric plasma along a magnetic field line between Jupiter and its satellite Io. Matsuda et al. (2010) used a static Vlasov code for the plasma distribution along a magnetic field line between Jupiter and Io to study the altitude distribution of the Io-related decametric radio sources. We develop a static Vlasov code by referring to Matsuda et al. (2010) and used the obtained plasma distribution for the study of the property of Alfven waves. In the developed code, assuming bi-Maxwellian distributions for the initial velocity distributions of both ions and electrons at the ionospheric end and at the magnetic equator, we solve the spatial variation of the velocity distributions of ions and electrons by considering the spatial distribution of the background magnetic field intensity, gravity and centrifugal forces as well as the electrostatic potential along a field line. We compute charge densities of ions and electrons by integrated the velocity distributions at each grid point along a field line and evaluate the electrostatic potential iteratively to obtain a solution satisfying the quasi-neutrality. We assume the boundary conditions that protons and electrons originate from the Jovian ionosphere, and hot electrons, cold electrons and ions (O^+, S^+, S^{2+}, H^+) from Io. The electrostatic potential difference between Jupiter and Io is initially assumed to be 30 kV. In the simulation result, we obtained a solution showing the electrostatic potential of almost 30 kV from the Jovian ionosphere to 0.029 RJ from Jupiter, and the potential gap from 30 kV to about 20.5 kV at 0.029 RJ and from 20.5 kV to about -20 V near 2 RJ, where RJ represents Jupiter's radius. We also computed the Alfven speed from the obtained distribution of ions and showed a peak close to the speed of light near 1 RJ. In this presentation, we show results of the developed static Vlasov code and discuss the comparison between Jupiter and the Earth, as well as our future study on the Alfvenic acceleration process under the plasma distribution obtained by the static Vlasov code.

Keywords: Jupiter-Io system, magnetized planets, Alfven waves

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Characteristics of Jovian polar atmosphere derived from multispectral and polarimetric observations

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Polarimetric observation is an effective method for determining the particle properties of the planet's surface and atmosphere. From this reason, many polarimetric observations of Jovian atmosphere have been performed so far. Although previous studies show the difference in the polarization degree depending on the Jovian latitude [McLean et al., 2017, Schmid et al., 2011], there are few observations tracking the regional differences of the polarization degree in a short term period, such as a few hours or a few days. Thus, the data volume is insufficient enough to discuss the temporal variations of particle characteristics. The purpose of this study is to observe the motion of the polar upper layer in the Jovian atmosphere and the temporal variations of the particle characteristics from the polarimetric and multispectral imaging using the 1.6 m Pirka telescope operated by Hokkaido University and to clarify the convection mechanism of the Jovian atmosphere by comparing the multispectral imaging data to polarimetric imaging data.

In this presentation, we introduce the results derived from the spectral imaging observations and the polarimetric imaging observations using the Multi Spectral Imager (MSI) (pixel scale = 0.39 "/ pix) with the band-pass filters of 650 nm, 727 nm, and 889 nm, which is mounted on the Pirka telescope. We conducted the MSI observations from May to August 2019. The images at the methane absorption wavelength of 727 nm and 889 nm show bright clouds and haze layers in Jovian atmosphere due to the higher ratio of scattered light. Liquid Crystal Variable Filter (LCTF) installed in the MSI can be used for the polarimetric observations with the linear polarizer. We obtained the polarimetric data of May 22, 2019 (observed longitudinal range was 120 –270 deg) and June 24, 2019 (0 –180 deg). The latitudinal variations of the stokes parameter are comparable with the results reported by the previous studies. In order to monitor the temporal variations of the cloud/haze structure and their polarimetric characteristics, it is necessary to simultaneously obtain the multispectral and polarimetric data with the time resolution of 1 day. In the 2019 season, we obtained the continuous multispectral imaging data. But, we failed to obtain the continuous polarimetric data due to the climate conditions. From this reason, we could not enough compare the cloud/haze structure in the Jovian polar atmosphere confirmed by the multispectral imaging data with the polarization degree derived from the polarimetric observations. At the presentation, we will show the initial results derived from the image analysis and will show the future observation plan more in detail.

Keywords: Jupiter, Polarimetry, Ground-based telescope

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Numerical simulations of electron elastic collisions with neutral H_2O originated from Enceladus

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Saturn’s inner magnetosphere is dominated by water group neutrals originated from Enceladus. The water group neutrals (H_2O, OH, and O) play the dominant role in loss of energetic plasmas [e.g., *Paranicas et al.,* 2007; *Sittler et al.,* 2008]. The observations of injected plasmas in the inner magnetosphere suggest that these particles do not survive very long time due to the neutral cloud originated from Enceladus [e.g., Paranicas et al., 2007; 2008]. Thus, the previous studies suggested that the neutrals contribute to loss processes of plasma in the inner magnetosphere. However, little has been reported on a quantitative study of the electron loss process due to electron-neutral collisions.

Tadokoro et al., [2014] examined the time variations of equatorial electron pitch angle distribution and electrons within loss cone through 1keV electron pitch angle scattering due to elastic collisions around Enceladus, conducting one dimensional test particle simulation. The result showed that the electrons of 11.4 % are lost in ~380 sec. This time corresponds to the time scale of the co-rotation of the flux tube passing through the region of the dense H_2O in the vicinity of Enceladus. Assuming the uniform azimuth H_2O density structure in the Enceladus torus, they estimated the electron loss rate of 33% during one co-rotation.
We show the energy dependent electron (500 eV –50 keV) loss rates through pitch angle scattering due to elastic collisions. We show the comparison of the loss rates between the high (in the vicinity of Enceladus) and low (in the Enceladus torus) H_2O density regions. The collision is solved by a Monte-Carlo method. The cross section is based on experimental data. We show the calculation errors by making 10 times calculations. We also estimate the auroral brightness by using calculated electrons.

Keywords: elastic collision, Enceladus, Saturn

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High-contrast imaging of planetary and satellite atmospheres by the 1.8 m off-axis PLANETS telescope

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We are carrying out a 1.8-m aperture off-axis telescope project PLANETS (Polarized Light from Atmospheres of Nearby ExtraTerestrial Systems). The PLANETS telescope is characterized by high-contrast imaging and spectroscopic capability thanks to low-scattering in the optical system by combining off-axis mirror, adaptive-optics (AO), and stable atmospheric conditions of an observatory site at a high-altitude. In particular, the off-axis system brings us no cross-shaped diffraction pattern caused by the secondary mirror support in the optical path, and thus the scattering light of PLANETS is estimated to be more than 10 times better than that of a normal large telescope. PLANETS Foundation (www.planets.life), whose board members are from Japan, USA, Germany, and Brazil, manages this project.

Our major scientific goal is to detect faint emission surrounding planet and satellite in the solar system as well as exoplanets, such as Jovian satellite Europa’ s plume and Martian ionosphere. These emissions are so faint (10^{-3} to 10^{-6} to the brightness of planetary or satellite disk) close to the main disk (less than a few arcsec) that the measurement of these distributions and time variabilities are difficult. PLANETS is appropriate to observe these targets by taking advantages of high-contrast imaging and spectroscopic capability and monitoring operation optimized for the targets.

The telescope optics has a Gregorian focus with a FOV of 6' (F/13). The main mirror is Clearceram Z-HS with a diameter of 1850 mm and thickness of 100 mm. So far, the glass ceramic blank of main mirror was made by Ohara Inc. in 2010, the rough grinding was carried out by Harris/Excelis in 2012. After that, the main mirror has been stored at the University of Hawaii. Last December, the mirror was shipped to Japan to carry out the final polishing. We glued 36 metal adapters on the backside of mirror to connect the mirror support. The mirror support adopts the whiffletree with warping harness system which is similar to TMT and the Seimei telescope. We made the elemental test of the whiffletree system, and confirmed that the performance for stress input is as expected by the structure model with a finite element method (FEM), and the repeatability (hysteresis) for stress change is in the acceptable range. We are now developing the whiffletree support, and will complete by the end of March 2020. After that, we will carry out the final polishing using a dragging three probe method with a robot-arm system at Logist Lab./Astro-Aerospace within a year. Compared with a traditional CGH-type interferometric metrology, the dragging three probe method and polishing with the robot arm are characterized by the free-form metrology with three-probe. We expect to obtain the accuracy of main mirror better than 20 RMS nm by the final polishing. In addition, we will fabricate the telescope mount and structures using the proto-type mount Seimei telescope now stored at Nagoya University. We will assemble the whole PLANETS telescope, and achieve the first light and technical demonstration, particularly on the high-contrast and low-scattering capability, in Japan within a few years. Further, we already have the construction permit with conservation district use application (CDUA) at the summit of Haleakala, Hawaii, and we plan to install PLANETS there as soon as we get the funding for the observatory construction.

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Keywords: telescope, PLANETS, development, high contrst, planetary atmosphere, satellite

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Development of Generic Plasma Irradiation System for Modeling of Space Weathering at Solar System Bodies

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Surface and atmosphere of solar system bodies are continuously irradiated with the planetary magnetospheric plasma, solar wind, solar photon, cosmic dusts, and ring grains, which are responsible for long-term alteration of surface and atmospheric materials on timescales up to geological scale (Giga years) known as the 'space weathering'. The space weathering accompanies creation and destruction of molecules in the surface and atmospheric materials (see e.g., Johnson et al., in Jupiter textbook, 2004). For example, organic compounds like tholins are likely created and destroyed via the space weathering at Titan's upper atmosphere and icy moon's surfaces at Jupiter and Saturn (e.g., Waite et al., 2007; Lopez-Puertas et al. 2013). This suggests that the newly created/destroyed molecules are accumulated on the surface over the geological time scale, which are likely essential energy and material sources for evolutions of the surface, atmosphere, and possibly interior. However, the creation and destruction balance of surface/atmospheric molecules on the geological timescale are still unknown because of small irradiation doses in the previous laboratory experiments. Here we develop a new laboratory experiment system for modeling of the space weathering on geological timescales. In order to associate the space weathering with evolution of body's magnetic field, we first try to model the plasma space weathering with a high-fluence charged particle irradiation (<1e+23 particles/cm2). Now fabrication of the plasma irradiation system is going on after structural and thermal designs. The current status of development will be presented in this poster.

Keywords: Space weathering, Plasma, Surface bounded exosphere bodies

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS01] High performance computing for next generation weather, climate, and environmental sciences

convener:Hiromu Seko(Meteorological Research Institute), Takemasa Miyoshi(RIKEN), Chihiro Kodama(Japan Agency for Marine-Earth Science and Technology), Masayuki Takigawa(Japan Agency for Marine-Earth Science and Technology)

A lot of advanced simulation studies are being conducted by high performance supercomputers, such as K computer and Earth Simulator, in various fields including meteorology. The high performance supercomputers enable us to conduct numerical simulations and data assimilation of observation big-data (huge high-density and high-frequency data) with a few orders of magnitude higher resolutions and ensemble numbers than those with the previous supercomputers. In addition, the post-K computer, Fugaku will be available as a successor of K, and studies for the Fugaku computer are in progress. At this session, we comprehensively pick up the topics in the Atmospheric and Hydrospheric Sciences Sessions of the 2020 Union Meeting that comprise the atmospheric, oceanic and land sciences. This session aims to promote recent studies related to the issues on high performance computing in weather, climate, and environmental studies using the K computer and other supercomputers, study plans using the Fugaku computer, and to enhance discussions on future directions of numerical simulations in meteorology.

[AAS01-01] Big Data Assimilation: Real-time Workflow for 30-second-update Forecasting and Perspectives toward DA-AI Integration

*Takemasa Miyoshi[1], Takumi Honda[1], Shigenori Otsuka[1], Arata Amemiya[1], Yasumitsu Maejima[1], Yoshihiro Ishikawa[2], Hiromu Seko[2], Yoshito Yoshizaki[2], Naonori Ueda[1], Hirofumi Tomita[1], Yutaka Ishikawa[1], Shinsuke Satoh[3], Tomoo Ushio[4], Kana Koike[5], Yasuhiko Nakada[6] (1.RIKEN, 2.Japan Meteorological Agency, 3.National Institute of Information and Communications Technology, 4.Osaka University, 5.MTI Ltd., 6.Tokyo Electric Power Company Holdings)

[AAS01-02] Evaluating the impact of precipitation radar observations from a geostationary satellite on typhoon forecasts

★Invited Papers

*James David Taylor[1], Atsushi Okazaki[3], Moeka Yamaji[2], Takuji Kubota[2], riko Oki[2], Takemasa Miyoshi[1] (1.RIKEN Center for Computational Science, 2.Earth Observatory Research Center, 3.Pennsylvania State University)

[AAS01-03] Formation Process of a Tornado that Formed in a Quasi Linear Convective System Over Kanto Plain, Japan

*Eigo Tochimoto[1], Hiroshi Niino[1] (1.Atmosphere and Ocean Research Institute, The University of Tokyo)

[AAS01-04] **Exploring the potential of assimilating lightning flash observations with an ensemble Kalman filter**

*Takumi Honda[1], Yousuke Sato[2], Takemasa Miyoshi[1] (1.RIKEN, 2.Hokkaido University)

[AAS01-05] Impacts of vessel GNSS data on the heavy rainfall forecasts obtained by JMA's mesoscale data assimilation system (NAPEX)

*Hiromu Seko[1], Yoshinori Shoji[1], Daisuke Hotta[1], Ko Koizumi[2], Yasutaka Ikuta[2] (1.Meteorological Research Institute, 2.Japan Meteorological Agency)

[AAS01-06] Accounting for the horizontal observation error correlation of satellite radiances in ensemble Kalman filter

*Koji Terasaki[1], Takemasa Miyoshi[1] (1.RIKEN Center for Computational Science)

Big Data Assimilation: Real-time Workflow for 30-second-update Forecasting and Perspectives toward DA-AI Integration

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The Japan’s Big Data Assimilation (BDA) project started in October 2013 and ended its 5.5-year period in March 2019. The direct follow-on project was accepted and started in April 2019 under the Japan Science and Technology Agency (JST) AIP (Advanced Intelligence Project) Acceleration Research, with emphases on the connection with AI technologies, in particular, an integration of DA and AI with high-performance computation (HPC). The BDA project aimed to fully take advantage of “big data” from advanced sensors such as the phased array weather radar (PAWR) and Himawari-8 geostationary satellite, which provide two orders of magnitude more data than the previous sensors. We have achieved successful case studies with newly-developed 30-second-update, 100-m-mesh numerical weather prediction (NWP) system based on the RIKEN’s SCALE model and local ensemble transform Kalman filter (LETKF) to assimilate PAWR in Osaka and Kobe. We have been actively developing the workflow for real-time weather forecasting in Tokyo in summer 2020. In addition, we developed two precipitation nowcasting systems with the every-30-second PAWR data: one with an optical-flow-based system, the other with a deep-learning-based system. We chose the convolutional Long Short Term Memory (Conv-LSTM) as a deep learning algorithm, and found it effective for precipitation nowcasting. The use of Conv-LSTM would lead to an integration of DA and AI with HPC. This presentation will include an overview of the BDA project toward a DA-AI-HPC integration under the new AIP Acceleration Research scheme, and recent progress of the project.

キーワード：データ同化、ビッグデータ、フェーズドアレイ気象レーダ、ビッグデータ同化、数値天気予報
Keywords: Data Assimilation, Big Data, Phased Array Weather Radar, Big Data Assimilation, Numerical Weather Prediction

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Evaluating the impact of precipitation radar observations from a geostationary satellite on typhoon forecasts

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Over the past two decades precipitation radars (PR) onboard low-earth orbiting satellites such as the Tropical Rainfall Measuring Mission (TRMM) and the Global Precipitation Measurement (GPM) Core Observatory have provided valuable measurements of the three-dimensional structure of precipitation, improving our understanding of the role of precipitation in the global climate system. Building upon this success, Japan Aerospace Exploration Agency (JAXA) is now exploring the feasibility and usefulness of a new PR satellite stationed in geostationary orbit (Okazaki et al 2019). Such an instrument would have much higher observation frequency of global precipitation compared to previous and existing instruments, bringing new insight into the distribution and variability of rainfall, as well as advances in numerical weather prediction (NWP) through data assimilation.

Okazaki et al (2019) previously showed that obtaining the three-dimensional structure of precipitation from a geostationary PR is feasible and that assimilation of observations within a NWP model has positive impact on typhoon forecasts. The study also demonstrated that observation quality and resolution depended on the size of beam width and beam span, with larger beam widths and coarser beam spans unable to observe weaker precipitation at lower altitudes due to heavy contamination from surface clutter. Owing to the limitations on antenna size that could be delivered for a satellite in geostationary orbit, the resolution of observations are expected to be several times coarser than those onboard low-earth orbiting satellites. Given this, is important to consider a range of resolutions and beam sampling spans and understand their impact on NWP, in order to provide better forward guidance pertaining to future satellite mission design and strategy.

In this study we perform an Observing Simulation System Experiment (OSSE) to investigate the impact of GPR observations with horizontal resolutions and beam sampling spans ranging between 5km and 30km on forecasts for a typhoon case (Typhoon Soudelor 2015). The results show that the assimilation of observations at higher resolution (5km) improved representation of the typhoon structure and intensity in the analysis and reduced intensity forecast error compared to assimilating observations at lower resolution (20km). This was due to the smaller beam width able to observe the higher intensity precipitation regions at lower altitudes. Representation of the typhoon structure and intensity forecasts was also improved for experiments where the beam sampling span was narrowed from 20km to 5km.

Okazaki et al 2019: Simulating precipitation radar observations from a geostationary satellite. Atmos. Meas. Tech., 12 (7),3985-3996

Keywords: geostationary, precipitation radar, typhoon, forecasts, assimilation

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Formation Process of a Tornado that Formed in a Quasi Linear Convective System Over Kanto Plain, Japan

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Tornadoes are mainly classified into three groups based on different types of convective systems: supercells, quasi-linear convective systems (QLCSs), and non-supercells. In the United States, it is estimated that 18% of all tornadoes are spawned by QLCSs. In Japan, although tornadoes associated QLCSs also occur and cause severe damages, the detailed features and formation mechanism of tornadoes have not been well understood. Thus, we performed a high-resolution numerical simulation to reproduce and examine the formation process of a tornado that formed in a QLCS at Chiyoda-town, Ibaraki prefecture, Japan on 8 December 1992.

A quadruple-nested simulation using Japanese Meteorological Agency non-hydrostatic model was performed. A simulation with the finest horizontal scale of 50m successfully reproduced the tornado in the QLCS. At around 500m height, a low-level mesovortex, which was accompanied by strong updrafts (>20m/s), formed and developed around the location of tornadogenesis. A lagrangian circulation analysis showed that the source of the mesovortex was due to environmental wind fields. A lagrangian vorticity budget analysis showed that vertical tilting of crosswise vorticity associated with vertical shear in the forward inflow region contribute to the increase of vertical vorticity and then the vertical vorticity was stretched by strong updrafts. Near the surface, at 1 or 2 minutes before the tornadogenesis, strong rear-inflow jet (RIJ) accompanied by relatively cold air developed and cyclonic circulation was intensified in the northern part of the RIJ region. The tornadogenesis occurred in the northern part of the RIJ. Thus, it is suggested that the RIJ play significant roles in the formation and development of the tornado. The lagrangian circulation analysis showed that a half of the cyclonic circulation of the tornado was produced by frictional effects and another half of the cyclonic circulation originated from environmental wind fields.

キーワード：竜巻、対流システム
Keywords: Tornado, Convective system

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Exploring the potential of assimilating lightning flash observations with an ensemble Kalman filter

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To predict severe storm development, it is essential to obtain good initial conditions with data assimilation. Many previous studies have assimilated radar observations into severe convective storms and shown the profound impact on Numerical Weather Prediction (NWP). Besides, a few studies have demonstrated the potential of high-spatiotemporal resolution infrared radiance observations by next-generation geostationary satellites for improving sudden severe rainfall prediction. Satellite observations may play a major role over the ocean and mountains, where ground-based radar observations are not available.

To further improve the accuracy of NWP for severe storms, it would be beneficial to assimilate lightning flash observations from geostationary satellite-borne lightning sensors. Hydrometeors may obtain electric charge via collision processes, and their charge separation depends on the surrounding environment. Therefore, lightning flash observations would reflect microphysical processes and storm development more directly compared to infrared radiance observations by geostationary satellites. This study aims to explore the potential of assimilating the lightning flash observation for improving severe-storm prediction. To do so, we use an ensemble Kalman filter with an NWP model including explicit lightning discharge processes. As the first step, ensemble-based correlations between lightning flash observations and the atmospheric variables are investigated. The results show that the infrared radiance observations do not always detect the location of the convective core due to broad-range anvil clouds, whereas the lightning flash observations are more directly associated with the convective core.

キーワード：データ同化、数値天気予報、雷
Keywords: Data assimilation, Numerical Weather Prediction, Lightning

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メソ数値予報実験システム（NAPEX）を用いた船舶GNSSの同化実験
Impacts of vessel GNSS data on the heavy rainfall forecasts obtained by JMA's mesoscale data assimilation system (NAPEX)

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大雨に供給される下層インフローの水蒸気分布を改善することにより，降水予報の精度を向上させることが期待できる．ここでは船舶GNSSで得られた東シナ海の水蒸気量をデータ同化に用い，九州北部で発生した大雨へのインパクトを調べた．船舶GNSSのデータ同化により，東シナ海の水蒸気分布が修正し，九州北部の大雨の降水予報が改善する場合もあることが確認できた．さらにバイアス補正と正時に加えて15分前，30分前の観測値を加えた実験の結果から，より正しい可降水量をより多くの点で与えることが重要であることがわかった．

本研究は，「ビッグデータ同化とAI によるリア ルタイム気象予測の新展開」（JST AIP JPMJCR19U2），ポスト「京」プロジェクト重点課題4「観測ビッグデー タを活用した気象と地球環境の予測の高度化」(課題ID: hp190156)の 支援を受けたものです．

キーワード：データ同化、GNSS
Keywords: Data assimilation , GNSS

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Accounting for the horizontal observation error correlation of satellite radiances in ensemble Kalman filter

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A recent development in sensing technology increased the number of observations both in space and time. It is essential to effectively utilize the information from observations to improve numerical weather prediction (NWP). It is known to have correlated errors in observations measured with a single instrument, such as satellite radiances. The error-correlated observations are usually thinned to compensate for neglecting the horizontal observation error correlation in data assimilation. This study explores to explicitly account for the horizontal observation error correlation of Advanced Microwave Sounding Unit-A (AMSU-A) radiances using global atmospheric data assimilation system NICAM-LETKF, which comprises the Nonhydrostatic ICosahedral Atmospheric Model (NICAM) and Local Ensemble Transform Kalman Filter (LETKF).
In this study, we estimate the horizontal observation error correlation of AMSU-A radiances using innovation statistics (Desroziers, 2005). The computation cost of inverting the observation error covariance matrix will increase when non-zero off-diagonal terms are included. In this study, we assume uncorrelated errors between different instruments and observation variables, so that the observation error covariance matrix becomes block diagonal. We can suppress the computational cost by up to 10 % by inverting the small block diagonal matrices. We perform data assimilation experiments at 112-km horizontal resolution with diagonal and non-diagonal observation error covariance matrices. The results show that the analyses and forecasts of temperature and zonal wind are improved by accounting for the horizontal error correlations in the mid- and upper-troposphere. We will present the most recent results at the workshop.

Keywords: Data assimilation, Observation error correlation, Satellite radiances, Ensemble Kalman filter

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS01] High performance computing for next generation weather, climate, and environmental sciences

convener:Hiromu Seko(Meteorological Research Institute), Takemasa Miyoshi(RIKEN), Chihiro Kodama(Japan Agency for Marine-Earth Science and Technology), Masayuki Takigawa(Japan Agency for Marine-Earth Science and Technology)

A lot of advanced simulation studies are being conducted by high performance supercomputers, such as K computer and Earth Simulator, in various fields including meteorology. The high performance supercomputers enable us to conduct numerical simulations and data assimilation of observation big-data (huge high-density and high-frequency data) with a few orders of magnitude higher resolutions and ensemble numbers than those with the previous supercomputers. In addition, the post-K computer, Fugaku will be available as a successor of K, and studies for the Fugaku computer are in progress. At this session, we comprehensively pick up the topics in the Atmospheric and Hydrospheric Sciences Sessions of the 2020 Union Meeting that comprise the atmospheric, oceanic and land sciences. This session aims to promote recent studies related to the issues on high performance computing in weather, climate, and environmental studies using the K computer and other supercomputers, study plans using the Fugaku computer, and to enhance discussions on future directions of numerical simulations in meteorology.

[AAS01-07] Projected future changes in tropical cyclone genesis and its seed frequencies by using HighResMIP multi model ensemble simulation

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[AAS01-08] 100-member ensemble forecast by NICAM to examine forecast bust case Typhoon Krosa (2019)

*Masuo Nakano[1], Ying-Wen Chen[2], Masaki Satoh[2] (1.JAMSTEC Japan Agency for Marine-Earth Science and Technology, 2.AORI / The University of Tokyo)

[AAS01-09] From K to Fugaku: activities toward extended-range prediction using NICAM/NICOCO

*Tomoki Miyakawa[1] (1.Atmosphere and Ocean Research Institute University of Tokyo)

[AAS01-10] Toward an integrated NWP-DA-AI system for precipitation prediction

*Shigenori Otsuka[1], Yasumitsu Maejima[1], Pierre Tandeo[2], Takemasa Miyoshi[1] (1.RIKEN Center for Computational Science, 2.IMT Atlantique)

[AAS01-11] **Parameterization of Subgrid Momentum Transport Using a Global Cloud Resolving Model and AI**

★Invited Papers

*Haruna Tone[1], Masaki Satoh[2], Junshi Ito[2] (1.School of Science, The University of Tokyo, 2.Atmosphere and Ocean Research Institute, The University of Tokyo)

[AAS01-12] Precipitation Nowcasting Based on Convolutional Neural Networks

★Invited Papers

*Maha Mdini[1], Shigenori Otsuka[1], Takemasa Miyoshi[1] (1.RIKEN Center for Computational Science)

Projected future changes in tropical cyclone genesis and its seed frequencies by using HighResMIP multi model ensemble simulation

*山田 洋平[1]、小玉 知央[1]、佐藤 正樹[2,1]、杉 正人[3]、Roberts Malcolm[4]、水田 亮[3]、野田 暁[1]、那須野 智江[1]、中野 満寿男[1]、Vidale Pier-Luigi[5]
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Projection of the frequency of tropical cyclone genesis due to global warming, even in signs of change, depends on the literatures. Here we systematically examine the projected changes in tropical cyclone using six global atmospheric models with middle and high horizontal resolutions participating in the sixth phase of Coupled Model Intercomparison Project / High Resolution Model Intercomparison Project (Haarsma et al., 2016). Simulated tropical cyclones were detected by an objective tracking algorithm, TempestExtremes (Ullrich and Zarzycki, 2017; Zarzycki and Ullrich, 2017). Here we simply regard a candidate of tropical cyclone in the algorithm as a tropical cyclone seed, which is a low-pressure system with a closed isobar. Changes in the frequency of tropical cyclone genesis could be broken down into the contributions from tropical cyclone seed, and survival rate, a rate of frequency of tropical cyclone genesis to that of tropical cyclone seed. The multi model ensemble mean indicates that the frequencies of the tropical cyclone genesis are significantly decreased during the period of 1950–2049, and it is attributable to the changes in the tropical cyclone seed. Analysis of individual model shows that, although most models project more or less decreasing trend of the frequencies of the tropical cyclone genesis and seed, the survival rate also contributes to the result in some models. This study suggests a usefulness of the decomposition into the frequency of the tropical cyclone seed and the survival rate to understand the cause of the uncertainty in the projected frequency of the tropical cyclone genesis.

キーワード：地球温暖化、熱帯低気圧の種、HighResMIP
Keywords: Global warming, tropical cyclone seed, HighResMIP

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100-member ensemble forecast by NICAM to examine forecast bust case Typhoon Krosa (2019)

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Typhoon Krosa formed near the Mariana Islands at 0600 UTC on 6 August 2019 then translated northwest-north northwestward and made landfall western part of Mainland of Japan on 15 August. At the early stage of Krosa’s lifetime, multicenter operational models predicted huge diversity of track: JMA (ECMWF) model predicted Krosa would translate north-northeastward (northwest-north northwestward), thus it would not (would) hit Japan.
To examine why such diversity in predicted tracks occurred, 100-member ensemble forecast experiments were performed using 28-km mesh nonhydrostatic icosahedral atmospheric model (NICAM). The model was initialized with NICAM-LETKF JAXA Research Analysis (NEXRA).
In the experiments initialized at 1200 UTC on 6 August showed large uncertainty of Krosa’s track as predicted in multicenter operational models and the west most simulated tracks captured Krosa’s analyzed track by RSMC Tokyo. An ensemble-based sensitivity analysis revealed that westward extension of subtropical Pacific high led to northwest/north-northwest trajectory. Dependency of initial data and mechanism which caused westward extension of the subtropical high will be discussed at the presentation.

キーワード：アンサンブル予報、NICAM、NEXRA、台風
Keywords: ensemble forecast, NICAM, NEXRA, typhoon

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From K to Fugaku: activities toward extended-range prediction using NICAM/NICOCO

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After the global cloud-resolving model NICAM successfully reproduced the Madden-Julian oscillation (MJO) on the Earth Simulator (Miura et al. 2007), it became one of the major issues for high performance computing atmospheric science to make the most of the MJO signal for the realization of extended-range prediction (> 2 weeks). The computational power of the K computer enabled ensemble experiments of MJOs using NICAM, and it has been shown that the prediction of MJO is possible for about a month (Miyakawa et al. 2014). In the post-K program, a full 3-dimensional ocean component has been coupled to NICAM, which is viewed as a key piece upon utilizing the MJO signal to improve disaster prediction, such as Typhoon development.
In this talk, I will summarize the related efforts on the K computer and the remaining issues to be addressed on Fugaku, scheduled to start full-scale operation in 2021.

キーワード：全球雲解像モデル、マッデン・ジュリアン振動、海洋結合
Keywords: global cloud resolving model, Madden Julian Oscillation, ocean coupling

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Toward an integrated NWP-DA-AI system for precipitation prediction

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The Phased-Array Weather Radar (PAWR), developed by the National Institute of Information and Communications Technology, Osaka University, and Toshiba Corporation, has been in operations since 2012 in Japan. The PAWR scans the whole sky in the 60-km range every 30 seconds at 110 elevation angles. Four PAWRs of the same type have been installed in Osaka, Kobe, Okinawa, and Tsukuba, and two similar ones of other types have been installed in Japan. Taking advantage of the PAWRs' frequent and dense three-dimensional volume scans, we developed two systems: a high-resolution regional numerical weather prediction (NWP) system (SCALE-LETKF, Miyoshi et al., 2016a,b, Lien et al., 2017), and a three-dimensional (3D) precipitation nowcasting system (Otsuka et al., 2016).

Our 30-second-update 3D nowcasting system is running in real time since 2017; the system adopts an optical-flow-based algorithm in the 3D space. Because convective clouds evolve rapidly within a 10-minute forecast, sometimes the assumption of Lagrangian persistence is violated, and the prediction skill of the optical-flow-based system drops quickly with the forecast lead time. The SCALE-LETKF system, on the other hand, provides physically based predictions; therefore, we would expect that the NWP outperforms the nowcast for longer forecasts. Therefore, merging NWP and nowcast will provide better predictions compared to each of them.

Recent advances in the machine-learning algorithms will provide an efficient algorithm for that purpose. In this study, a three-dimensional extension of the Convolutional Long Short-Term Memory (Conv-LSTM; Shi et al., 2015), a kind of deep-learning algorithm, is applied to PAWR nowcasting. In addition to the Conv-LSTM with past observations, we also develop a Conv-LSTM that accepts forecast data from numerical weather prediction (NWP) or optical-flow-based nowcast. NWP uses HPC resources with full physics equations of the atmosphere, so that Conv-LSTM with NWP would be a new direction toward fusing Big Data and HPC, in which training with the big data from high-resolution NWP and Data Assimilation (DA), as well as PAWR observation would be a challenge.

The 3D Conv-LSTM successfully made predictions of convective storms; in some cases, Conv-LSTM had additional skill in capturing intensification and weakening of precipitation that were not predicted by the optical-flow. On average, the Conv-LSTM-based system outperformed the optical-flow-based system statistically. Furthermore, Conv-LSTM with forecast data outperformed that without forecast data.

キーワード：ナウキャスト、機械学習、数値天気予報

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Keywords: nowcast, machine learning, NWP

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高解像度大気モデルとAIを用いたサブグリッド運動量輸送効果のパラメタリゼーション

Parameterization of Subgrid Momentum Transport Using a Global Cloud Resolving Model and AI

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高解像度全球非静力学モデルNICAMによるシミュレーション結果からサブグリッド運動量輸送効果を直接計算し、その結果を利用して機械学習(いわゆるAI)を用いた熱帯域のサブグリッド運動量輸送効果のパラメタリゼーションを試みた。水平格子間隔14kmのNICAM計算によるメソ循環を直接解像した30日分の計算結果を用いて、22.5N-22.5Sの熱帯域の5.625度×5.625度格子におけるサブグリッド効果を評価する。サブグリッド擾乱による平均運動エネルギーの生成量Eとサブグリッド擾乱によるシア生成量Sを評価する。

機械学習(AI)として、畳み込みニューラルネットワーク(CNN)を利用し、パラメタリゼーションするグリッドおよびその周辺の９格子における水平速度(*u,v*) 及び地表面温度 *T*を入力することで、EおよびSの鉛直プロファイルを推定する。ここでは、出力として4層における正負の分布で単純化した16パターンから1つ選択する。

テストデータに対する学習済みAIによるE・Sの鉛直プロファイルパターンの予測正解率は20~25%程度となり 、一か月平均した気候場的な特性として、直接計算によって得られた正負の水平分布パターンをおおまかに再現することができた。

キーワード：高解像度大気モデル、機械学習、パラメタリゼーション
Keywords: global cloud resolving model, Artificial Intelligence, parameterization

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Precipitation Nowcasting Based on Convolutional Neural Networks

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I. Objective

Short-term prediction of precipitation based on latest precipitation observations is called “nowcasting,” and widely used for various purposes such as disaster prevention. The aim of this project is to predict precipitation amounts within 10--30 minutes by taking advantage of dense and frequent observations of Phased-Array Weather Radar (PAWR). Among various techniques, we compared a classical convolutional neural network (CNN) model with a modified version of InceptionV3 [1].

II. Data

We used a dataset of 3D PAWR images of Kobe area with a frequency of one image every 30 seconds. The image size is 321×321×57 pixels. The grid spacing is 250 m. We used three months of data from 01/05/2018 to 31/07/2018. The prediction is based on the last hour images. For computation reasons, we aggregated data frequency from 30 seconds to 10 minutes.

III. Challenges

1. High dimensionality:

The output is a predicted image having the same size as the input images. The high dimensionality of the output leads to a large number of local minima in the objective function during the optimization process. The model is more likely to converge to a local minimum rather than the global one. To address this issue, we use stacked CNNs, each contributing to the prediction of a portion of the output image.

2. Sparsity:

The images are sparse (2% on average contain rain). The sparsity of data leads to two issues: space complexity and time complexity. Space complexity refers to the incapacity to fit data into the memory during processing due to its large size.

Time complexity denotes the processing time growth induced by the data size. To deal with these issues, we introduce a compressed data structure that contains only significant information (rain pixels).

3. Border Effect:

We have limited information about pixels in the image border. So, the prediction accuracy is lower than the pixels in the image center. As the image size is large, images are split into patches for the learning phase. To prevent the accuracy loss due to border effect at the border of each patch, we use a sliding patch and predict only the central part at each step.

4. Resolution:

The prediction accuracy in the case of high resolution (HR) images is higher compared to low resolution (LR) images. However, for HR images, the accuracy drops quickly after about 10-minute prediction unlike LR where the accuracy is relatively stable. Consequently, we use HR images for short-range prediction up to 10 minutes and LR for longer-range prediction.

IV. Results and future work

The results given by CNN are promising in terms of precision and recall. The next step of our work is to extend our study to Convolutional Long Short-Term Memory (LSTM) and to Reservoir computing. Our goal is to compare the performance of different algorithms to select the most suitable solution for 3D precipitation nowcasting.

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[1]C. Szegedy, V. Vanhoucke, S. Ioffe, J. Shlens, Z. Wojna, "Rethinking the Inception Architecture for Computer Vision," Computer Vision and Pattern Recognition, 2016.

Keywords: Precipitation Nowcasting, Convolutional Neural Networks, Deep Learning

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS02] Abnormal weathers and disasters in urban environments in East Asia related to climate change

convener:Masaru Inatsu(Faculty of Science, Hokkaido University), Yukari Takayabu(Atmosphere and Ocean Research Institute, the University of Tokyo)

Global climate change possibly increases weather disasters such as heatwave, gale, torrential rain, and heavy snowfall. Abnormal global-to-synoptic scale phenomena at least lay behind the frequent occurrence of local-scale extremes. The relation between large-scale pattern and local-scale abnormal weathers has recently been scrutinized by statistical analysis of high-resolution data derived from artificial-satellite observation and numerical simulations. Moreover, impact assessment of climate change to various sectors like water resource management, agriculture, energy control should be reduced to adaptation policies for industries and local governments including urban areas. This reduction generally requires close communication between scientists and stakeholders, with an aid of storyline approach to represent uncertain information on climate change. Therefore, studies on climate change, if limited to East Asia, range from global to urban scales and are interdisciplinary from fundamental to applications. This session calls for research topics in a various related field, and the participants can share possible future extensions of climate change studies.

[AAS02-01] A Statistical study of large-scale environment associated with extreme precipitation using AMeDAS and JRA55/ERA5 data

*Ryosuke Shibuya[1], Yukari Takayabu[1], Chie Yokoyama[1], Hiroki Tsuji[1], Hirotaka Kamahori[1] (1.Atmosphere and Ocean Research Institute, The University of Tokyo)

[AAS02-02] Future Projections of Precipitation Characteristics around Japan in Early Summer Combining GPM DPR and CMIP5 Data: Analysis of multi-model variations

*Chie Yokoyama[1], Yukari Takayabu[1], Osamu Arakawa[2], Tomoaki Ose[3] (1.Atmosphere and Ocean Research Institute, University of Tokyo, 2.Japan Agency for Marine-Earth Science and Technology, 3.Meteorological Research Institute)

[AAS02-03] **Spatiotemporal structure of extreme precipitations during landfalling of typhoons over northern Japan**

*Sridhara Nayak[1], Tetsuya Takemi[1] (1.Disaster Prevention Research Institute, Kyoto University)

[AAS02-04] **A composite empirical-pareto distribution approach to correct the bias of daily precipitation from climate models**

*Wenpeng Zhao[1], Tsuyoshi Kinouchi[1] (1.Tokyo institute of technology)

[AAS02-05] Reproducibility of an extremally high-temperature event in d4PDF regional climate model experiment

*Akifumi Nishi[1], Hiroyuki Kusaka[1] (1. Center for Computational Sciences, University of Tsukuba.)

[AAS02-06] Large-eddy simulations of turbulent flow over urban areas of Osaka, Japan

*Guangdong DUAN[1], Tetsuya Takemi[1] (1.DPRI, Kyoto Univ., Japan)

A Statistical study of large-scale environment associated with extreme precipitation using AMeDAS and JRA55/ERA5 data

A Statistical study of large-scale environment associated with extreme precipitation using AMeDAS and JRA55/ERA5 data

*澁谷 亮輔[1]、高薮 縁[1]、横山 千恵[1]、辻 宏樹[1]、釜堀 弘隆[1]
*Ryosuke Shibuya[1], Yukari Takayabu[1], Chie Yokoyama[1], Hiroki Tsuji[1], Hirotaka Kamahori[1]

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Large-scale atmospheric circulations associated with extratropical extreme precipitation events around Japan are statistically examined in this study. Extreme precipitation events are defined as top 1.0 percentile precipitation events for the period from 1979 to 2019 using AMeDAS, which is the automated meteorological data acquisition system managed by Japan Meteorological Agency. The AMeDAS observing stations, which comprises approximately 1,300 stations throughout Japan, are objectively separated into several groups using a clustering analysis based on the similarity among the occurrence of the extreme precipitation events. A composite of extreme precipitation events in each cluster shows a different circulation pattern with the moistened local environment. Detailed analysis shows that the dynamically forced ascent is one of the key components for extreme precipitation in the cluster which expands over Kyusyu region.

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Future Projections of Precipitation Characteristics around Japan in Early Summer Combining GPM DPR and CMIP5 Data: Analysis of multi-model variations

*横山 千恵[1]、高薮 縁[1]、荒川 理[2]、尾瀬 智昭[3]
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1. Atmosphere and Ocean Research Institute, University of Tokyo, 2. Japan Agency for Marine-Earth Science and Technology, 3. Meteorological Research Institute

Early-summer precipitation around Japan has different characteristics such as heavy rainfall in the later stage of Baiu. It is important to obtain information on how it will change in the future, but current climate models still have difficulties in simulating detailed precipitation characteristics. Recently, we developed a method to project future changes in precipitation characteristics by combining GPM satellite-borne Dual-frequency Precipitation Radar (DPR) and CMIP5 25 climate models (Yokoyama et al. 2019). In this method, we first classified rainfall events observed with the GPM DPR into “small”, “organized”, and “midlatitude” types according to their characteristics, and related each type of precipitation to the large-scale environment such as mid-tropospheric large-scale vertical velocity and sea surface temperature (SST). Using these precipitation-environment relationships, we then reconstructed precipitation distributions for each type with reference to large-scale environments in CMIP5 models for the present and future climates. In the presentation, we will introduce future projections of the reconstructed precipitation for each type and discuss their multi-model variations.

Consequently, future changes in precipitation are found to vary widely among the three types in association with the large-scale environments. More than 90% of models project an overall increase in small-type precipitation and northward enhancement of organized-type precipitation around Japan in the future. Multi-model variance of future projections of organized-type precipitation tends to be large corresponding to that of large-scale circulations such as the subtropical jet, while variance of small-type precipitation is affected by variations of both large-scale circulations and SST. It is revealed that the distributions of multi-model variations of future projections also differ among the three types in association with the large-scale environments.

[Acknowledgment]: This study is supported by the University of Tokyo through a project “Research hub for the big data analysis of global water cycle and precipitation in changing climate”, and the Environment Research and Technology Development Fund (2-1904) of the Environmental Restoration and Conservation Agency.

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Spatiotemporal structure of extreme precipitations during landfalling of typhoons over northern Japan

*Sridhara Nayak[1], Tetsuya Takemi[1]

1. Disaster Prevention Research Institute, Kyoto University

Typhoons are considered as one of the hazardous weather phenomena in the earth those cause widespread flooding to the landfall regions. Thus to comprehend the severity of such devastating events, many previous studies have focused on the typhoon induced precipitation intensities. In our study, we investigated the spatiotemporal structure of extreme precipitations induced by unusual landfalling of four typhoons in August 2016 over northern Japan. Three typhoons [Typhoon Chanthu (T1607), Typhoon Mindulle (T1609), and Typhoon Kompasu (T1611)] made landfall over Hokkaido region and one typhoon [Typhoon Lionrock (T1610)] made landfall over Tohoku region. The main focus was on to understand the cell sizes and spell durations of these typhoon induced extreme precipitations over northern Japan from the Radar Automated Meteorological Data Acquisition System (Radar-AMeDAS) observed hourly precipitation. To do this, the independent cell sizes and spell durations of extreme precipitations (various percentiles) are stratified into different bins and the frequency in each bin are computed. Our results indicate that the normalized durations of the extreme precipitations induced by three typhoons landfalling over Hokkaido region exhibit similar features, while the typhoon landfalled over Tohoku region shows relatively long-lived extreme precipitation durations. However, all the four typhoons show a robust feature in the normalized extreme precipitation sizes over northern Japan. The occurrence of extremely heavy precipitations (higher than 99th percentile) carried out by all the four typhoons are mostly short-lived and last up to 6-9 hours. We would like to discuss more on this by downscaling these typhoons at 1-km grid resolution in present climate and with pseudo global warming (PGW) conditions by using Weather Research and Forecasting (WRF) model to understand the response of spatiotemporal precipitation structures of these typhoons to climate change.

Keywords: Precipitation characterization, Typhoon, Extreme precipitation

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A composite empirical-pareto distribution approach to correct the bias of daily precipitation from climate models

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Systematic biases relative to observed rainfall makes rainfall from climate models unfit for direct use. To correct the biases of these rainfall, Quantile Delta Mapping (QDM), which is an adaption of quantile mapping (QM), is recently used as it doesn’ t rely on the assumption of stationarity. However, QDM employs an empirical way to fit extreme rainfall events, which is not accurate. In order to improve the accuracy of simulating extreme rainfall events, pareto distribution has been used to fit these extremes. In specific, this paper proposes a Modified Quantile Delta Mapping (MQDM) approach by using a composite empirical-pareto distribution to fit the rainfall events. Empirical distribution is used for the normal rainfall events while generalized Pareto distribution is used for 99th percentile extreme rainfall events. MQDM is compared with QDM by using “obsprecip” and “modprecip” dataset, which contain the observed and simulated daily precipitation data at MOSS in Norway, in R “qmap” package and Root-Mean-Square Error (RMSE) is calculated by the simulated extremes and observed ones. The result showed MQDM is found to be more accurate than QDM. For 99th percentile extreme rainfall events, QDM had RMSE of 2.9 mm while MQDM had RMSE of 1.53 mm. For the highest 5 extreme rainfall events, QDM had RMSE of 7.6 mm while MQDM had RMSE of 1.7 mm. MQDM can be used to correct the bias of extreme rainfall events from climate models in the future.

Keywords: Modified quantile delta mapping, Generalized Pareto distribution, Statistical bias correction, Extreme rainfall, Climate change

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Reproducibility of an extremally high-temperature event in d4PDF regional climate model experiment

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In this study, we confirm whether extremely high-temperature events in the future can be expressed in regional climate model experiment of the database for Policy Decision making for Future climate change (d4PDF-RCM). Multiple dynamical downscaling (DDS) experiments from d4PDF-RCM with Weather Research and Forecasting model (WRF) were conducted and the downscaled temperature and wind fields around Niigata city on EHT event were compared with the d4PDF-RCM. In a DDS experiment with a horizontal resolution of 3 km (WRF3), the daily maximum temperature is about 3 ℃ higher than the d4PDF-RCM. In a DDS experiment with the topography of the d4PDF-RCM and a horizontal resolution of 20 km (WRF20d), the daily maximum temperature is about 2 ℃ higher than that of the d4PDF-RCM.
The reason for these differences in daily maximum temperatures is that the horizontal resolution of the d4PDF-RCM and its topography was too coarse to express small-scale phenomena such as the foehn winds. The spatio-temporal structure of foehn winds is clearly expressed in WRF3. On the other hand, in the d4PDF-RCM, the structure cannot be expressed at all. Therefore, it can be not enough to directly analyze d4PDF-RCM to discuss the regional EHT events in the future climate. In addition, the spatio-temporal structure of foehn winds in WRF20d is not clearer than that of WRF3. From these results, we concluded that the DDS experiment with appropriate horizontal-resolution and topography needs to be performed to discuss regional EHT events in the future climate.
The results of the WRF3 and a DDS experiment without topography shows that foehn winds have a contribution of about 2.0 ℃ on this EHT event. This result suggests that more than half of the difference between the maximum temperature of the WRF3 and d4PDF-RCM was brought by the topography effect. This contribution of foehn winds is almost the same as that in the current EHT event, shown in the previous study.

Acknowledgments: This research was supported by the Environment Research and Technology Development Fund (2-1905) of the Environmental Restoration and Conservation Agency of Japan. This study used d4PDF produced with the Earth Simulator jointly by science programs (SOUSEI, TOUGOU, SI-CAT, DIAS) of the Ministry of Education, Culture, Sports, Science, and Technology (MEXT), Japan.

キーワード：極端高温事例、d4PDF、フェーン
Keywords: extremely high-temperature event, d4PDF, foehn winds

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Large-eddy simulations of turbulent flow over urban areas of Osaka, Japan

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Urban turbulent boundary-layer flows are strongly perturbed by the roughness elements mounted on the ground surface; however, the flows are primarily driven by large-scale forcing at higher levels. Knowledge of the complex interactions between the urban surface roughness and the boundary-layer processes is not merely important for improved urban canopy parameterisations (UCPs), it is also desired for developing optimised schemes towards the downscaling of mesoscale meteorological perturbations. Using large-eddy simulation (LES) and wavelet analysis, results relevant to both aspects are presented for realistic urban areas in Osaka, Japan. For the former, time-averaged Eulerian statistics show that the inertial sub-layer, wherein close-to-constant Reynolds shear stresses are often expected, may not be always clearly identified compared to idealised roughness arrangements; nonetheless well-defined logarithmic wind profiles are established allowing the formulation of the surface aerodynamics parameters (z_0 and d) in terms of the surface roughness features. To complement existing UCP schemes, the parameterisation of z_0 and d using machine learning is investigated. For the latter, the turbulence statistics exhibit a great dependence on height: wavelet-analysis results show that the turbulence eddies are much more fluctuated at lower heights; by contrast, the eddies away from the surface layers are well organized on different scales, suggesting that the downscaling of mesoscale perturbations needs to be treated differently according to the vertical heights that the perturbations would be incorporated in the urban computational fluid dynamics (CFD) models. The potential of applying wavelet analysis, which may allow signals to be coupled in a manner admitting both the multiscale nature and the unsteadiness of large-scale forcing, is discussed.

Keywords: Wavelet analysis, Urban canopy parameterization, Urban-mesoscale coupling, Boundary-layer turbulence

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS03] Atmospheric Chemistry in Highly Polluted Environments

convener:Hongliang Zhang(Fudan University), Jianlin Hu(NUIST Nanjing University of Information Science and Technology), Jia Xing(Tsinghua University), Siyu Chen(Lanzhou University)

Due to the rapid growth of economy and fossil fuel consumption and lack of emission controls, Many Asian regions have experienced substantially elevated concentrations of air pollutants, such as China, India, and Southeast Asia. High concentrations of air pollutants have significant impacts on public health and also play an important role in the climate system. Understanding the emissions, fate, and impact of high air pollution in these regions is essential for designing effective control strategies.
In the many highly polluted regions, large amount of anthropogenic emissions from industrial and/or residential activities are mixed with biogenic emissions, wind-blown dust, and biomass burning, then undergo complex atmospheric chemistry processes and form secondary pollutants such as ozone and particulate matter. Many studies suggested that high pollution formation is much faster in these regions and cannot be completely explained by knowing atmospheric chemistry, indicating additional chemistry processes in highly polluted environments, which are likely associated with the complex emission sources, unique climate and topography. Progress has been made in several aspects, such as additional sources and formation pathways of atmospheric radicals, heterogeneous reactions on particle surface for sulfate and organic aerosol formation.
Studying atmospheric chemistry in highly polluted environments involves field measurements, lab experiments, and numeric modeling. It will advance our scientific understanding of the formation processes, improve our knowledge in sources of air pollutants, help develop air pollution control strategies for protecting public health and climate in these regions.

[AAS03-01] Secondary organic aerosol formation through chlorine-initiated VOCs oxidation in East Asia

★Invited Papers

*Qi Ying[1], Min Su Choi[1] (1.Texas A & M University College Station)

[AAS03-02] **Modeling diurnal variation of surface $PM_{2.5}$ concentration over East China with WRF-Chem: Impacts from boundary layer mixing and anthropogenic emission**

★Invited Papers

*Chun Zhao[1] (1.University of Science and Technology of China, Hefei, China)

[AAS03-03] **Investigation of the Driving Forces for the Recent Trends in Surface Fine Particulate Matter Concentrations in Nanjing, China**

*Jianlin Hu[1], Zhihao Shi[1] (1.NUIST Nanjing University of Information Science and Technology)

[AAS03-04] **The significant role of vehicle ammonia emissions in urban secondary aerosol formation for Chinese megacities**

*Shaojun Zhang[1], Xinyu Liang[1], Yifan Wen[1], Shuxiao Wang[1], Ye Wu[1] (1.Tsinghua University)

[AAS03-05] Fast sulfate production in Beijing haze associated with elevated HONO and N_2O

*Xinlei Ge[1], Junfeng Wang[1] (1.Nanjing University of Information Science and Technology)

Secondary organic aerosol formation through chlorine-initiated VOCs oxidation in East Asia

*Qi Ying[1], Min Su Choi[1]

1. Texas A & M University College Station

The Community Multiscale Air Quality (CMAQ) model v5.0.1 with a modified SAPRC-11 gas-phase mechanism and heterogeneous reactions for reactive chlorine species is further updated in this study to include formation and gas/particle partitioning of semi-volatile products from chlorine-initiated oxidation of aromatic compounds, terpenes and isoprene (Cl-SOA) to provide a full assessment of the impact of chlorine chemistry on the formation of secondary organic aerosol (SOA). Reported SOA-yield data on Cl-SOA formation from environmental chamber studies are used to derive the mass-yield and volatility data for the two-product equilibrium partitioning model. The updated model is applied to study Cl-SOA formation in east Asia in January (winter) and July (summer) of 2013. The results during the winter show that heterogeneous reactions of chloride ion (pCl-) with gas-phase N_2O_5 and O_3 lead to a significant increase in the Cl_2 and $ClNO_2$ and subsequently chlorine (Cl) and hydroxyl radical (OH) concentrations. A large augmentation of SOA mass concentration up to 5-15% due to irreversible uptake of the glyoxal (GLY) and methyl-glyoxal (MGLY) is predicted as a result of the increased OH concentrations. In addition, the Cl-SOA from the reactions of Cl radical with VOCs adds to additional SOA concentrations up to 0.5-2.5 ug/m^3, which accounts for 5-10% of total SOA mass concentration. Overall, an increase of SOA concentrations by ~10-25% is predicted due to chlorine reactions in winter. The impact of chlorine reactions in the summer on SOA is much smaller due to lower concentrations of pCl- and high levels of OH that dominates the oxidation of VOCs during daytime hours.

Keywords: volatile organic compounds, secondary organic aerosol, reactive chlorine species

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Modeling diurnal variation of surface $PM_{2.5}$ concentration over East China with WRF-Chem: Impacts from boundary layer mixing and anthropogenic emission

*Chun Zhao[1]

1. University of Science and Technology of China, Hefei, China

Diurnal variation of surface $PM_{2.5}$concentration (diurnal $PM_{2.5}$) could dramatically affect aerosol radiative and healthy impact, and can also well reflect the physical and chemical mechanisms of air pollution formation and evolution. So far, diurnal $PM_{2.5}$and its modeling capability over East China has not been investigated, and therefore, is examined in this study. Based on the observations, the normalized diurnal amplitude of surface$PM_{2.5}$concentrations averaged over East China is the weakest (~1.2) in winter, and reaches ~1.5 in other seasons. The diurnal $PM_{2.5}$shows the peak concentration during the night in spring and fall and during the daytime in summer. The simulated diurnal $PM_{2.5}$with WRF-Chem and its contributions from multiple physical and chemical processes are examined in the four seasons. The simulated diurnal $PM_{2.5}$with WRF-Chem is primarily controlled by planetary boundary layer (PBL) mixing and emission variations, andis significantly overestimated against the observation during the night. This modeling bias is likely primarily due to the inefficient PBL mixing of primary $PM_{2.5}$during the night. The simulated diurnal $PM_{2.5}$is sensitive to the PBL schemes and vertical layer configurations with WRF-Chem. Besides the PBL height, the PBL mixing coefficient is also found as the critical factor determining the PBL mixing of pollutants in WRF-Chem. With reasonable PBL height, the increase of lower limit of PBL mixing coefficient during the night can significantly reduce the modeling biases in diurnal $PM_{2.5}$and also the mean concentrations, particularly at the major cities of East China. It can also reduce the modeling sensitivity to the PBL vertical layer configurations. The diurnal variation and injection height of anthropogenic emissions also play roles on simulating diurnal $PM_{2.5}$, but the impact is relatively smaller than that from the PBL mixing. This study underscores that more efforts are needed to improve the boundary mixing process of pollutants in models with observations of PBL structure and mixing fluxes in addition to PBL height, in order to simulate reasonably the diurnal $PM_{2.5}$over East China. The diurnal variation and injection height of anthropogenic emissions are also necessary to be included to simulate the diurnal $PM_{2.5}$ over East China.

Keywords: WRF-Chem, PBL mixing, diurnal cycle

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Investigation of the Driving Forces for the Recent Trends in Surface Fine Particulate Matter Concentrations in Nanjing, China

*Jianlin Hu[1], Zhihao Shi[1]

1. NUIST Nanjing University of Information Science and Technology

Meteorological conditions and emissions play very important roles in the formation of $PM_{2.5}$ pollution. PM2.5 concentrations in Nanjing have been decreasing rapidly from ~70 μg/m3 in 2013 to ~50 μg/m3 in 2016. The contributions of inter-annual variation of meteorological conditions and emissions to the rapid PM2.5 reduction remain unknown. In this study, we used several methods to quantify the contributions. First, we established a generalized linear regression model (GLM) based on meteorological parameters to assess the effect of meteorological conditions and pollution control strategies on reducing the air pollution level in Nanjing. Second, we conducted sensitivity simulations with the WRF/CAMQ model, in which we perturb seven major meteorological parameters, i.e., wind speed, wind direction, temperature, humidity, boundary layer height, precipitation, and cloud cover, and then simulate the changes of PM2.5 concentrations to analyze its sensitivity to meteorological variations. Third, we simulated $PM_{2.5}$ concentrations in Nanjing in 2013 and 2015 using different years of emissions to investigate the impacts of emissions change and meteorological variations on PM2.5 concentrations. The results using the three methods will be compared and discussed.

Keywords: ozone, particulate matter, trends, driving forces

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The significant role of vehicle ammonia emissions in urban secondary aerosol formation for Chinese megacities

*Shaojun Zhang[1], Xinyu Liang[1], Yifan Wen[1], Shuxiao Wang[1], Ye Wu[1]

1. Tsinghua University

Tailpipe aftertreatment devices of on-road vehicles are effective to control emissions of regulated pollutants but would result in ammonia (NH_3) emissions as unwanted side product. For example, three-way catalyst (TWC) converters used by gasoline vehicles generate NH_3 emissions. For diesel vehicles, NH_3 emissions are in general related to urea injection for selective catalyst reduction converters (SCR). Based on recent tailpipe emission measurements for gasoline [1] and diesel [2] vehicles in China, we update the vehicle NH_3 emission inventory for on-road vehicles in China [3]. The results indicate that, at the national level, on-road vehicles currently are responsible for a minor fraction (~90 kt, 0.8%) of total anthropogenic NH_3 emissions in China. The contribution fractions vary from below 0.5% in remote provinces (e.g., Tibet, Xinjiang, Inner Mongolia) to more than 5% in populated municipalities (e.g., Beijing, Shanghai). Of note, supported by detailed street-level traffic data, a high-resolution emission inventory [4] for the urban area of Beijing (note: the urban area of Beijing is about 1000 km^2 and denotes the area within the Fifth Ring Road and. By comparison, the total area of the municipality of Beijing is about 16,000 km^2) suggest that on-road vehicles are the leading source (approximately 80%) of anthropogenic NH_3 emissions, of which gasoline cars are estimated to contribute more than 70%.

We further apply an atmospheric chemical transport model (WRF/CMAQ 5.3; 3 km-and-1 km simulation resolutions) to quantify the role of vehicle NH_3 emissions in the formation of secondary inorganic aerosol, in particular focusing on the impact of the spatial heterogeneity of vehicle NH_3 emissions. With the Brute-Force method by closing all vehicle NH_3 emissions, we find that total $PM_{2.5}$ concentrations in the urban area of Beijing are lowered by 1 $\mu g/m^3$ (3%) in the summer. The wintertime reduction of $PM_{2.5}$ is quite significant, which is up to 10 $\mu g/m^3$ (9%). The changes in two seasons are both predominantly caused by the reduction in ammonium nitrate. This study, by implication, suggest that vehicle emissions are an important source of NH_3 emissions in traffic-dense urban areas of megacities in China, and contribute significantly to urban $PM_{2.5}$ pollution (particularly in winter). Further source apportionment studies by using atmospheric models should carefully consider the high concentration of vehicle NH_3 emissions in urban areas.

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large-scale, real-world traffic datasets. *Atmospheric Chemistry and Physics*, 19(13): 8831-8843 (2019)

Keywords: Vehicle emissions, Ammonia, Emission inventory, Inorganic secondary aerosol, PM2.5, CMAQ

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Fast sulfate production in Beijing haze associated with elevated HONO and N_2O

*Xinlei Ge[1], Junfeng Wang[1]

1. Nanjing University of Information Science and Technology

Severe events of wintertime particulate air pollution in Beijing (“winter haze”) are associated with high relative humidity (RH) and fast production of particulate sulfate from the oxidation of sulfur dioxide (SO_2) emitted by coal combustion. There has been considerable debate regarding the mechanism for SO_2 oxidation. Here we show from field observations that rapid conversion of SO_2 to sulfate in Beijing haze is associated with increases in nitrous oxide (N_2O) and nitrous acid (HONO), and decrease in nitrogen dioxide (NO_2). Sulfate shifts to larger particle sizes, indicative of fog/cloud processing. Fog/cloud readily forms under winter haze conditions, leading to high liquid water contents (LWCs) with high pH (> 5.5) from elevated ammonia. Such conditions enable fast aqueous-phase oxidation of SO_2 by NO_2, producing HONO which can in turn oxidize SO_2 to yield N_2O.This mechanism could provide a general explanation for particulate sulfate formation in winter haze.

Keywords: sulfate, PM2.5, aqueous phase

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS03] Atmospheric Chemistry in Highly Polluted Environments

convener:Hongliang Zhang(Fudan University), Jianlin Hu(NUIST Nanjing University of Information Science and Technology), Jia Xing(Tsinghua University), Siyu Chen(Lanzhou University)

[AAS03-07] Trend reversal of boundary layer height in China and its influential factors

★Invited Papers

*Jianping Guo[1] (1.Chi. Aca. Meteorol. Sci., CMA)

[AAS03-08] A simplified aerosol retrieval algorithm based on Landsat-8 and Sentinel-2 over urban area

★Invited Papers

*Siwei Li[1], Hao Lin[1], Jie Yang[1], Qingxin Wang[1] (1.Wuhan University)

[AAS03-09] Light-absorbing properties, chromophore composition and sources of brown carbon aerosol in Xi'an, Northwest China

*rujin huang[1], wei yuan[1], lu yang[1], jie guo[1], jing duan[1], haiyan ni[1] (1.Institute of Earth Environment, CAS)

[AAS03-10] Fugitive Road Dust PM 2.5 Emissions and Their Potential Health Impacts

*Siyu Chen[1] (1.Lanzhou University)

[AAS03-11] Online shape and density measurement of single black carbon aerosol particles

Shurong Wang[1], Xin Yang[1], *Xiaofei Wang[1] (1.Fudan University)

[AAS03-12] Heterogeneous Oxidation of SO_2 in Sulfate Production during Nitrate Photolysis at 300 nm: Effect of pH, Relative Humidity, Irradiation Intensity, and the Presence of Organic Compounds

*Masao Gen[1], Chak Chan[2], Ruifeng Zhang[2], DanDan Huang[3], Yongjie Li[4] (1.Faculty of Frontier Engineering, Institute of Science and Engineering, Kanazawa University, 2.School of Energy and Environment, City University of Hong Kong, 3.Shanghai Academy of Environmental Sciences, 4.Department of Civil and Environmental Engineering, Faculty of Science and Technology, University of Macau)

Trend reversal of boundary layer height in China and its influential factors

*Jianping Guo[1]

1. Chi. Aca. Meteorol. Sci., CMA

Our knowledge concerning the trend in boundary layer height (BLH) in China is limited due to the unavailability of reliable and high-resolution radiosonde measurements. In this talk, we will present the trend of BLH over China, using the radiosonde observations (at 08:00 pm) at 89 stations for the period 1979–2016. Overall, the annual mean BLH averaged over all the available stations in China exhibits a distinct west-to-east negative gradient. Most stations exhibit an increasing trend in BLH during 1979-2003 and shift to a declining trend in BLH during 2004-2016. The trend of seasonal mean BLH bears resemblance to annual mean BLH. The meteorological influence on the temporal disparity of the BLH trend is investigated as well, showing that BLH at most sounding sites is negatively associated with the soil moisture, lower tropospheric stability (LTS) and surface relative humidity, but positively associated with the near-surface temperature. An increase of BLH (9.4m yr^{-1} during 1981-1988,14.0m yr^{-1}during 1989-2003) from 1979 to 2003 is found to be related to an increase in near-surface temperature (mean=0.04 ºC yr^{-1}), a reduction of soil moisture (mean=-2.18 kg $m^{-2}yr^{-1}$), a reduction of LTS (mean=-0.03 K yr^{-1}), a decrease in surface relative humidity (mean=-0.007 % yr^{-1}) during 1979-2003.A weakening of near-surface temperature and the increase of soil moisture, LTS and surface relative humidity are found to contribute to the decreasing trend of BLH during 2004-2016. The major findings obtained from this study help us better understand the climatology of BLH over China and its association with related meteorological variables.

Keywords: Boundary layer height, radiosonde, trend reversal, China

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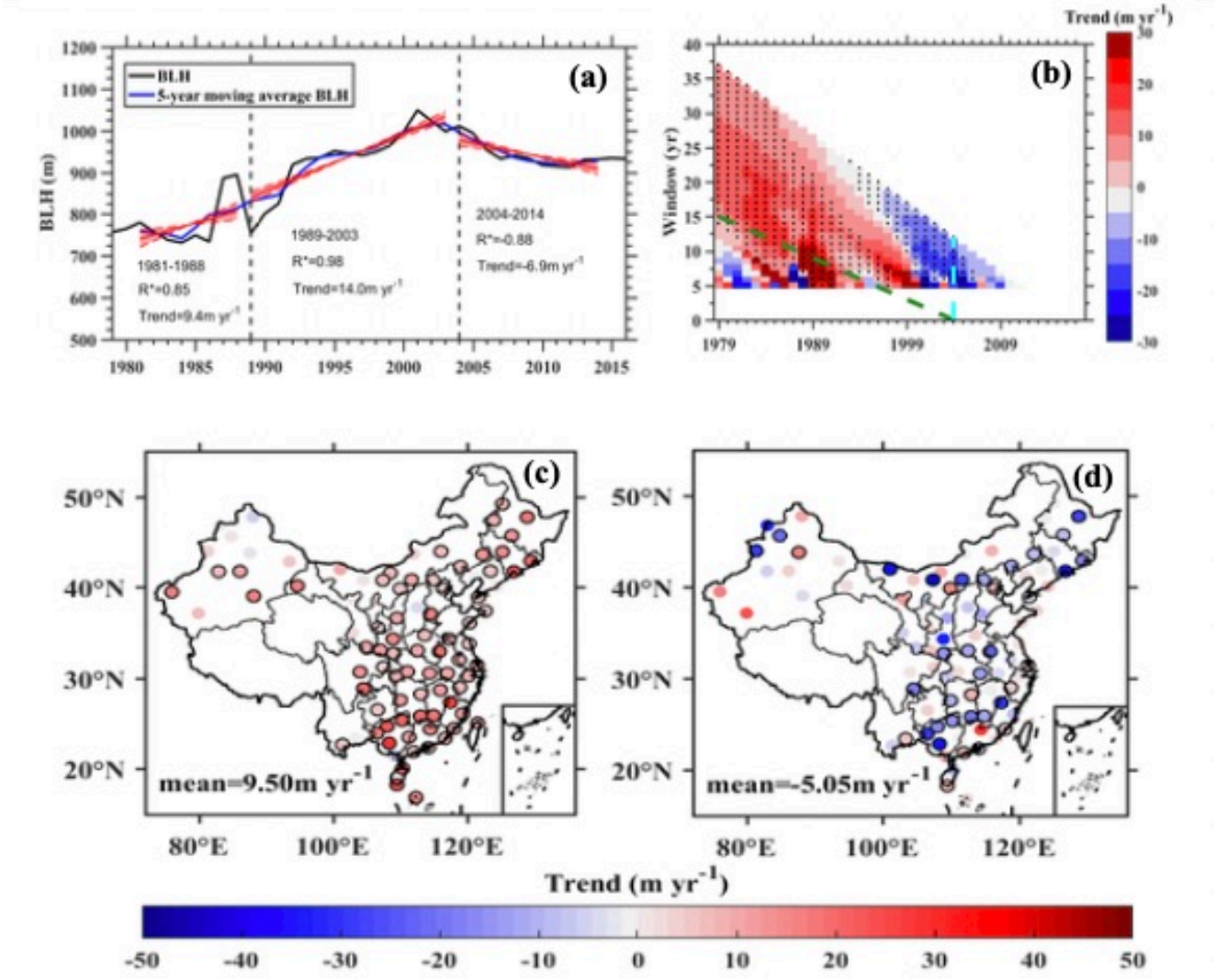

Figure 1. (a) Time series of annual mean BLH (black line) and 5–year moving average BLH (blue line) for 89 stations in China at 2000 BJT for the 1979–2016 period. The red lines denote the least-square linear fitting trend, the climate shifts in the time series of BLHs are marked by vertical dashed black lines in 1989 and 2004, respectively. Red shading areas and dash lines represent 95% confidence intervals. (b) Running window linear trends in annual mean BLH during 1979–2016. The x-axis represents the start year of the analysis period, while the y-axis represents the length of the analysis period. The dashed green line denotes all linear trends that end with the year 2004, while the dashed cyan line indicates trends that start with the year 2004. Trends that are statistically significant at the 95% confidence level are indicated by black dots. Note that running windows with lengths less than 5 years are not considered. Also shown is the spatial distribution of the trend (color shaded dots) of annual mean BLH in China during the periods of 1979–2003 (c) and 2004–2016 (d). Circles outlined with black indicate that trends are statistically significant ($p<0.05$), and the overall value of trend is given for each panel as well.

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A simplified aerosol retrieval algorithm based on Landsat-8 and Sentinel-2 over urban area

*Siwei Li[1], Hao Lin[1], Jie Yang[1], Qingxin Wang[1]

1. Wuhan University

Observation of aerosols is critical due to aerosols radiative effects on radiation balance and adverse impacts on public health. Aerosol optical depth (AOD) which is the measure of aerosols distributed within a column of air from surface to the top of atmosphere is now a common index for investigating aerosols loading over the world. However, high spatial resolution AOD observations which is important for improving air pollution model especially in urban areas are still limited. In this study, a simplified aerosol retrieval algorithm based on the Landsat-8 and Sentinel-2 measurements is developed to retrieve high resolution AOD over urban areas. With the high resolution radiation measurements from the Landsat-8 and Sentinel-2 satellites, the spatial resolution of the retrieved AOD could be as high as 30 m. The retrieval algorithm is evaluated based on 5 year data from Landsat-8, 2 year data from Sentinel-2 and 5 year AERONET AOD data at 5 sites in Beijing. Overall, the correlation coefficient between the satellite-based AOD and AERONET provided AOD is better than 0.95. About 85.8% retrieved AOD based on the Landsat-8 measurements fall within the expected error(EE) with a root-mean-square error(RMSE) of 0.106 while 78.6% retrieved AOD based on the Sentinel-2 fall within the EE with the RMSE of 0.126. The results show that the new algorithm performs well in AOD retrieval over the complex urban area. The algorithm may provide a way to monitor high resolution air pollution in urban area and has potential to help improving current air pollution model.

Keywords: aerosol optical depth, high resolution aerosol retrieval, satellite, Landsat-8, Sentinel-2

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Light-absorbing properties, chromophore composition and sources of brown carbon aerosol in Xi’ an, Northwest China

*rujin huang[1], wei yuan[1], lu yang[1], jie guo[1], jing duan[1], haiyan ni[1]

1. Institute of Earth Environment, CAS

The impact of brown carbon aerosol (BrC) on the Earth’ s radiative forcing balance has been widely recognized but remains uncertain, mainly because the relationships among BrC sources, chromophores, and optical properties of aerosol are poorly understood. In this work, the light absorption properties and chromophore composition of BrC were investigated for samples collected in Xi’ an. The mass absorption efficiency show distinct seasonal differences, which could be attributed to the differences in sources and chromophore composition of BrC. Three groups of light-absorbing organics were found to be important BrC chromophores, including those show multiple absorption peaks at wavelength > 350 nm (12 polycyclic aromatic hydrocarbons and their derivatives) and those show single absorption peak at wavelength < 350 nm (10 nitrophenols and nitrosalicylic acids and 3 methoxyphenols). These measured BrC chromophores show distinct seasonal differences and contribute on average about 1.1% and 3.3% of light absorption of methanol-soluble BrC at 365 nm in summer and winter, respectively, about 7 and 5 times higher than the corresponding mass fractions in total organic carbon. The sources of BrC were resolved by positive matrix factorization (PMF) using these chromophores instead of commonly used non-light absorbing organic markers as model inputs. Our results show that in spring vehicular emissions and secondary formation are major sources of BrC (~70%), in fall coal combustion and vehicular emissions are major sources (~70%), in winter biomass burning and coal combustion become major sources (~80%), while in summer secondary BrC dominates (~60%).

Keywords: Brown carbon, Light absorption, Composition , Sources

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Fugitive Road Dust PM 2.5 Emissions and Their Potential Health Impacts

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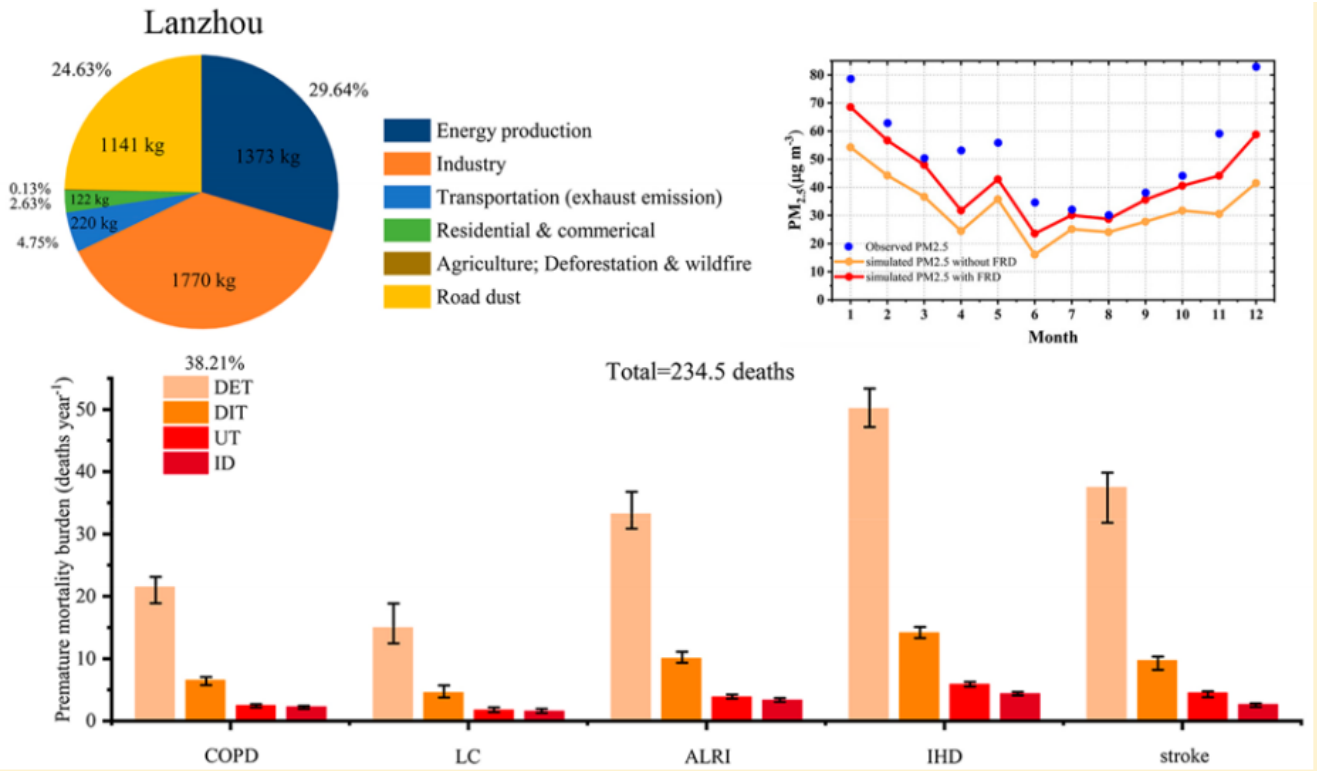
1. Lanzhou University

Fugitive road dust (FRD) particles emitted by traffic-generated turbulence are an important contributor to urban ambient fine particulate matter (PM2.5). Especially in urban areas of developing countries, FRD PM2.5 emissions are a serious environmental threat to air quality and public health. FRD PM2.5 emissions have been neglected or substantially underestimated in previous study, resulting in large uncertainties in modeling PM concentrations and estimating their health impacts. This study constructed the FRD PM2.5 emissions inventory in a major inland city in China (Lanzhou) in 2017 at the high-resolution (500 m×500 m), and further investigated the spatiotemporal characteristics of the FRD emissions in different urban function zones, and quantified their health impacts. The FRD PM2.5 emission was approximately 1141± 71 kg d-1, accounting for 24.6% of total PM2.5 emission in urban Lanzhou. Spatially, high emissions exceeding 3×104 μg m-2 d-1 occurred over areas with smaller particle sizes, larger traffic intensities, and more frequent construction activities. The estimated premature mortality burden induced by FRD PM2.5 exposure was 234.5 deaths in Lanzhou in 2017. Reducing FRD emissions are an important step forward to protect public health in many developing urban regions.

Keywords: Road Dust , PM 2.5 , Health Impacts



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Online shape and density measurement of single black carbon aerosol particles

Shurong Wang[1], Xin Yang[1], *Xiaofei Wang[1]

1. Fudan University

Black carbon (BC) aerosols in the atmosphere play crucial roles in affecting global radiative budget and human health. Density and morphology are key properties that infer the chemical composition, mixing state and aging pathway of BC particles. Here, we developed a novel method to assess morphology and density of single black carbon aerosol particles by measuring their aerodynamic diameters (*Da*) , electrical mobility diameters (*Dm*) and mass of their black carbon contents (*mBC*). Three groups of ambient aerosols with different *Da* (200nm, 350nm, 500nm) selected by AAC were studied during two sampling periods (2018 winter and 2019 summer). The BC-dominated particles (almost pure BC) were observed at Mode (***Da*** *=200nm,****Dm1*** *=135nm*), which contributed the largest number fraction[XW1] of particles with a D_a of 200nm. The morphology of these BC-dominated particles was found to be near-spherical, as their shape factor was ~1.02, indicating the aging of freshly emitted-BC particle was fast and a small amount of secondary materials was sufficient to change particle shapes from fractal aggregate to near-spherical. Besides, traffic was found to be one of the main emission sources of the BC-dominated particles, which was consistent with the fact that the number fraction of BC-dominated particle in BC particles increased significantly during the morning and evening rush-hour. The majority of BC particles with D_a of 350nm and 500nm were coated by thick layers of secondary substances. The shape of these particles with thick coating was likely to be spherical. The particles in Mode(Da =350nm,Dm =259.5nm) and the particles in Mode(Da =500nm,Dm =358.7nm) accounted for a main fraction of particles with the D_a of 350nm and 500nm, respectively. It is found that the density of these BC particles in Mode(Da =350nm,Dm =259.5nm) and Mode(Da =500nm,Dm =358.7nm)was 1.62 and 1.77g/cm^3, repectively, suggesting that ammonium sulfate (bulk density: 1.73 g/cm^3) and ammonium nitrate (bulk density: 1.77 g/cm^3) internally mixed with organic materials (~1.2 g/cm^3) could be their main components, which was consistent with their average single particle mass spectra. The AAC-DMA-SP2 online system is a novel method to investigate both morphology and density of each single BC particle, which can help identify the formation and aging pathway of BC aerosols.

Keywords: Black carbon, Aerosol, Single particle

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Heterogeneous Oxidation of SO_2 in Sulfate Production during Nitrate Photolysis at 300 nm: Effect of pH, Relative Humidity, Irradiation Intensity, and the Presence of Organic Compounds

*Masao Gen[1], Chak Chan[2], Ruifeng Zhang[2], DanDan Huang[3], Yongjie Li[4]

1. Faculty of Frontier Engineering, Institute of Science and Engineering, Kanazawa University, 2. School of Energy and Environment, City University of Hong Kong, 3. Shanghai Academy of Environmental Sciences, 4. Department of Civil and Environmental Engineering, Faculty of Science and Technology, University of Macau

Heterogeneous oxidation of SO_2 is one of the promising mechanisms to account for high loading of sulfate during severe haze periods in China. Our earlier work reported the SO_2 oxidation by OH and NO_2 produced during nitrate photolysis (*Environ. Sci. Technol. Lett.* 2019, 6, 86−91). Here, we extend that work to examine sulfate production during nitrate photolysis at 300-nm irradiation, which can additionally generate NO_2^- or HNO_2, N(III). Flow cell/in-situ Raman experiments showed that the reactive uptake coefficient of SO_2 can be expressed as $1.64 \times p_{NO3^-}$, the nitrate photolysis rate in the range of $(1.0 - 8.0) \times 10^{-5}$ M s^{-1}. Our kinetic model predicts that N(III) is the main contributor to the SO_2 oxidation, followed by NO_2 contribution. Furthermore, the addition of OH scavengers (e.g., glyoxal, or oxalic acid) does not suppress the sulfate production, because of the reduced N(III)-consuming reactions, and the high particle pH sustained by their presence. Our calculations illustrate that, under characteristic haze conditions, nitrate photolysis mechanism can produce sulfate at ~1 μg m^{-3} h^{-1} at pH = 4−6 and $p_{NO3^-} = 10^{-5}$ M s^{-1}. The present study highlights the importance of nitrate photolysis in heterogeneous oxidation of SO_2 by reactive nitrogen (NO_2^-/HNO_2 and NO_2) under atmospherically relevant actinic irradiation.

Keywords: Sulfate, Nitrate photolysis, Oxidation

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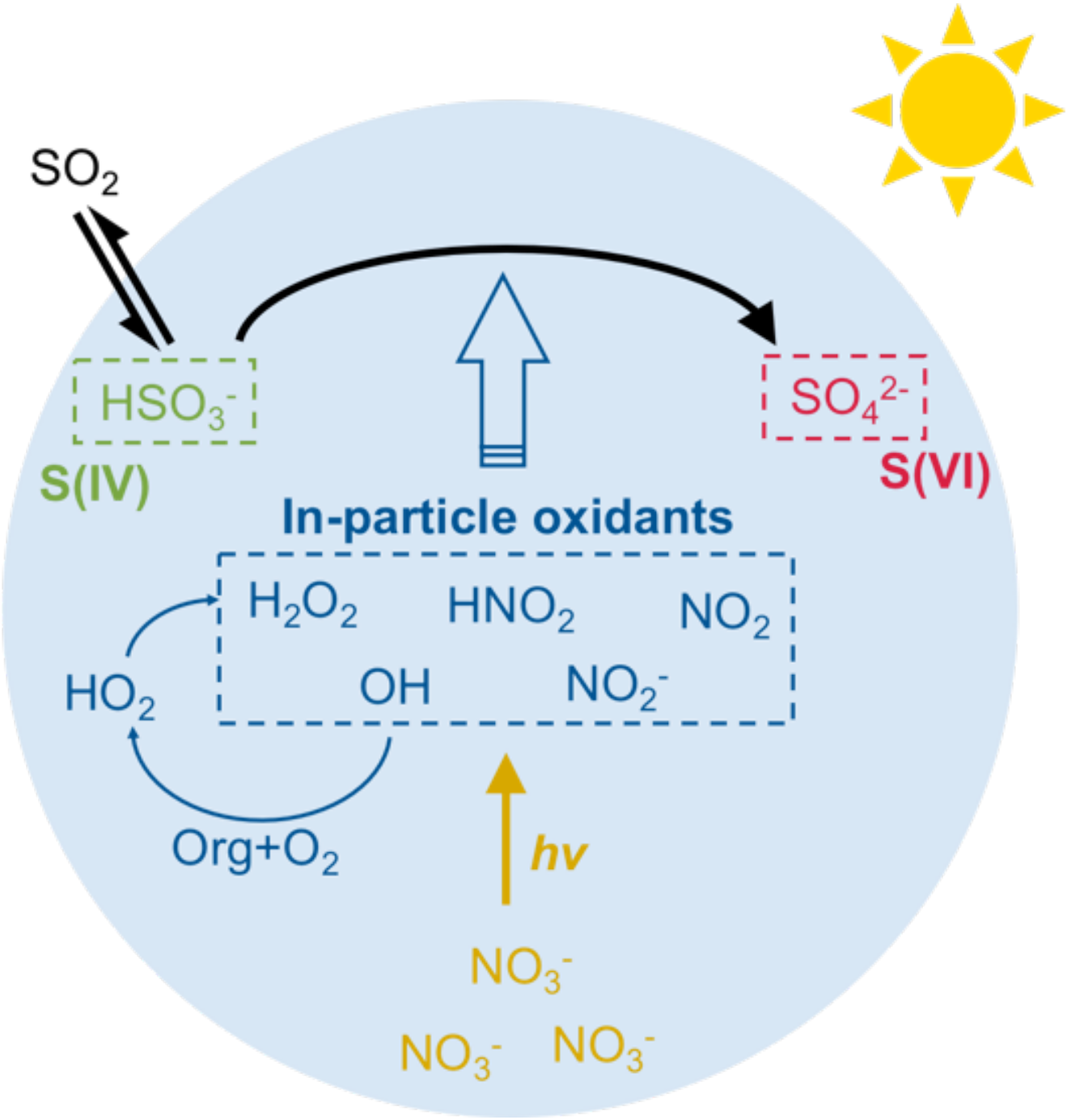

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS04] Formation of Air Pollution and Its Interactions with Weather/Climate

convener:Yang Yang(Nanjing University of Information Science & Technology), Meng Gao(State Key Laboratory of Environmental and Biological Analysis), Guangxing Lin(Pacific Northwest National Laboratory)

Introduction

[AAS04-01] Trends of surface ozone in China in recent years and the roles of anthropogenic emissions and meteorology

★Invited Papers

*Hong Liao[1] (1.Nanjing University of Information Science and Technology)

[AAS04-02] Estimation of Biomass Burning Emissions in Tropical Continents Based on Satellite Observations from 2001 to 2017

★Invited Papers

*Yusheng Shi[1] (1.Aerospace Information Research Institute, Chinese Academy of Sciences)

[AAS04-03] **Numerical Simulation Study on Aerosol-boundary Layer Interaction**

*Zilin Wang[1] (1.Nanjing Univ.)

[AAS04-04] Global and Regional Climate Responses to Black Carbon Emissions from the Arctic and Mid-latitudes

*Yang Yang[1], Sijia Lou[2], Hailong Wang[3], Steven J. Smith[3] (1.Nanjing University of Information Science and Technology, 2.Nanjing University, 3.Pacific Northwest National Laboratory)

[AAS04-05] Mesoscale modeling of aerosol transport over Southeast Asia during the dry season: effects of fire and new emissions

*Shuo Wang[1], Jason Blake Cohen[1] (1.Sun Yat-Sen University)

Trends of surface ozone in China in recent years and the roles of anthropogenic emissions and meteorology

*Hong Liao[1]

1. Nanjing University of Information Science and Technology

Observations of surface ozone available from ~1,000 sites across China for the past years (2013–2019) show severe summertime pollution and regionally variable trends. We assess the effects of changes in anthropogenic emissions and/or meteorological parameters on the ozone trends. Simulations with the Goddard Earth Observing System Chemical Transport Model (GEOS-Chem) indicate that an important factor for ozone trends in the eastern China is the ~40% decrease of fine particulate matter ($PM_{2.5}$) over the past years, slowing down the aerosol sink of hydroperoxy (HO_2) radicals and thus stimulating ozone production. Both statistical and modeling approaches indicate that changes in meteorological conditions contributed largely to the increases in ozone in China. We quantify the meteorology driven increases in ozone by model sensitivity studies to separate roles of changes in natural emissions, chemical reactions and transport.

Keywords: Ozone pollution in China, Recent trends, Chemistry mechanism, Changes in meteorology

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Estimation of Biomass Burning Emissions in Tropical Continents Based on Satellite Observations from 2001 to 2017

*Yusheng Shi[1]

1. Aerospace Information Research Institute, Chinese Academy of Sciences

Biomass burning emissions contribute significantly to the atmospheric CO_2 budget and the interannual variation of CO_2 concentrations in the troposphere. This study developed a high-resolution monthly inventory of biomass burning emissions across five land types in the tropical continents (Central and South America, Africa, and South and Southeast Asia) during 2001–2017. The inventory estimates of emissions from biomass burning are based on the newly released MCD64A1 Version 6 Burned Area data product, satellite and observational data of biomass density, and spatial and temporal variable combustion factors. Results from the inventory demonstrated that the average annual amounts in tropical continents during 2001–2017 were 1.73 Tg BC, 10.85 Tg CH_4, 261.41 Tg CO, 6083.69 Tg CO_2, 3.60 Tg NH_3, 39.75 Tg NMOC, 11.99 Tg NO_x, 18.40 Tg OC, 29.63 Tg $PM_{2.5}$, and 2.19 Tg SO_2. Taking CO_2 as an example, Africa was found to be the largest contributor to the total biomass burning CO_2 emissions in tropical continents (3765.41 Tg of CO_2, 62%). Asia and Americas accounted for 20% (1204.60 Tg of CO_2) and 18% (1113.68 Tg of CO_2), respectively. After categorizing into five major land types based on the vegetation and fire sources, we found that woody savanna/shrubland fire was the largest contributor (3161.43 Tg, 52%), followed by savanna/grassland (1649.16 Tg, 27%), forest (1024.38 Tg, 17%), cropland (194.44 Tg, 3%), and peatland (54.27 Tg, 1%), respectively. However, these proportions varied between the continents; in the Americas and Asia, the largest biomass burning emissions came from forest fires, and in Africa the largest emissions were from fires in woody savanna/shrubland. The total CO_2 emissions in these tropical continents exhibited strong interannual variations from 2001 to 2017, with peak emissions in March and August to September, and forest fires were the primary land type controlling the interannual variations.

Keywords: biomass burning, CO2 emissions, tropical continents

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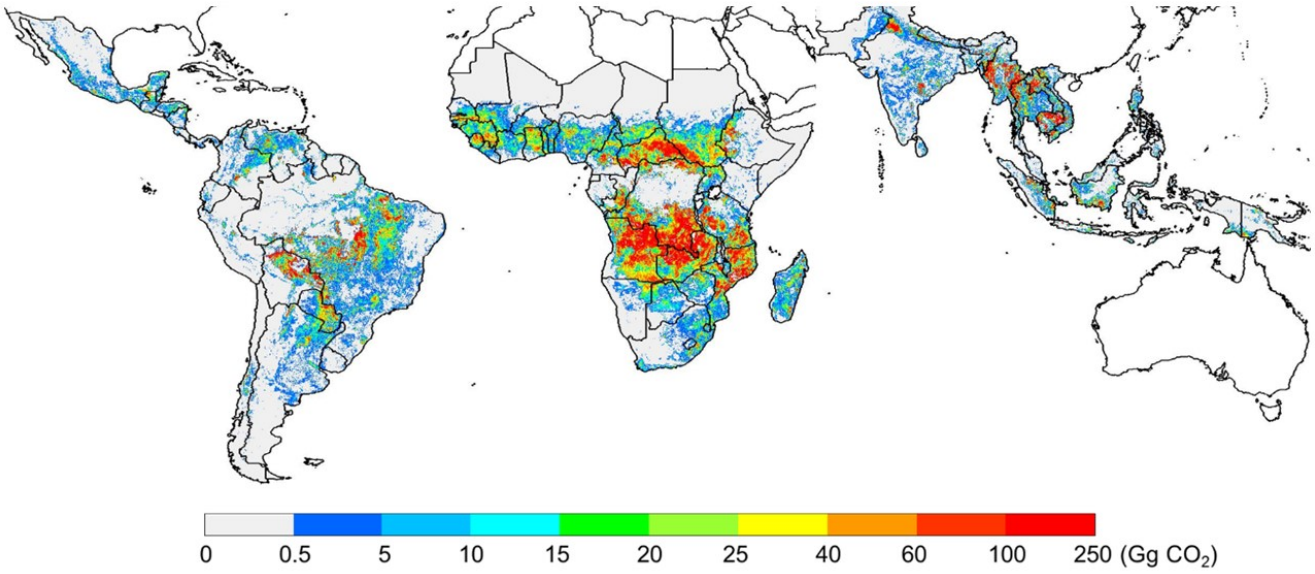

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Numerical Simulation Study on Aerosol-boundary Layer Interaction

*Zilin Wang[1]

1. Nanjing Univ.

Atmospheric aerosols could interact with boundary-layer meteorology through their radiative effects, exerting an impact on regional and global climate. Black carbon (BC) has been identified to play a key role in aerosol-boundary layer interaction (ABI) and remarkably enhance haze pollution in high emission areas such as eastern China, which was previously defined as "dome effect". Our work aimed to quantify the impact of key influencing factors, i.e. vertical distribution of BC, its aging processes as well as the characteristics of underlying surface, on the formation of such two-way feedback. It turns out that the upper-level BC, especially that near the capping inversion, is more essential in suppressing the PBL height and weakening the turbulent mixing. The dome effect of BC mixed with scattering aerosols during winter haze events tends to be significantly intensified. In addition, the feedback is more substantial in rural areas than that in the urban cities. Since the impact of BC on planetary boundary layer is much sensitive to the altitude of aerosol layer, a set of key-level targeted vertical grids was designed and applied to real-time air quality modelling. Compared with default configurations, optimized grids are more capable of characterizing temperature stratification and extreme fine particle ($PM_{2.5}$) concentration as well as its diurnal variation during haze episodes. The optimization of vertical grid setting could help better simulate ABI and its effect on haze pollution, hence better prediction of extreme near-surface pollution episodes.

Keywords: Black carbon, WRF-Chem, Aerosol-radiation interaction

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Global and Regional Climate Responses to Black Carbon Emissions from the Arctic and Mid-latitudes

*Yang Yang[1], Sijia Lou[2], Hailong Wang[3], Steven J. Smith[3]

1. Nanjing University of Information Science and Technology, 2. Nanjing University, 3. Pacific Northwest National Laboratory

Black carbon (BC) particles exert a potentially large warming influence on the Earth system, which drew attentions for climate mitigation from reducing BC emissions. For the first time, we evaluate climate responses, non-linearity, and short-term transient responses to BC emission perturbations in the Arctic, mid-latitudes, and globally based on a comprehensive set of emission-driven experiments using the Community Earth System Model (CESM). We found that the BC effects do not scale linearly with the amount of emissions. While stronger BC emission perturbations have a higher burden efficiency (defined as the ratio of burden to emission), their temperature sensitivity is lower. Our CESM results show that BC can impact air temperature much faster than greenhouse gases, with transient temperature responses in the Arctic and mid-latitudes approaching a quasi-equilibrium state at a timescale of 2–3 years in the coupled system. We also found that BC originating from mid-latitude continental sources changes cloud structure over downwind oceans and reduces land-sea thermal contrast and, consequently, weakens the East Asian winter monsoon winds. A strong increase in the Arctic BC also weakens East Asian winter monsoon through changing large-scale circulations. In addition, the increases in both Arctic and mid-latitude BC emissions are found to weaken latitudinal temperature gradient and poleward heat transport, lead to tropical energy convergence, increase surface temperature of the tropical oceans, and consequently increase the frequency of extreme El Nino-Southern Oscillation events.

Keywords: Black Carbon, Climate Response

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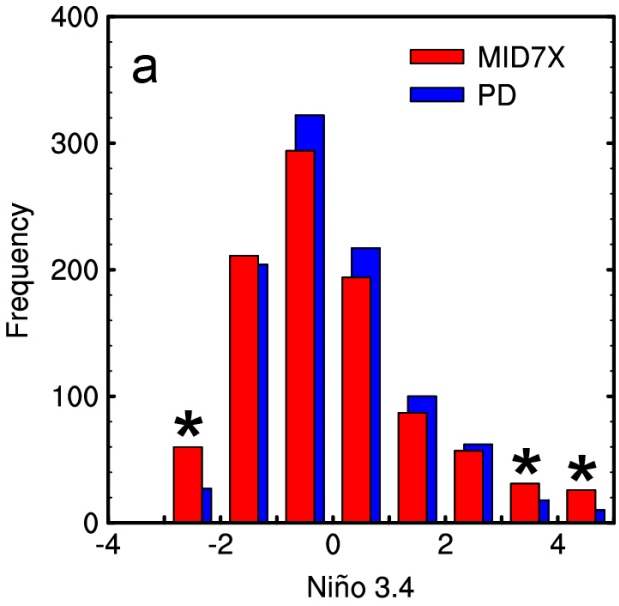

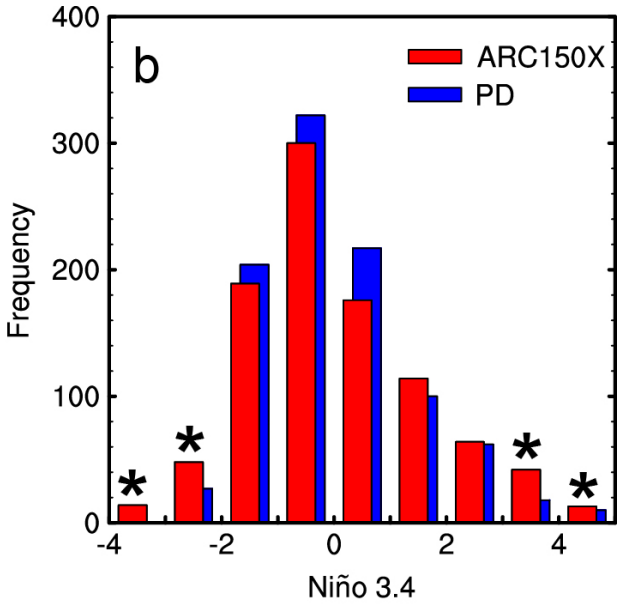

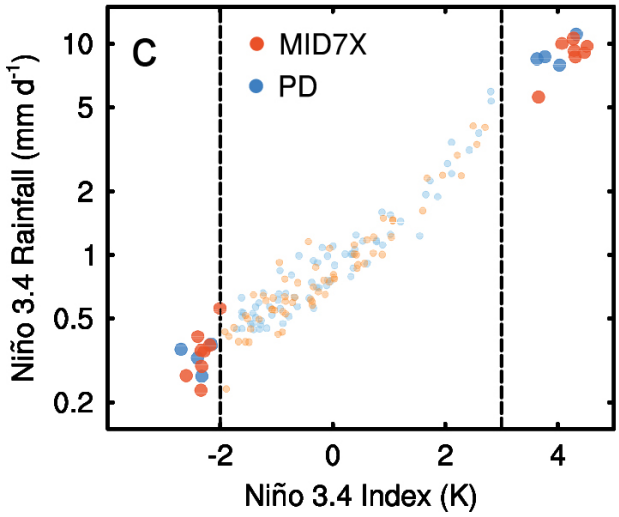

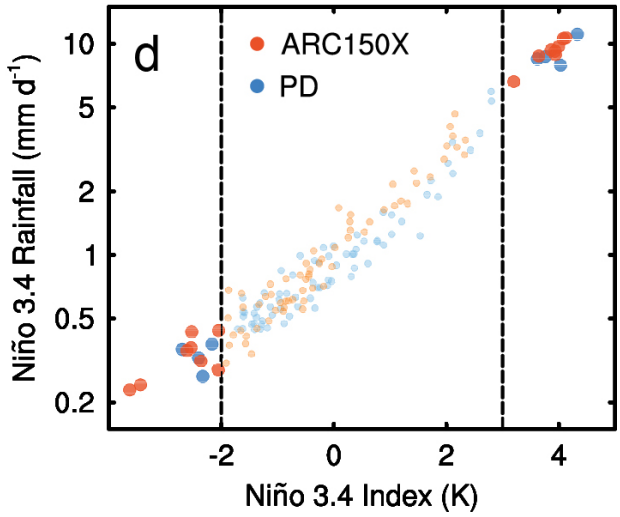

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Mesoscale modeling of aerosol transport over Southeast Asia during the dry season: effects of fire and new emissions

*Shuo Wang[1], Jason Blake Cohen[1]

1. Sun Yat-Sen University

In general, biomass burning is considered to make a significant and continuously increasing contribution to anthropogenic aerosol emissions over the South Asia, Southeast Asia, and East Asia. Observed large-scale aerosol events are frequently related to local biomass burning which have a significant impact on the regional atmosphere, the climate, the ecosystem, and human health. Meanwhile, biomass burning is also a major source of multiple trace gases into the atmosphere and affects the formation of atmospheric chemicals, such as ozone, VOCs, SOA and so on.

Due to the fact that biomass burning has a very strong periodicity (annual or even bi-annual in general), the effects of biomass burning aerosols may be climatologically small, but quite important on a specific regional or seasonal basis. The focus of this work therefore is to quantify the aerosol source and transmission path during a typical biomass burning season. During the dry season (January-April) in northern Southeast Asia, a large amount of aerosols are released into the atmosphere. A large number of studies have proved that these aerosols move eastward under the influence of the Indian Ocean monsoon, but due to thousands of kilometers of cloud cover, there has not been a consistent message in terms of how far downwind these can transport, as detected by satellite. Therefore, we expect the actual transport of aerosol is much higher than predicted by the current generation of models which do not use our newly derived aerosol emissions geospatial products.

This work uses a completely new method to enhance the model’ s ability to reproduce the spatial and temporal distribution of total aerosol emission over Monsoon Asia during the extreme fire burning season in 2016. At the same time, this method is considered reliable by comparing ground stations and satellite data, as the description of aerosol distribution is one of the weaker aspects of atmospheric science. This new approach allows us to more accurately predict aerosol plume emissions heights through a deeper understanding of the physical mechanisms of aerosol motion and formation. In turn, through sensitivity analysis, this paper provides a new perspective to reduce the uncertainty (dynamic mechanisms, multi-data coupling, etc.) of the model's ability to accurately transport aerosols thousands of kilometers downwind.

We find that ground and column observations throughout Southeast and East Asia are most consistent with our model results using the new blended emissions. Next, we conclude that the impact of biomass burning coincides with the highest aerosol loadings of the year in many locations. Third, we find that in regions far downwind, that many measured local peaks occur at the same time that aerosols have been transported downwind from the burning regions. The results show that first, a significant amount of the smoke is lofted into the lower free Troposphere and subsequently transported thousands of kilometers downwind. Second, a significant increase in biomass burning emissions were observed when using a blend of multiple remotely sensed measurements, leading to a new approximation several times the current inventory. Finally, compared with existing inventories, the use of these multiple techniques leads to a better spatial and temporal match with measured peak aerosol events.

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Keywords: aerosol transportation, WRF-CHEM, emission inventory

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS04] Formation of Air Pollution and Its Interactions with Weather/Climate

convener:Yang Yang(Nanjing University of Information Science & Technology), Meng Gao(State Key Laboratory of Environmental and Biological Analysis), Guangxing Lin(Pacific Northwest National Laboratory)

Air pollutants, such as aerosols and ozone, have significantly affected environment, human health, ecosystem, and climate. Anthropogenic emissions of air pollutants in major economic regions of the world, which have changed rapidly over the past few decades owing to economic development and environmental measures, will continue to change in the near future. Air pollution from the changing sources not only degrades local and remote air quality, but also modifies energy balance, cloud, precipitation and circulation patterns, leading to regional and global environmental and weather/climate change. Climate change and variabilities in the changing world can in turn affect the emission, chemistry, transport and removal of air pollutants at different scales. To better understand the formation of air pollution, and air pollution-weather/climate interactions, advances are needed in theoretical, observational and modeling studies.
Relevant topics include but are not limited to:
(1) formation mechanism of air pollution, both physical and chemical;
(2) source attribution of air pollutants in the past and future;
(3) impact of air pollution on weather (boundary layer, cloud, precipitation, etc.), modes of variability and climate change;
(4) influence of historical climate variability on air pollution (ENSO, PDO, AO, etc.);
(5) predictability of future climate change associated with projected emission changes and feedback on air pollution.

[AAS04-06] **Relieved drought in China by 1.5°C global warming under a low emission scenario**

★Invited Papers

*Xu Yue[1] (1.Nanjing University of Information Science and Technology)

[AAS04-07] Observed dependence of surface ozone on increasing temperature in Shanghai, China

*Yixuan Gu[1], Ke Li[2], Jianming Xu[1], Hong Liao[3] (1.Yangtze River Delta Center for Environmental Meteorology Prediction and Warning, 2.John A. Paulson School of Engineering and Applied Sciences, Harvard University, 3.School of Environmental Science and Engineering, Nanjing University of Information Science and Technology)

[AAS04-08] A Study of Air Pollution with Different Synoptic Weather Systems in Taiwan

Hsin-Chih Lai[1], *JUI-TENG OU[1], Li-Wei Lai[1], Mei-Chi Lin[1], Ching-Yen Wang[1] (1.Chang Jung Christian University, Taiwan)

[AAS04-09] Quantifying the Impacts of Cold Airmass on Aerosol Concentrations Over North China Using Isentropic Analysis

*Qian Liu[1], Guixing Chen[1], Toshiki Iwasaki[2] (1.Sun Yat-sen University, 2.Tohoku University)

[AAS04-10] To what extents do urbanization and air pollution affect fog?To what extents do urbanization and air pollution affect fog?

*Shuqi Yan[1,2,3,4], Bin Zhu[1,2,3,4], Yong Huang[5,6], Jun Zhu[7], Hanqing Kang[1,2,3,4], Chunsong Lu[1,2,3,4], Tong Zhu[8] (1.Collaborative Innovation Centre on Forecast and Evaluation of Meteorological Disasters, Nanjing University of Information Science & Technology, Nanjing, China, 2.Key Laboratory for Aerosol-Cloud-Precipitation of China Meteorological Administration, Nanjing University of Information Science & Technology, Nanjing, China, 3.Key Laboratory of Meteorological Disaster, Ministry of Education (KLME), Nanjing University of Information Science & Technology, Nanjing, China, 4.Special test field of National Integrated meteorological observation, Nanjing University of Information Science & Technology, Nanjing, China, 5.Anhui Meteorology Institute, Key Lab of Atmospheric Science and Remote Sensing Anhui Province, Hefei 230031, China, 6.Shouxian National Climatology Observatory, Shouxian 232200, China, 7.Xiangshan Meteorological Bureau, Xiangshan 315700, China, 8.IMSG at NOAA/NESDIS/STAR, 5830 University Research Ct., College Park, MD 20740, USA)

[AAS04-11] Evolution and Assessment of the Atmospheric Composition in Hangzhou and its Surrounding Areas during the G20 Summit

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Relieved drought in China by 1.5˚C global warming under a low emission scenario

*Xu Yue[1]

1. Nanjing University of Information Science and Technology

Drought is detrimental to both natural systems and human societies. It remains unclear how the drought activities may respond to a low warming target such as 1.5˚C, which is set by the Paris Agreement to combat climate change. In this study, future changes of self-calibrating Palmer Drought Severity Index (scPDSI) in China are projected for the periods of 1.5˚C global warming under two different scenarios based on outputs from Coupled Model Intercomparison Project phase 5 (CMIP5). For a high emission scenario, national average scPDSI decreases by 0.04 relative to present day, because warmer climate enhances evapotranspiration while changes in precipitation are too limited to compensate the water loss. On the contrary, for a low emission scenario, mean scPDSI increases by 0.20 with regional enhancement of 0.52 in the Southeast, where precipitation is projected to increase likely because of reductions in aerosols. Consequently, an associated control of both carbon and air pollution emissions helps retain the warming target globally and relieve drought risks regionally.

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Observed dependence of surface ozone on increasing temperature in Shanghai, China

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Eight-year measurements at urban (Xujiahui, XJH) and remote (Dongtan, DT) stations during 2010-2017 are employed to examine the surface ozone (O_3)-temperature relationship in Shanghai, China. O_3 pollution was getting worse in Shanghai, with daily maximum O_3 concentrations increasing at a rate of 2.45 ppb yr^{-1} in urban site. The climate penalty ($m_{O3\text{-}T}$), defined as the slope of O_3 change with increasing temperature, exhibited largest values in summer. Summertime O_3 increased faster as temperature increased, with mean rates of 6.7 and 13.7 ppb $^{\circ}C^{-1}$, respectively in XJH and DT above 30°C. Sensitivity experiments indicate that the temperature dependence of biogenic volatile organic compounds (VOCs) emissions should be the main chemical driver of the high-temperature O_3 response in summer, since simulated values of $m_{O3\text{-}T}$ are most sensitive to the temperature-related changes in biogenic isoprene emissions. NO_x emission reductions strengthened the high-temperature O_3 response in Shanghai, with summer mean $m_{O3\text{-}T}$ values increasing from 1.52 ppb$^{\circ}C^{-1}$ during 2010-2012 to 2.97 ppb $^{\circ}C^{-1}$ during 2013-2017. As NO_x emissions continue to decrease, the dependence of $m_{O3\text{-}T}$ on the biogenic VOC emissions could be weakened. Model results suggest that reductions in anthropogenic VOC emission reductions would effectively reduce the sensitively of O_3 to increasing temperatures in urban Shanghai. Effective emission reduction strategies should be formulated to balance VOC/NO_x ratios, so as to wrestle with the challenges for future O_3 pollution.

Keywords: Ozone, isoprene, temperature, atmospheric chemistry, Shanghai

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A Study of Air Pollution with Different Synoptic Weather Systems in Taiwan

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1. Chang Jung Christian University, Taiwan

Both of air pollution emissions and meteorological condition are important factors that affecting the air quality. In Taiwan, previous studies have focused mostly on the control of emission sources but still lack of detail discussion on meteorological and transport of pollutants, as the air pollution events happened in autumn and winter frequently are consistent with the time of lee-side vortex generation.
This study presents the different synoptic weather systems of spatial distribution correlation between the $PM_{2.5}$ concentration and lee-side vortex in Taiwan during air pollution events, 2013-2015. Weather Research and Forecasting Model (WRF) and Community Multi-scale Air Quality Model (CMAQ) are used to discuss the temporal and spatial distribution of the pattern of the ambient flow related with the $PM_{2.5}$ pollutant concentration. The results show when continental high pressure moving to Pacific Ocean, ambient airflow changes to the east to pitching Taiwan, lee-side vortices will be formed in Taiwan Strait, these vortices transport air pollutants to specific areas and cause to high air pollution accumulation. The findings provide valuable reference to understanding air-terrain-emission correlation and also for the improvements of air quality policy.

Keywords: PM2.5, Vortex, Synoptic weather systems

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Quantifying the Impacts of Cold Airmass on Aerosol Concentrations Over North China Using Isentropic Analysis

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1. Sun Yat-sen University, 2. Tohoku University

Winter air quality can vary markedly due to cold air activities. However, the impacts of the polar cold airmass on aerosol variations has not been clarified in a quantitative manner. Using an isentropic analysis method, we investigated changes in the cold airmass and sulfate aerosol distributions over North China during the winter of 2014/2015. The cold airmass and sulfate concentrations exhibited pronounced out-of-phase variations, with comparable amplitudes at subseasonal (30–60 days) and synoptic (4–6 days) scales. Subseasonal sulfate variations were closely associated with distribution of the polar cold airmass, as it shifted between zonal and meridional patterns, regulating cold airmass fluxes over North China. Typically, subseasonal surges in the cold airmass consisted of several synoptic disturbances, including one cold air outbreak event and 3–6 renewal/decay oscillations. These synoptic inflows of clean cold airmass repeatedly pushed the warm polluted airmass away from North China. Thus, spatio-temporal variations in sulfate better reflect cold airmass distributions and fluxes than northerly wind regimes. Using diagnostic equations derived herein, we estimated the contribution of various physical processes to aerosol variations during cold air anomalies. We found that the local changes in sulfate concentrations were mainly attributed to advection of warm airmasses, as well as advection and vertical displacement by horizontal convergence of the polar cold airmass. The latter two processes contributed most to sulfate decreases, leading to a relatively strong aerosol reductions during cold air outbreaks, while first two processes led to weaker aerosol reductions during cold air oscillations.

Keywords: North China, Cold air activity, Aerosol concentration, Isentropic analysis

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To what extents do urbanization and air pollution affect fog?To what extents do urbanization and air pollution affect fog?

*Shuqi Yan[1,2,3,4], Bin Zhu[1,2,3,4], Yong Huang[5,6], Jun Zhu[7], Hanqing Kang[1,2,3,4], Chunsong Lu[1,2,3,4], Tong Zhu[8]

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The remarkable development of China has resulted in rapid urbanization (urban heat island and dry island) and severe air pollution (aerosol pollution). Previous studies demonstrate that these two factors have either suppressing or promoting effects on fog, but what are the extents of their individual and combined effects? In this study, a dense radiation fog event in East China in January 2017 was reproduced by the WRF-Chem model, and the individual and combined effects of urbanization and aerosols on fog (indicated by liquid water content (LWC)) are quantitatively revealed. Results show that urbanization inhibits low-level fog, delays its formation and advances its dissipation due to higher temperatures and lower saturations. In contrast, upper-level fog could be enhanced because of the updraft-induced vapour convergence. Aerosols promote fog by increasing LWC, increasing droplet concentration and decreasing droplet effective radius. Further experiments show that the current pollution level in China is still below the critical aerosol concentration that suppresses fog. Urbanization influences fog to a larger extent than do aerosols. When urbanization and aerosol pollution are combined, the much weaker aerosol promoting effect is counteracted by the stronger urbanization suppressing effect on fog. Budget analysis of LWC reveals that urban development (urbanization and aerosols) alters LWC profile and fog structure mainly by modulating condensation/evaporation process. Our results infer that urban fog will be further reduced if urbanization keeps developing and air quality keeps deteriorating in the future.

Keywords: Fog, Urbanization, Aerosol, WRF-Chem

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Evolution and Assessment of the Atmospheric Composition in Hangzhou and its Surrounding Areas during the G20 Summit

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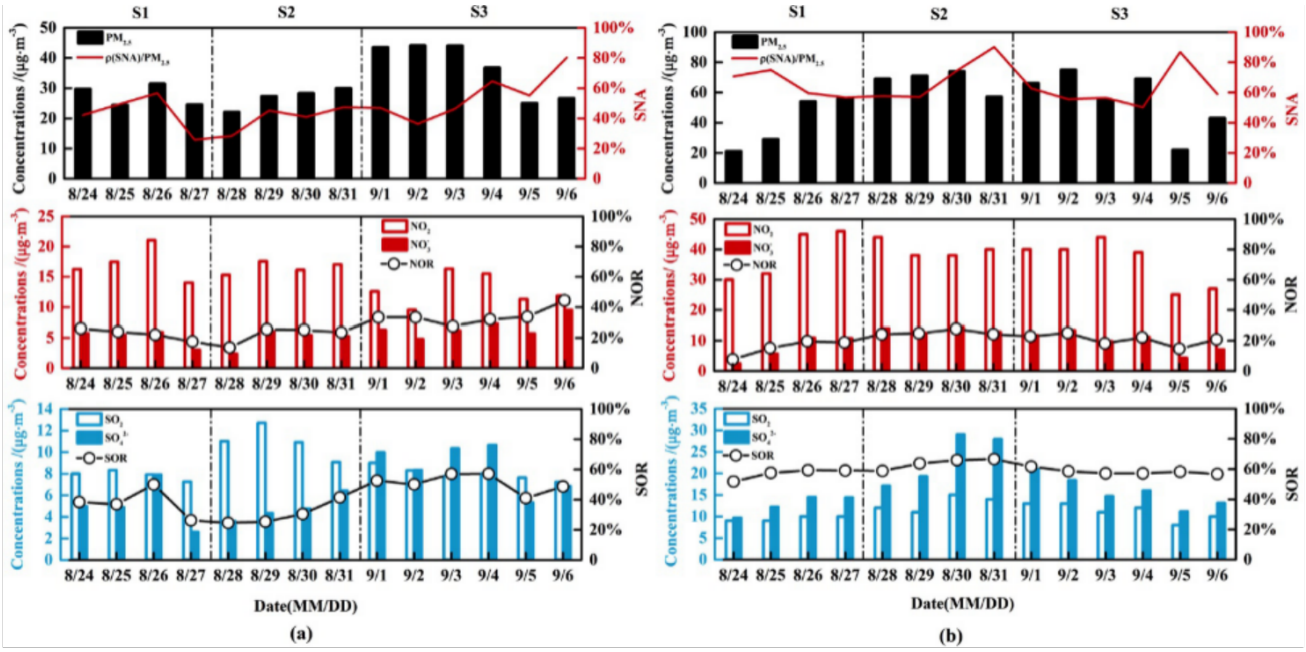
To evaluate the effectiveness of control strategies during the G20 Summit (August 24–September 6, 2016), five sites were selected for investigating the variation in air pollution in the city of Hangzhou and its surrounding areas. The results showed that the air quality in Hangzhou greatly improved after the implementation of strict emission controls. Compared to the same dates from the five preceding years, the G20 period exhibited low relative humidity during the early stage and no significant differences in other meteorological conditions. The SO_2, NO_2, PM_{10}, and $PM_{2.5}$ concentrations averaged across the five sites in Hangzhou decreased by 42.6%, 57.1%, 36%, and 38.5%, respectively, although the average O_3 concentration increased by 19%. These changes indicate that the emission reduction measures decreased the concentrations of several pollutants. Compared to the same dates from the previous year (August 24–September 6, 2015), the G20 period exhibited significantly decreased concentrations for most of the chemical components of $PM_{2.5}$, particularly SO_4^{2-}, NO_3^-, and NH_4^+. Additionally, the aerosol optical depth (AOD) and the NO_2 column concentrations followed a trend similar to that of the pollutants in this city.

Keywords: Air quality, Emission reduction, G20 Summit, Ozone sensitivity



Variations in sulfate, nitrate, and ammonia (SNA) in $PM_{2.5}$; sulfur oxidation ratio (SOR); and nitrogen oxidation ratio (NOR) during (a) the G20 period (August 24–September 6, 2016) and (b) the non-G20 period (August 24–September 6, 2015).

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS05] Large-scale moisture and organized cloud systems

convener:Hiroaki Miura(The University of Tokyo), Atsushi Hamada(University of Toyama), Satoru Yokoi(Japan Agency for Marine-Earth Science and Technology), Masaki Satoh(Atmosphere and Ocean Research Institute, The University of Tokyo)

Water vapor plays a significant role in regulating the global atmospheric circulation, especially in the troposphere. The overturning circulation is directly driven by the longwave radiative cooling of water vapor and the latent heating/cooling through microphysical processes to balance it. This global circulation is composed of diverse atmospheric phenomena with various spatial and temporal scales. Developments of some significant turbulent motions such as 3D isotropic turbulence in clouds, stratocumulus and cumulus convection, squall lines and tropical cyclones, and the Madden-Julian oscillation, are essentially associated with moisture anomaly in each scale. Moisture is accumulated relatively slowly in larger horizontal scales, but is consumed relatively quickly in smaller ones. This significant scale gaps between the accumulation and consumption may be one of the causes of the long-lasting difficulty in developing the theory of the moist atmosphere. The aim of this session is to share the recent researches about the relationships between moisture and organized cloud systems in wider spatial and temporal scales to enhance collaborations between modeling, observational, and theoretical approaches in tackling this challenging task. Research results relating to the Years of the Maritime Continent (YMC), Radiative-Convective Equilibrium Model Intercomparison Project (RCEMIP), and mesoscale simulations of severe weather are welcome.

[AAS05-01] The Madden-Julian Oscillation and Climate Change

★Invited Papers

*Eric D Maloney[1], Hien X Bui[1], Wei-Ting Hsiao[1], Elizabeth A Barnes [1] (1.Colorado State University Fort Collins)

[AAS05-02] Transient aggregation of convection: Observed behavior and underlying processes

*Hirohiko Masunaga[1], Christopher E Holloway[2], Hironari Kanamori[1], Sandrine Bony[3], Thorwald H. M. Stein[2] (1.Nagoya University, 2.University of Reading, 3.LMD/IPSL, CNRS, Sorbonne Universities)

[AAS05-03] Diversity of Initiation Regions of the MJO Associated with the Mutual Relationship Between the Intraseasonal and Low-frequency Variability

*Daisuke Takasuka[1], Masaki Satoh[1] (1.Atmosphere and Ocean Research Institute, The University of Tokyo)

[AAS05-04] The Diurnal Variability of Precipitating Cloud Populations during DYNAMO

★Invited Papers

*Naoko Sakaeda[1], Scott W Powell[4], Dias Juliana[2,3], George Kiladis[3] (1.University of Oklahoma Norman Campus, 2.CIRES, University of Colorado Boulder, 3.NOAA/Earth System Research Laboratory, 4.Naval Postgraduate School)

[AAS05-05] Observational study on energy and moisture budgets in the atmospheric boundary layer of the tropical deep convective regimes

*Satoru Yokoi[1] (1.Japan Agency for Marine-Earth Science and Technology)

[AAS05-06] Case study on mesoscale convective system near Japan from the perspective of diurnal cycle

*Takaya Yamashita[1], Hironobu Iwabuchi[1] (1.Graduate School of Science, Tohoku University)

The Madden-Julian Oscillation and Climate Change

*Eric D Maloney[1], Hien X Bui[1], Wei-Ting Hsiao[1], Elizabeth A Barnes [1]

1. Colorado State University Fort Collins

Recent modeling studies project that precipitation variability associated with the Madden-Julian oscillation (MJO) will increase in intensity in a warmer climate, while wind variability either decreases or increases at a slower rate than precipitation. This potential weakening of MJO winds relative to precipitation would have important consequences for prediction of extreme events modulated by the MJO, as many MJO impacts are regulated by the wind response. After briefly reviewing these recent findings, the CMIP5 archive is used to demonstrate that changes in the relative strength of MJO wind to precipitation amplitude can be detected as early as the period 2020-2040 in RCP8.5 relative to the historical record. It is also shown using reanalysis data from ERA5 and MERRA that a weakening of MJO winds relative to precipitation may already be detectable in the historical record. How increased tropical dry static stability in a warming climate regulates the MJO wind response to warming is discussed.

Finally, an aquaplanet version of the NCAR Community Atmosphere Model run in uncoupled mode and coupled to a slab ocean is used to better understand physical processes underlying changes in MJO behavior in a warmer climate. MJO changes are minimal when $4xCO_2$ forcing is applied but surface temperatures are held fixed at $1xCO_2$ conditions, indicating that MJO changes in a warmer climate are primarily driven by the SST change. The MJO propagates faster in the coupled model with SST warming. It is shown that this speed-up is due primarily to changes in horizontal moisture advection, with both zonal and meridional advection contributing. The slowing of the MJO zonal circulation per unit precipitation anomaly weakens drying by zonal advection to the east of the MJO precipitation center, causing more rapid MJO propagation in a warmer climate.

Keywords: Intraseasonal variability , Climate Change , Madden-Julian oscillation , Climate modeling

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Transient aggregation of convection: Observed behavior and underlying processes

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1. Nagoya University, 2. University of Reading, 3. LMD/IPSL, CNRS, Sorbonne Universities

Convective self-aggregation is among the most striking features emerging from RCE simulations, but its relevance to convective disturbances observed in the real atmosphere remains under debate. While some aspects of idealized simulations are unlikely to be observed in nature, some underlying physics at the process level may be testable against observations. This work seeks the observational signals of convective aggregation intrinsic to the life cycle of organized convective systems or cloud clusters, which typically have a sub-daily to daily time scale. To this end, composite time series of the Simple Convective Aggregation Index (SCAI), a metric of aggregation, and other variables are constructed around the temporal maxima of precipitation. All the parameters analyzed are large-scale means over 10˚×10˚ domains.

Major findings for the case of intense precipitation (P>35 d mm^{-1} at t=0) are (1) The composite evolution shows that cloud clusters are gathered into fewer and larger members during a period of ±12 h as precipitation picks up and the high-cloud cover expands to its peak, suggesting a transient occurrence of convective aggregation presumably in close association with the life cycle of cloud clusters; (2) This transient aggregation is detectable over warm oceans (SST>28℃) but less prominent over colder oceans; (3) The latent and sensible heat are invariant during the evolution; and (4) The horizontal advection imports MSE immediately before the precipitation peak, while the vertical advection exports MSE. When the composite samples are stratified into less-aggregated (SCAI>1.5 at t=0) and more-aggregated (0.6<SCAI<0.9 at t=0) cases, the evolution is very similar but with a subtle difference in the dynamics (advection).

Keywords: Tropical Meteorology, Moist Convection

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Diversity of Initiation Regions of the MJO Associated with the Mutual Relationship Between the Intraseasonal and Low-frequency Variability

*Daisuke Takasuka[1], Masaki Satoh[1]

1. Atmosphere and Ocean Research Institute, The University of Tokyo

The Madden–Julian oscillation (MJO) is known to be the most prominent tropical intraseasonal variability. Since MJO convection canonically starts to propagate eastward from the Indian Ocean (IO), most of the previous studies about MJO initiation have proposed various kinds of the mechanisms on the premise that the IO is the source region of the MJO. Meanwhile, several works have found that the MJO is sometimes initiated around the Maritime Continent (MC) and the western Pacific (WP), which implicates that analyses alone which postulate that the MJO is realized in the IO are not enough to grasp the whole picture of MJO initiation. In fact, the reason why the MJO initiation regions are modulated outside the IO cannot be explained by the pre-existing representative mechanisms.

To understand favorable environments for MJO initiation comprehensively, this study aims to examine a potential factor of the diversity of MJO onset basins and similar features in the initiation processes of the MJO even among different basins in terms of the relationship between intraseasonal and interannual variability. MJOs are categorized as those initiated in the IO (IO-MJO), MC (MC-MJO), and WP (WP-MJO). Both observations and 15-yr numerical experiments under a perpetual boreal winter condition using a global nonhydrostatic model reveal the following two points: (i) horizontal moisture advection by equatorial intraseasonal circulations is commonly important before MJO initiation in every region, and (ii) the variety of MJO onset basins is partly derived by the difference of the location where advective moistening is more likely to occur in association with the modulation of background circulations forced by interannual SST variability. For IO-MJO cases, intraseasonal convective organization supported by climatological ascent in the MC–WP causes convective suppression around the western MC, which further leads to moisture advection to the IO via intraseasonal low-level easterly anomalies. MC-MJO cases are more favored under the eastern-Pacific (EP) El Niño-like condition, because SST-induced background suppressed convection in the eastern MC causes the eastward shift of the intraseasonal circulation and convective pattern seen in IO-MJO cases and results in efficient moistening and subsequent development of convection around the western MC. WP-MJO cases tend to occur under the central-Pacific (CP) Niño-like state and dipole SST structure in the southern IO. This is owing to selective moistening in the WP due to westward intrusion of enhanced disturbances as a result of background convective enhancement in the WP–CP and suppression in the southeastern IO and EP.

Keywords: Madden–Julian Oscillation, Air-sea Coupled System, Large-scale Circulation

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The Diurnal Variability of Precipitating Cloud Populations during DYNAMO

*Naoko Sakaeda[1], Scott W Powell[4], Dias Juliana[2,3], George Kiladis[3]

1. University of Oklahoma Norman Campus, 2. CIRES, University of Colorado Boulder, 3. NOAA/Earth System Research Laboratory, 4. Naval Postgraduate School

This study uses high-resolution rainfall estimates from the S-Polka radar during the DYNAMO field campaign to examine variability of the diurnal cycle of rainfall associated with MJO convection over the Indian Ocean. Two types of diurnal rainfall peaks were found: 1) a late afternoon rainfall peak associated with the diurnal peak in sea surface temperatures (SSTs) and surface fluxes and 2) an early to late morning rainfall peak associated with increased low-tropospheric moisture. Both peaks appear during the MJO suppressed phase, which tends to have stronger SST warming in the afternoon, while the morning peak is dominant during the MJO enhanced phase. The morning peak occurs on average at 0000–0300 LST during the MJO suppressed phase, while it is delayed until 0400–0800 LST during the MJO enhanced phase. This delay partly results from an increased upscale growth of deep convection to broader stratiform rain regions during the MJO enhanced phase. During the MJO suppressed phase, rainfall is dominated by deep and isolated convective cells that are short-lived and peak in association with either the afternoon SST warming or nocturnal moisture increase. This study demonstrates that knowledge of the evolution of cloud and rain types is critical to explaining the diurnal cycle of rainfall and its variability. Some insights into the role of the complex interactions between radiation, moisture, and clouds in driving the diurnal cycle of rainfall are also discussed.

Keywords: Madden-Julian Oscillation, Diurnal Cycle, DYNAMO

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Observational study on energy and moisture budgets in the atmospheric boundary layer of the tropical deep convective regimes

*Satoru Yokoi[1]

1. Japan Agency for Marine-Earth Science and Technology

In order to deepen our understanding of what determine intensity of tropical deep convective systems, we analyze observational data taken by Research Vessel *Mirai* over tropical Indo-Pacific warm pool domain. Our analysis is based on boundary layer (BL) quasi equilibrium concept, in which import of moist static energy (MSE) to the BL in the form of turbulent surface heat fluxes is balanced with exports of MSE due to intrusion of convective downdraft, entrainment through the BL top, and radiative cooling in the BL. MSE is composed of dry static energy (DSE) and water vapor mixing ratio. Considering the budgets of these two conservative quantities separately, we can estimate daily mean mass flux of the convective downdraft and that of the entrainment from upper air sounding data and surface meteorology data. The convective downdraft mass flux exhibits daily time series that correlates significantly with measures of convective activity around the vessel, such as onboard gauge precipitation and fractional area covered by strong radar echo (>30 dBZ) within 30 km range. We then discuss what determine the variability in the convective outflow mass flux and find positive and significant correlation between the mass flux and surface sensible heat flux, which may primarily represent interaction between convection and the surface flux. The DSE of downdraft air parcels, which is primarily determined by mid-tropospheric humidity, also exhibits positive and significant correlation with the mass flux, which is consistent with well-known relationship between convective activity and precipitable water vapor.

Keywords: Tropical deep convective systems, Boundary layer quasi equilibrium, Research Vessel Mirai

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Case study on mesoscale convective system near Japan from the perspective of diurnal cycle

*Takaya Yamashita[1], Hironobu Iwabuchi[1]

1. Graduate School of Science, Tohoku University

The diurnal cycle of convective cloud, which can be explained by various processes, is an important feature to understand the mechanism for better weather forecast via the improvement of parameterization of physical processes. In the vicinity of Japan, the typhoon is a major target in the previous study and has a significant convective peak in the morning (e.g. Wu *et al.*, 2015). In contrast, mesoscale convective system (MCS) formed in this region is not well understood because of the lower frequency of occurrence. In this study, we examine the diurnal cycle of MCS, which appeared over the Yellow Sea on July 17, 2017 and moved southeastward to the northwest Pacific Ocean over July 22.

For cloud property data, we used the retrieval results from the Himawari-8 brightness temperature (Iwabuchi *et al.*, 2018). To reveal the process of MCS development, we classified the high cloud into three types with cloud optical depth (COD) and calculated the cloud cover for each cloud type. Clear diurnal cycle of cloud cover was observed after July 19, when the Baiu front disappeared in the weather maps. It developed with a maximum of thick-cloud cover at 0900 Japan Standard Time (JST) following the peak of rainfall intensity around 0700 JST and matured with the peak of cirrus cover at 2100 JST. Accompanying by the cloud cover expansion, diurnal pulse of cloud top height propagated outward from the convective center, the centroid of MCS weighted by COD, starting at 0400-0700 JST. In addition, COD became smaller as the pulse propagation.

We further conducted a composite analysis with meteorological field data for investigating the difference of convection between predawn (0300 JST) and afternoon (1500 JST). The result shows that deep convection (convection in upper tropospheric layer) appears within 100 km of the convective center at predawn (in the afternoon). Moreover, the diurnal anomaly of horizontal temperature anomaly with respect to the domain average is negative (positive) at predawn (in the afternoon) around the convective center in the upper troposphere. It is hard to argue that these characteristics of MCS are general near Japan because our research is just a case study. Nevertheless, these results indicate that the radiative cooling in the upper layer cloud at night may have a significant impact on the deep convection in the morning in our target region.

Keywords: diurnal variation, mesoscale convective system, radiation and convection, satellite observations

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS05] Large-scale moisture and organized cloud systems

convener:Hiroaki Miura(The University of Tokyo), Atsushi Hamada(University of Toyama), Satoru Yokoi(Japan Agency for Marine-Earth Science and Technology), Masaki Satoh(Atmosphere and Ocean Research Institute, The University of Tokyo)

Water vapor plays a significant role in regulating the global atmospheric circulation, especially in the troposphere. The overturning circulation is directly driven by the longwave radiative cooling of water vapor and the latent heating/cooling through microphysical processes to balance it. This global circulation is composed of diverse atmospheric phenomena with various spatial and temporal scales. Developments of some significant turbulent motions such as 3D isotropic turbulence in clouds, stratocumulus and cumulus convection, squall lines and tropical cyclones, and the Madden-Julian oscillation, are essentially associated with moisture anomaly in each scale. Moisture is accumulated relatively slowly in larger horizontal scales, but is consumed relatively quickly in smaller ones. This significant scale gaps between the accumulation and consumption may be one of the causes of the long-lasting difficulty in developing the theory of the moist atmosphere. The aim of this session is to share the recent researches about the relationships between moisture and organized cloud systems in wider spatial and temporal scales to enhance collaborations between modeling, observational, and theoretical approaches in tackling this challenging task. Research results relating to the Years of the Maritime Continent (YMC), Radiative-Convective Equilibrium Model Intercomparison Project (RCEMIP), and mesoscale simulations of severe weather are welcome.

[AAS05-07] Effects of microphysical processes on the precipitation spectrum in a strongly forced environment

★Invited Papers

*Chien-Ming Wu[1], Jin-De Huang[1] (1.Department of Atmospheric Sciences, National Taiwan University)

[AAS05-09] New Critical Length Scale for the Onset of Self-Aggregation of Moist Convection

★Invited Papers

*Tomoro Yanase[1,2,3], Seiya Nishizawa[1], Hiroaki Miura[4,1], Tetsuya Takemi[3], Hirofumi Tomita[1,5] (1.RIKEN Center for Computational Science, 2.Graduate School of Science, Kyoto University, 3.Disaster Prevention Research Institute, Kyoto University, 4.Graduate School of Science, The University of Tokyo, 5.RIKEN Cluster for Pioneering Research)

[AAS05-10] Evaluation of Mesoscale Convective Systems in Climate Simulations: Methodological Development and Results from MPAS-CAM over the U.S.

*Zhe Feng[1], Fengfei Song[1], Koichi Sakaguchi[1], Ruby Leung[1] (1.PNNL)

[AAS05-11] Evaluate the CMIP6 marine stratocumulus cloud albedo using satellite and reanalysis data

*bida jian[1], Jiming Li[1] (1.Lanzhou University)

[AAS05-12] Dependence of the reproducibility of the MJO convection on differences in the surface flux conditions in NICAM

*Tamaki Suematsu[1], Chihiro Kodama[2], Hisashi Yashiro[3], Tomoro Yanase[4], Hiroaki Miura[5], Tomoki Miyakawa[1], Masaki Satoh[1] (1.Atmosphere and Ocean Research Institute, The University of Tokyo, 2.Japan Agency for Marine-Earth Science and Technology, 3.National Institute for Environmental Studies, 4.Graduate School of Science, Kyoto University, 5.Graduate School of Science, The University of Tokyo)

Effects of microphysical processes on the precipitation spectrum in a strongly forced environment

*Chien-Ming Wu[1], Jin-De Huang[1]

1. Department of Atmospheric Sciences, National Taiwan University

This study investigates the effects of microphysical processes on the precipitation spectrum in a strongly forced environment using a vector vorticity cloud-resolving model (VVM). Experiments are performed under imposed advective cooling and moistening with two microphysics parameterizations: predicted particle properties scheme (P3) and Lin scheme (VVM-Lin). Even though the domain-averaged precipitation is similar in two experiments, P3 exhibits stronger extreme precipitation in the spectrum compared with VVM-Lin. Changes in convective structures are responsible for such a difference. Using the isentropic analyses, we identify that in P3, stronger convective updrafts take place in the high regime where air parcels rarely reach. This is caused by additional condensate heating in P3. Through defining convective core clouds, the relation between the convective structure on the isentropic diagram and the extreme precipitation can be identified. The shifts toward extreme intensity in both object-based precipitation spectrum suggest that the microphysical processes have significant impacts on the extreme precipitation by the convective core clouds. The treatment of microphysics has significant impacts on the convective structures and then alter the probability of extreme events under the strongly forced environment. Impacts of microphysical processes on convective aggregation will also be discussed.

Keywords: cloud-resolving model, microphysics, extreme precipitation

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New Critical Length Scale for the Onset of Self-Aggregation of Moist Convection

*Tomoro Yanase[1,2,3], Seiya Nishizawa[1], Hiroaki Miura[4,1], Tetsuya Takemi[3], Hirofumi Tomita[1,5]

1. RIKEN Center for Computational Science, 2. Graduate School of Science, Kyoto University, 3. Disaster Prevention Research Institute, Kyoto University, 4. Graduate School of Science, The University of Tokyo, 5. RIKEN Cluster for Pioneering Research

Self-organization of convective clouds, Convective Self-Aggregation (CSA), in an idealized modeling framework of the tropical climate, has been recognized as a key process to understand cloud-climate relationships. This study investigated how CSA occurs under an idealized radiative-convective equilibrium climate simulated by a regional cloud-resolving model with wide varieties of horizontal domain sizes and horizontal grid spacings. First of all, our results basically reproduced the results of Muller and Held (2012) that CSA is unlikely to occur from a homogeneous initial moisture field with finer resolution and/or smaller domain. However, by extending the domain size, we found that CSA occurs even with the finer resolution. Based on the dozens of experiments, we discovered a new critical domain size around 500 km above which CSA robustly occurs with a more reliable resolution range including a half kilometer. In addition to this, a sharp variation of the critical domain size across the grid spacing around 2 km became apparent. It implies that the resolution alters a multiscale interaction of moist convection ranged from individual convective elements to large-scale overturning circulation coupled with moisture field. Finally, the onset mechanism of CSA is discussed in terms of the competing effects on the boundary layer moisture distribution, by rethinking the negative effect of cold pools on the onset of CSA which have been reported by previous studies.

Keywords: Radiative-Convective Equilibrium(RCE), Organization of Tropical Convection, SCALE-RM

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Evaluation of Mesoscale Convective Systems in Climate Simulations: Methodological Development and Results from MPAS-CAM over the U.S.

*Zhe Feng[1], Fengfei Song[1], Koichi Sakaguchi[1], Ruby Leung[1]

1. PNNL

A process-oriented approach is developed to evaluate warm-season mesoscale convective system (MCS) precipitation and their favorable large-scale meteorological patterns (FLSMPs) over the U.S. This approach features a novel observation-driven MCS-tracking algorithm using infrared brightness temperature and precipitation feature at 25 km and 50 km resolution and metrics to evaluate the model large-scale environment favorable for MCS initiation. The tracking algorithm successfully reproduces the observed MCS statistics from a reference 4-km radar MCS database. The process-oriented approach is applied to two climate simulations produced by the Variable-Resolution Model for Prediction Across Scales (VR-MPAS) coupled to the CAM5.4 physics, with refined horizontal grid spacing at 50 km and 25 km over North America. With the tracking algorithm applied to simulations and observations at equivalent resolutions, the simulated number of MCS and associated precipitation amount, frequency and intensity are found to be consistently underestimated in the Central U.S., particularly from May to August. The simulated MCS precipitation shows little diurnal variation and lasts too long, while MCS precipitation area is too large and intensity is too weak. Simulation at 25-km grid spacing does produce more realistic MCS characteristics. The model is able to simulate four types of observed FLSMP associated with frontal systems and low-level jets (LLJ) in spring, but the frequencies are underestimated because of low-level dry bias and weaker LLJ. Precipitation simulated under different FLSMPs peak during daytime, in contrast to the observed nocturnal peak. Implications of these findings for future model development and diagnostics are discussed.

Keywords: Mesoscale convective system, Large-scale environments, Climate simulation, Model evaluation, Storm tracking

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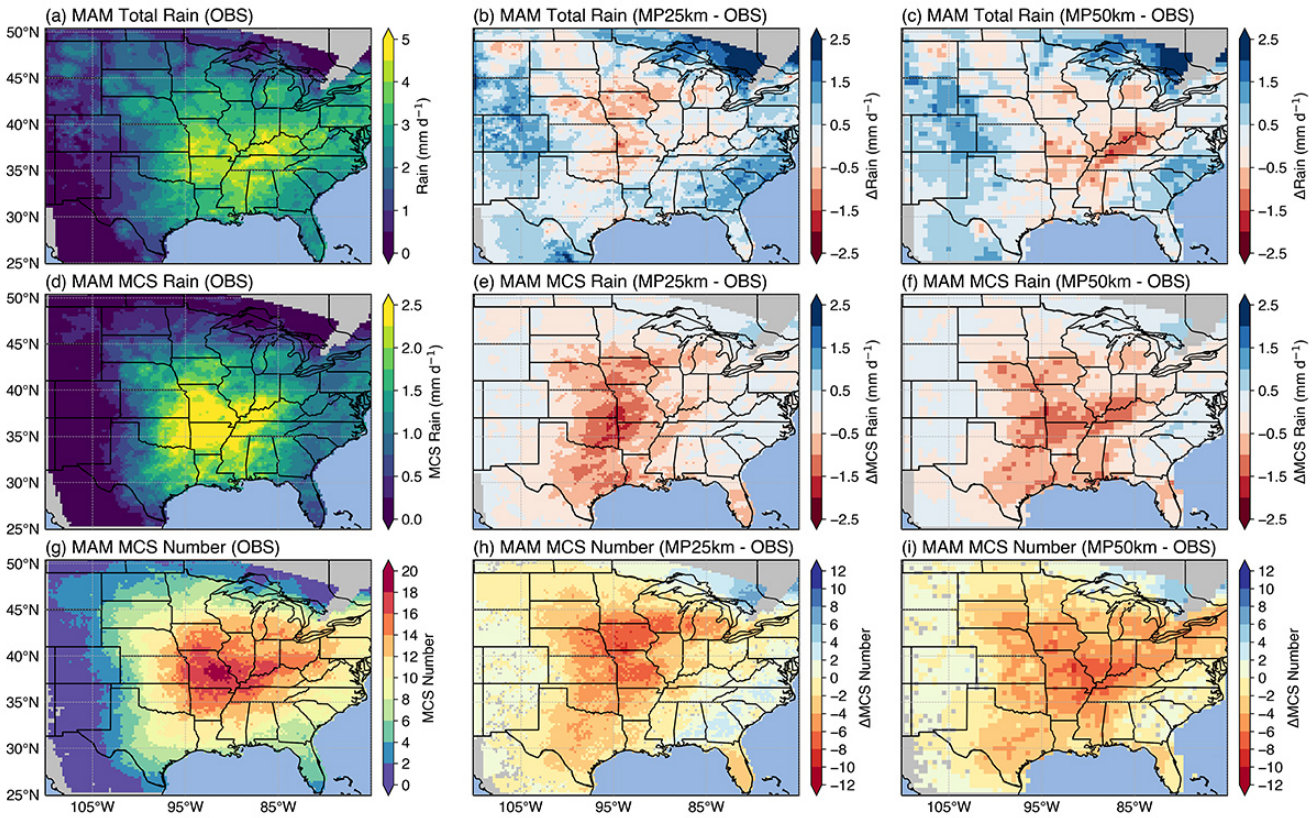

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Evaluate the CMIP6 marine stratocumulus cloud albedo using satellite and reanalysis data

*bida jian[1], Jiming Li[1]

1. Lanzhou University

Based on 12 years (2003–2014) of monthly data from multiple satellite and reanalysis data and eighteen Atmosphere Model Intercomparison Project (AMIP) simulations outputs of the Coupled Model Intercomparison Project Phase 6 (CMIP6), we evaluate the performance of current models in reproducing the marine stratocumulus cloud albedo, as well as examine the impact of different aerosol types and meteorological factors on cloud albedo in five marine stratocumulus regions. On the basis of predecessors' method, we calculate the long-term and monthly regional mean cloud albedo. It is found that the CMIP6/AMIP simulations agree with the observation well in both the monthly mean cloud albedo and correlation between albedo and cloud fraction, however, the new generation of models are not superior to CMIP5. Statistical results show that the temporal correlations between simulated and observed monthly cloud albedo are low (<0.30) for all models in all regions, even some correlations coefficients are negative. It indicates that the CMIP6/AMIP models are difficult to capture the cloud albedo changes. For the cloud albedo seasonal cycles, all the regions display obvious seasonal variations and single peak. And all the regions reach to peak value in winters. i.e., the cloud albedos reach to max in January and December months (NH), and June and July months (SH). It may links to the seasonal changes of aerososl loading, especially the biomass burning aerosols seasonal changes. The model ensemble mean (MEM) can captures the cloud albedo seasonal cycle well and the temporal correlations between simulated and observed cloud albedo seasonal cycles are highly positive in all regions (>0.6), except for the Canarian region, where the correlation is significant negative (-0.54).

Keywords: CMIP6, cloud albedo

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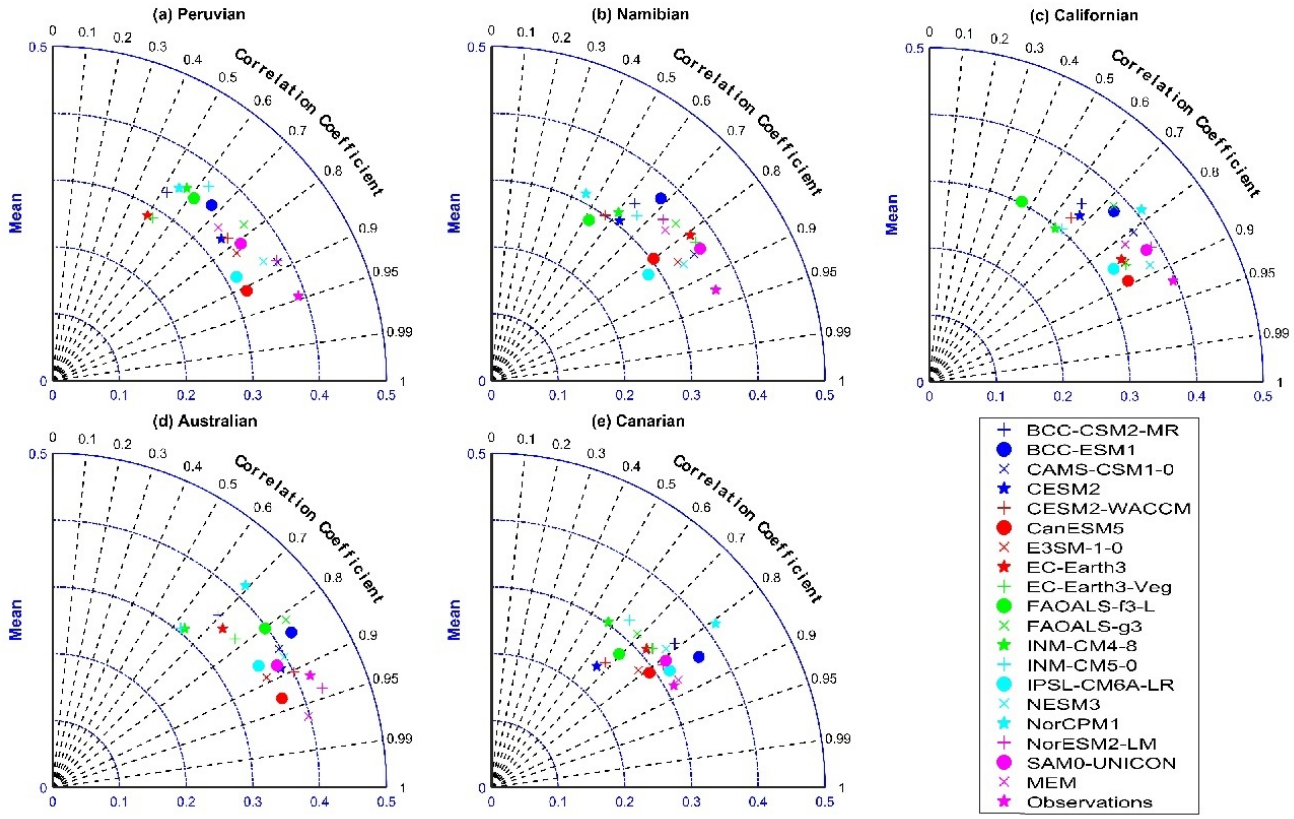

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Dependence of the reproducibility of the MJO convection on differences in the surface flux conditions in NICAM

*Tamaki Suematsu[1], Chihiro Kodama[2], Hisashi Yashiro[3], Tomoro Yanase[4], Hiroaki Miura[5], Tomoki Miyakawa[1], Masaki Satoh[1]

1. Atmosphere and Ocean Research Institute, The University of Tokyo, 2. Japan Agency for Marine-Earth Science and Technology, 3. National Institute for Environmental Studies, 4. Graduate School of Science, Kyoto University, 5. Graduate School of Science, The University of Tokyo

Simulation of the Madden-Julian Oscillation has been notoriously difficult in atmospheric models. Although it has been over a decade since the first realistic simulation of the Madden-Julian Oscillation has succeeded using the non-icosahedral atmospheric model (NICAM; Miura et al. 2007), reproducibility of the MJO remains highly sensitive to parameters that are often difficult to fix from observation or theory, and require empirical tuning based on model behaviors. Moreover, model settings fine-tuned for MJO simulations are not necessarily compatible with longer simulations due to biases in the long-term mean. Therefore, the selection of parameters that adequately simulate the MJO without undermining the long-term mean remains a challenging problem.
To address this problem, we conducted parameter sweep experiments on NICAM on parameters that regulate the surface latent heat fluxes, which in turn influence the development of convection. From the parameter sweep experiments, we selected parameter sets that best simulate the MJO case from December to January 2019, and investigated how the changes in the parameters influenced the month-long mean states. We found that while the best performing parameter sets for MJO simulation displayed overly high surface latent heat flux over the equatorial Pacific, it also mitigated the double ITCZ bias in the month-mean precipitation patterns.

Keywords: NICAM, Cloud Resolving Model, Madden-Julian Oscillation

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS06] Advances in Tropical Cyclone Research: Past, Present, and Future

convener:Yoshiaki Miyamoto(Faculty of Environment and Information Studies, Keio University), Sachie Kanada(Nagoya University), Akiyoshi Wada(Department of Typhoon and Severe Weather Research, Meteorological Research Institute), Kosuke Ito(University of the Ryukyus)

Tropical cyclones (TC) cause severe disasters in many countries by torrential rainfall and destructive winds. Strong TCs caused severe damages in many areas of Japan in this couple years; a record-breaking heavy rainfall occurred in western Japan due partly to Typhoon Prapirooon (2018), Kansai airport was forced to be closed by Typhoon Trami (2018), and Typhoon Faxai (2019) caused a long-term shut-down in Chiba prefecture. As the surface temperature of ocean, - the energy source of TC -, increases with global warming, TCs are expected to intensify in the future. Therefore, it is an urgent problem to obtain deeper understanding of mechanisms on TC intensity, structure, and motion, more accurate mid- to long-term projections of the TC parameters, and better forecast of TC. The TC researches are important for disaster prevention as well as the academic development, and hence do contribute to the future progress of earth and planetary science. In this session, we welcome papers on various aspects of TC studies. We hope that the session will provide a new direction for future TC researches.

[AAS06-01] Convective bursts with gravity waves in tropical cyclones: case study with the Himawari-8 satellite and idealized numerical study

★Invited Papers

*Takeshi Horinouchi[1], Udai Shimada[2], Akiyoshi Wada[2] (1.Faculty of Environmental Earth Science, Hokkaido University, 2.Meteorological Research Institute)

[AAS06-02] Inner-core wind field in a concentric eyewall replacement of Typhoon Trami (2018): A quantitative analysis based on the Himawari-8 satellite

*Satoki Tsujino[1], Takeshi Horinouchi[1], Taiga Tsukada[1], Hiroyuki Yamada[2], Kazuhisa Tsuboki[3] (1.Hokkaido University, 2.University of Ryukyus, 3.Nagoya University)

[AAS06-03] Future Changes in a Typhoon in the Midlatitude Regions: Downscaling simulations form d4PDF data by using a 4-km-mesh nonhydrostatic model

*Sachie Kanada[1], Kazuhisa Tsuboki[1], Izuru Takayabu[2] (1.Nagoya University, 2.Meteorological Research Institute)

[AAS06-04] A numerical and theoretical study of the cirrus banding accompanying tropical cyclones

*Kazuya Yamazaki[1], Hiroaki Miura[1] (1.Department of Earth and Planetary Science at the University of Tokyo)

[AAS06-05] Structural and Intensity Changes in simulated Typhoon 1915 before landfall

*Yoshiaki Miyamoto[1], Hironori Fudeyasu, Akiyoshi Wada (1.Faculty of Environment and Information Studies, Keio University)

Discussion

Convective bursts with gravity waves in tropical cyclones: case study with the Himawari-8 satellite and idealized numerical study

*Takeshi Horinouchi[1], Udai Shimada[2], Akiyoshi Wada[2]

1. Faculty of Environmental Earth Science, Hokkaido University, 2. Meteorological Research Institute

Convective bursts occur frequently in tropical cyclones and help their intensification by diabatic heating, but their quantitative importance has not been established. By using the high-frequency observation of infrared brightness temperature with Himawari-8, a latest-generation geostationary meteorological satellite, convective bursts in Typhoon Lan (2017) were studied. Aided with a series of numerical simulations, it was revealed that the anvil edges of many bursts are associated with finite-amplitude gravity waves consistent with internal bores, creating warm anomalies by subsidence ahead of the edges. As the edges spread, they are thinned, and their propagation speeds are often decreased. In many such instances, gravity waves, now linear, are separated from the edges to propagate away, spreading convective heating. It is proposed that by quantifying these processes with geostationary satellites, diabatic heating by convective bursts can be estimated to diagnose their impacts on tropical-cyclone intensification.

This work was recently published as:
Horinouchi, T., Shimada, U., & Wada, A. (2020). Convective bursts with gravity waves in tropical cyclones: case study with the Himawari-8 satellite and idealized numerical study. Geophysical Research Letters, 47, e2019GL086295. https://doi.org/10.1029/2019GL086295

Keywords: Tropical cyclone, Atmospheric gravity wave, Convective burst

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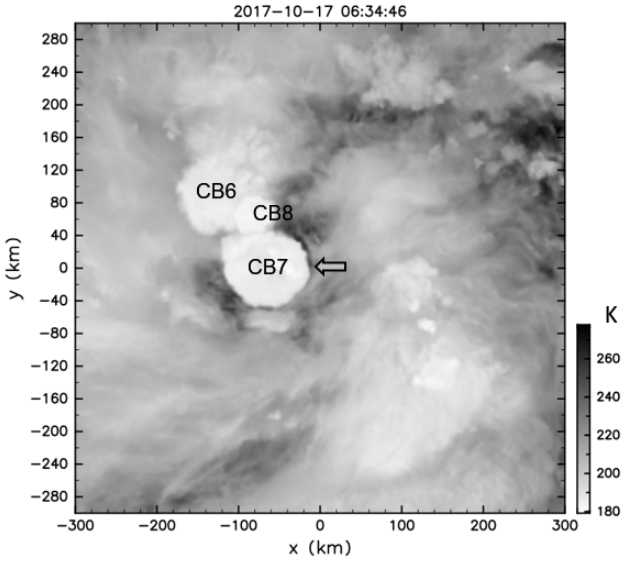
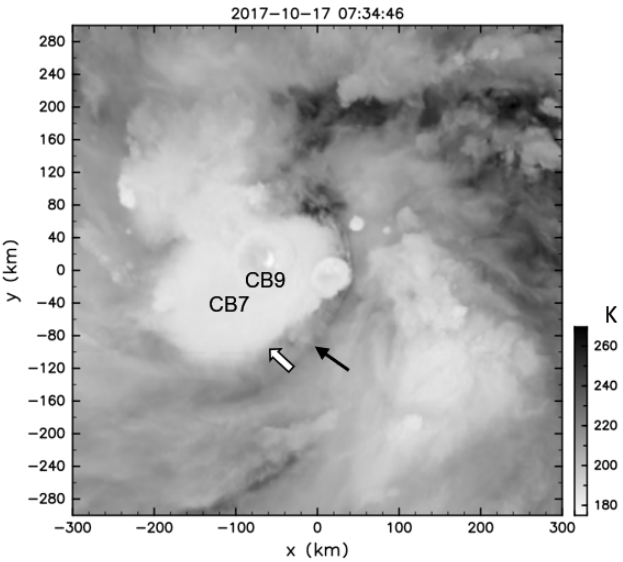


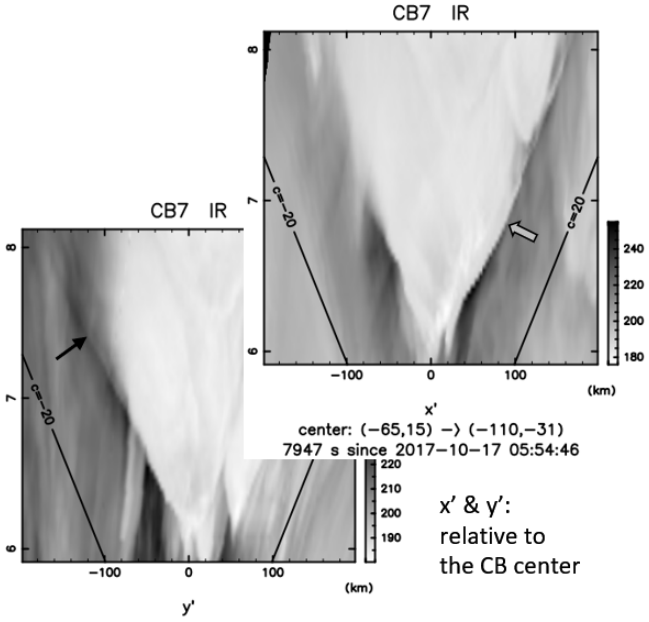
⇦ : sharp CB anvil edge fringed by brightness T increase by downward displacement of pre-existing upper cloud (tip of bore)



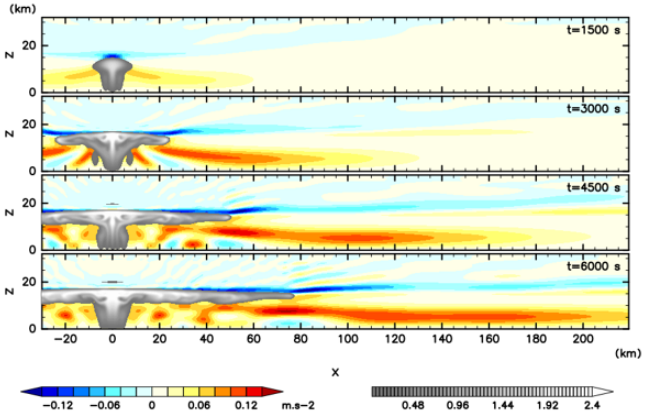
⇖ : obscured anvil edge

↖ : tip of gravity wave separated from the anvil edge

x & y: relative to the TC center (best track)



x' & y': relative to the CB center



buoyancy ∝ T anomaly

passive scalar ~ cloud

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Inner-core wind field in a concentric eyewall replacement of Typhoon Trami (2018): A quantitative analysis based on the Himawari-8 satellite

*Satoki Tsujino[1], Takeshi Horinouchi[1], Taiga Tsukada[1], Hiroyuki Yamada[2], Kazuhisa Tsuboki[3]

1. Hokkaido University, 2. University of Ryukyus, 3. Nagoya University

Strong tropical cyclones (TCs) often have concentric eyewalls (CEs), and experience eyewall replacement cycles (ERCs). Formation of the CE structure leads to increase in the storm size. The CE storm can drastically change the maximum wind and the radius of maximum wind speed within 24 h during an ERC. Dynamics of the CE formation and ERC are important for understanding and prediction of the intensity and size changes in the TCs. Inner-core wind field in the TCs is essential for understanding of the CE-formation and ERC dynamics. However, it is difficult to estimate the inner-core wind field associated with the CE formation and ERC because the strong TCs mostly move over open oceans with less instruments. Recently, a geostationary satellite of Himawari-8 was launched by the Japan Meteorological Agency. The satellite has a target observation for typhoons with high frequency (temporal interval of 2.5 min). Time series of imageries in the high-frequency observation allow us to trace each cloud. The present study conducts a quantitative analysis of the inner-core wind field in a typhoon with clear CE structure, based on the temporally high-resolution imageries in the target observation.

The present study focuses on Typhoon Trami (2018), which had a clear CE structure near the mature stage. After the secondary eyewall formation, the original inner eyewall in Trami gradually decayed. Evolution of the inner core is similar to an ERC event. We used data of brightness temperature (Tb) captured by an infrared band (Band 13) in the target observation of the Himawari-8. The quantitatively estimation of the wind field is based on a spectral analysis of time series for the Tb in azimuthal directions, which is similar to that in conventional estimation of zonal propagation speeds of tropical waves. At a certain radius from the typhoon center, the Tb on the physical space of azimuthal angle and time is transformed to the spectral space of wavenumber and frequency. Tangential wind speed at the cloud top is estimated as a function of radius based on the azimuthal phase speeds in wavenumbers and frequencies with high spectra in the Tb.

After formation of the CE structure, the maximum (~50 m s^{-1}) of the tangential wind speed is estimated in the inner edge (~30-km radius) of the eyewall cloud. Vertical component of relative vorticity derived by the estimated tangential wind has typical monopole structure with the vorticity peak at the center. During the decay of the inner eyewall, the maximum of the tangential wind speed rapidly decreased (~30 m s^{-1}), and the location of the maximum wind speed expanded to a radius of 100 km from the center. Moreover, the satellite-derived wind field is validated by dropsonde observations in a special field campaign. The tangential wind speed based on the satellite had difference of about 5 m s^{-1} with the dropsondes. In spite of the relatively small difference, the maximum wind speed of 50 m s^{-1} based on the satellite was quite similar to that in the dropsondes (~50 m s^{-1}) before the ERC.

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The results suggest that the high-frequency observation in the Himawari-8 is available to quantitatively estimate the inner-core wind field associated with the CE structure. Moreover, the estimated wind field and its time series might be helpful for understanding of the CE-formation and ERC dynamics.

Keywords: Typhoon, Meteorological satellite

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Future Changes in a Typhoon in the Midlatitude Regions: Downscaling simulations form d4PDF data by using a 4-km-mesh nonhydrostatic model

*Sachie Kanada[1], Kazuhisa Tsuboki[1], Izuru Takayabu[2]

1. Nagoya University, 2. Meteorological Research Institute

Future projection studies have recently shown that the tropical cyclone (TC) intensity in the higher latitude will increase in the future warmer climate. To understand the impact of global warming on TCs in the higher latitude, changes in a typhoon that travels over the sea to the east of Japan were investigated using an unprecedentedly large ensemble of climate simulations for current and 4K warming climates with a 60-km-mesh atmosphere global circulation model (d4PDF: Mizuta et al, 2017).

All the typhoons that hit eastern Hokkaido in northern Japan (142˚E–146˚E and 42˚N–46˚N) from the western North Pacific Ocean were selected as the targeted typhoons. In total, 98 and 125 typhoons were selected from the 3,000 years current and 5,400 years 4K warming climate runs. Then, the downscaling experiments on all the targeted typhoons were conducted using a high-resolution non-hydrostatic regional model, the Cloud Resolving Storm Simulator version 3.4 (CReSS; Tsuboki and Sakakibara 2002). CReSS considers the SST-cooling associated with the storm passage by a simple thermal diffusion model. The horizontal domain of the CReSS simulation covers 132˚E–155˚E and 25˚N–50˚N, and is discretized with a grid spacing of 0.04˚ by 0.04˚. The results in 136˚E–150˚E and 30˚N–46˚N were used for the analyses.

Mean minimum central pressure (MCP) in the analysis region decreased from 955 hPa to 945 hPa from current to the warming climates at the 95% confidence level based on Welch's t-test. The frequency of intense typhoon in the warming climate with a MCP not larger than 940 hPa increases nearly three times as much as that in the current climate. Furthermore, the future typhoons traveled northward at a slower translation speed than in the current climate. The results implied that the coastal regions of Japan will be exposed to a stronger typhoon to a longer period of precipitation in the future warmer climate. Downscaling experiments by CReSS indicate significant increases in mean precipitation and wind speed averaged within 200 km of the typhoon center by 30-40% and 10% from the current to warming climates, respectively. The large changes were seen around the storm center. Furthermore, much taller and stronger eyewall updrafts developed in the core-region of future typhoons, although little changes appeared in a radius of the maximum wind speed (RMW). In the current climate, the typhoon in the vicinity of Japan tended to decrease the storm height and increase RMW losing the axisymmetric structures as its traveled northward. In the warming climate, SST is projected to increase by 4˚C and the baroclinicity will decrease in the vicinity of Japan. The high SST and the reduction of baroclinicity allow the typhoon to remain the axisymmetric TC structure with tall and intense eyewall updrafts and led the significant increases in precipitation amount and wind speed around the center of the storm in the higher latitude regions.

Keywords: Future Changes in a Typhoon, Downscaling simulations, a 4-km-mesh nonhydrostatic model

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A numerical and theoretical study of the cirrus banding accompanying tropical cyclones

*Kazuya Yamazaki[1], Hiroaki Miura[1]

1. Department of Earth and Planetary Science at the University of Tokyo

Cirrus banding is defined as wave-like cirrus that typically form near a jet axis or an outflow region of tropical cyclones. Previous studies have suggested two possible mechanisms for the formation of the cirrus banding: the Kelvin-Helmholtz (KH) instability and the thermal-shear instability. However, the understandings of the cirrus banding is still limited because those previous works lacked observational evidences, quantitative evaluation of destabilization mechanisms, and stability analyses under a realistic basic state. To solve those issues, observational case studies, numerical experiments and a linear stability analysis were carried out.

Analyses of high-resolution radiosonde observations detected 27 cases of the cirrus banding. To increase the number of cases, those analyses targeted cirrus banding accompanying jet streams as well as tropical cyclones. The vertical profiles of all of the 27 cases shared a feature of a statically unstable layer within a cloudy layer in the upper troposphere. The vertical wind shear in the unstable layer was nearly parallel to the direction of the observed cloud bands, which is consistent with those emerging under the thermal-shear instability. The moist buoyancy frequency was close to zero, indicating that the moist processes were nonneligible even in the cold upper troposphere.

A cloud-system-resolving model, SCALE-RM, was used for simulating cirrus bands accompanying a tropical cyclone formed under an ideal condition. Roll-shaped convection cells were successfully generated inside cirrus banding on the outflow cirrus clouds. Statically unstable layers and vertical wind shear parallel to the banding clouds, found in the radiosonde observations, also appeared in this numerical experiment. An analysis of the heat budgets revealed that the radiative process heated the cloud bottom and cooled the cloud top by about 0.5 K/hour in the banding clouds. In a sensitivity experiment about the cloud-radiation interaction, where cloud optical properties were changed to be transparent to radiative processes, cirrus bands ceased to form within several hours. This result indicates that the radiative processes contribute to the formation and maintenance of cirrus bands, as suggested by previous studies.

A linear stability analysis was conducted to obtain growth rates of various modes under realistic basic states that were defined based on the radiosonde observations and the numerical experiments. The fastest growing mode was parallel to the vertical wind shear of the basic state and was vertically localized in the statically unstable layer, which was consistent with the radiosonde observations and the numerical experiments, and similar to the thermal-shear instability investigated by Asai (1970) in simpler basic states. The horizontal wavelength of the fastest-growing mode was 1 to 2 km, and this result can only explain the shortest portion of the wavelengths of the cirrus bands (1 km - 30 km) estimated from high-resolution polar-orbiting satellite images. The longer wavelength of the observed cirrus bands may be attributed to nonlinear effects.

Those results indicate that the cirrus banding consists of roll-shaped convection cells driven by the thermal-shear instability. This conclusion is consistent with recent modeling studies, and this study newly provides observational and theoretical evidences. Remaining issues include the following: establishing an objective method of the analyses of observational data, additional numerical sensitivity experiments on the intensity of the shortwave incidence and the microphysics parameterization, and a verification of nonlinear effects on the growth of the wavelength of the cirrus banding.

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Keywords: Cirrus banding, Tropical cyclone

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Structural and Intensity Changes in simulated Typhoon 1915 before landfall

*Yoshiaki Miyamoto[1], Hironori Fudeyasu, Akiyoshi Wada

1. Faculty of Environment and Information Studies, Keio University

The energy source of tropical cyclone (TC) is underlying ocean and hence low sea-surface temperature in mid-latitudes is unfavorable for TCs. In addition, because of temperature gradient in the meridional direction, wind speed in the zonal direction is fast and vertical wind shear (VWS) is strong. VWS tends to weaken TC intensity. As a result, TCs in general weaken when they go to mid-latitudes, while some can re-intensify as a mid-latitudinal cyclone.

However, because of the increasing trend of SST over the globe due to global warming, the probability of strong TCs is also increasing in mid-latitudes. Typhoon Faxai (2019) made landfall at Tokyo area and caused severe damage in Boso peninsula. The intensity of Faxai at landfall was 955 hPa, which is the peak intensity of Faxai and is the strongest intensity out of typhoons that have made landfall around Kanto area.

We examine physical processes to change the intensity and structure of Faxai by conducting a numerical simulation, in order to explore the reason why the TC can sustain such a strong intensity until its landfall.

Keywords: Typhoon structure

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS06] Advances in Tropical Cyclone Research: Past, Present, and Future

convener:Yoshiaki Miyamoto(Faculty of Environment and Information Studies, Keio University), Sachie Kanada(Nagoya University), Akiyoshi Wada(Department of Typhoon and Severe Weather Research, Meteorological Research Institute), Kosuke Ito(University of the Ryukyus)

Tropical cyclones (TC) cause severe disasters in many countries by torrential rainfall and destructive winds. Strong TCs caused severe damages in many areas of Japan in this couple years; a record-breaking heavy rainfall occurred in western Japan due partly to Typhoon Prapirooon (2018), Kansai airport was forced to be closed by Typhoon Trami (2018), and Typhoon Faxai (2019) caused a long-term shut-down in Chiba prefecture. As the surface temperature of ocean, - the energy source of TC -, increases with global warming, TCs are expected to intensify in the future. Therefore, it is an urgent problem to obtain deeper understanding of mechanisms on TC intensity, structure, and motion, more accurate mid- to long-term projections of the TC parameters, and better forecast of TC. The TC researches are important for disaster prevention as well as the academic development, and hence do contribute to the future progress of earth and planetary science. In this session, we welcome papers on various aspects of TC studies. We hope that the session will provide a new direction for future TC researches.

[AAS06-06] **Modeling Contribution of Sea Spray in Air-Sea Enthalpy and Momentum Exchange Coefficients in Rapidly Intensifying Tropical Cyclones**

★Invited Papers

*Alexander Soloviev[1], Breanna Vanderplow[1], Roger Lukas[2] (1.Nova Southeastern University, 2.University of Hawaii at Manoa)

[AAS06-07] A Super Best Track Data Set for Tropical Cyclone Studies

★Invited Papers

*Michael Fiorino[1] (1.AORI, University of Tokyo)

[AAS06-08] Direct Multi-class AUC Maximization for Forecasting Rapidly Intensifying Tropical Cyclones

*Hirotaka Hachiya[1,2], Shumpei Kurora[2], Udai Shimada[3], Naonori Ueda[1] (1.Center for Advanced Intelligence Project, RIKEN, 2.Graduate School of Systems Engineering, Wakayama University, 3.Meteorological Research Institute, Japan Meteorological Agency)

[AAS06-09] Warm ocean conditions and increased typhoon intensity in 2019

*Akiyoshi Wada[1] (1.Department of Typhoon and Severe Weather Research, Meteorological Research Institute)

[AAS06-10] Simulated atmosphere-ocean-biogeochemical interaction under the passage of tropical cyclone Trami (2018)

*Kosuke Ito[1], Jaedeok Lee[1], Takahiro Toyoda[2], Kei Sakamoto[2] (1.University of the Ryukyus, 2.Meteorological Research Institute)

[AAS06-11] Binary Tropical Cyclones in a Three-Dimensional Idealized Framework

Jaedeok Lee[1], *Kosuke Ito[1], Johnny Chan[2] (1.University of the Ryukyus, 2.City University of Hong Kong)

Modeling Contribution of Sea Spray in Air-Sea Enthalpy and Momentum Exchange Coefficients in Rapidly Intensifying Tropical Cyclones

*Alexander Soloviev[1], Breanna Vanderplow[1], Roger Lukas[2]

1. Nova Southeastern University, 2. University of Hawaii at Manoa

Tropical storm intensity prediction remains a challenge in tropical meteorology. Some tropical storms undergo dramatic rapid intensification, such as Hurricane Maria 2017, which intensified to a Category 5 storm within 24 hours and destroyed Puerto Rico. The official forecast and all computer models were unable to predict its rapid intensification. Hurricane Dorian in 2019 was predicted as a tropical storm; unpredictably, it intensified into a Category 5 storm and devastated the Bahamas. The tropical cyclone forecast substantially depends on computer power, environmental information, and the physics incorporated in the model. Even though computer power increased significantly during the last 40 years, and the available environmental information is now much better, there has only been a little to no improvement in the tropical cyclone rapid intensification prediction. A likely explanation is that the physics of tropical cyclones, especially momentum and energy fluxes between the ocean and atmosphere and the role of the air-sea interface in this process, have not been properly incorporated in forecast models. The computational and laboratory experiments by Soloviev et al. (2017) suggest that there is an “aerodynamic drag well” around a 60 m/s wind speed, which could explain the process of rapid storm intensification under the assumption of a constant enthalpy exchange coefficient. The enthalpy exchange coefficient is influenced by sea spray. Questions regarding the appropriate method for the incorporation of sea spray in tropical cyclone models still exist (Peng and Richter 2019). Due to the spray feedback effect, sub-micrometer and micrometer scale sea spray particles, which have relatively large residence time, may contribute significantly contribute to the air-sea flux of enthalpy in tropical cyclones. The total mass of these small spray particles is also too small to influence the momentum exchange and drag coefficient. Larger sea spray particles (spume) are not subject to the substantial feedback effect due to a shorter residence time. In addition, spume has a much larger mass and can take a part of the airflow momentum to accelerate the spray particles to the speed of the airflow, which may noticeably increase the air-sea drag coefficient under major tropical cyclones. In order to study the effect of spume on the thermodynamics of tropical cyclones, we have implemented a Volume of Fluid to Discrete-Phase Model (VOF to DPM). This model re-meshes the areas with increased curvature, which are suspicious for the interface instability. The generated water particles that satisfy the condition of asphericity are converted into Lagrangian particles, which are involved in a two-way interaction with the airflow. Spray size distributions measured in air-sea interaction facilities are used for model verification. Due to dynamic remeshing, VOF to DPM resolves spray particles ranging in size from tens of micrometers to a few millimeters, which corresponds to spume. The VOF to DPM model also incorporates the effect of surfactants. The inclusion of surfactants increases the overall amount of spume particles under tropical cyclone conditions. Results of the numerical simulation show a dramatic increase of spume generation under major tropical cyclones. Though sub-micrometer and micrometer scale spray particles are not resolved in this simulation, they are less significant in the enthalpy and momentum exchange at the air-sea interface than spume. These results are expected to contribute to the parameterization and proper treatment of spray in forecasting models, including cases of rapid intensification.

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Soloviev, A. V., R. Lukas, M. A. Donelan, B. K. Haus, I. Ginis, 2017. Is the state of the air-sea interface a factor in rapid intensification and rapid decline of tropical cyclones? *Journal of Geophysical Research: Oceans* 122, 10174-10183.

Keywords: tropical cyclone, rapid intensification, sea spray, sea surface

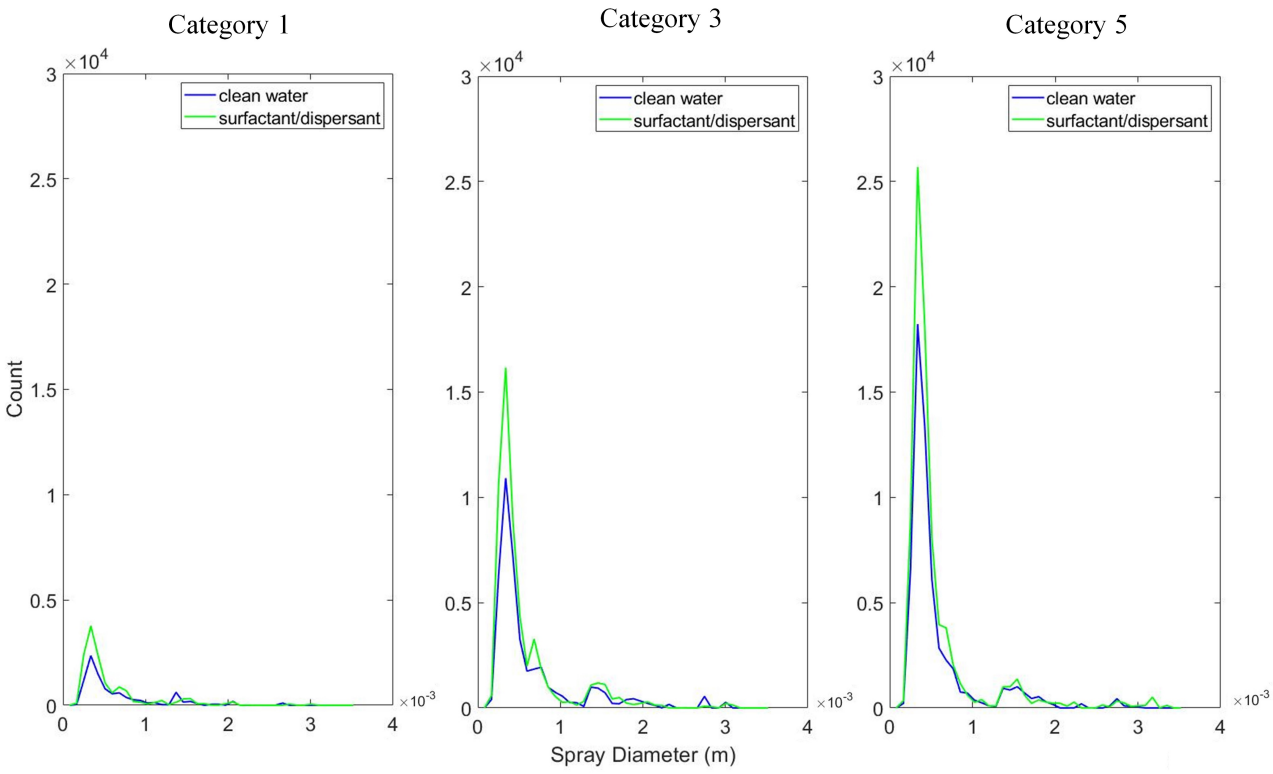

Figure 1. Spray (spume) size distribution under tropical cyclone conditions.

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A Super Best Track Data Set for Tropical Cyclone Studies

*Michael Fiorino[1]

1. AORI, University of Tokyo

Deterministic track forecasts have become so accurate in the medium range (e.g., the mean 72-h position error of the global models is now *below* predictability ‘limits’) that long-term tropical cyclone (TC) studies and forecasting can move in new directions with different emphases. For forecasting two new directions are:

1) a more explicit (and better) prediction of the surface wind field (e.g., intensity and the wind radii); and
2) ‘completing the forecast’ with predictions of genesis (and dissipation).

For climate studies, the availability of high-resolution global reanalysis will allow a more in-depth examination of the relationship between TC activity and the tropical general circulation.

Current best track data sets have several deficiencies for both forecasting and climate research; specifically, they lack:

1) observational analyses of the surface wind field (e.g., the NOAA Multiplatform Satellite Surface Wind Analysis) and precipitation
2) position data in the pre/potential TC (pTC) genesis stage
3) a ‘diagnostic file,’ with environmental variables known to be related to intensity change, derived from high-quality and consistent global (re)analyses/forecasts (e.g., vertical wind shear)
4) track forecasts for both pTCs and TCs that include TC structure, e.g., pressure/radius of the outermost closed isobar

The foundation of the super best track (SBT) is the ‘final’ best tracks of the two US operational forecast centers –the Joint Typhoon Warning Center (JTWC) and the National Hurricane Center (NHC). The SBT is thus global and unique in three important ways by including:

1) pTC tracks taken from a curated archive of *all* (both ‘numbered’ and INVEST or 9X systems) working best track data from JTWC/NHC since 2007
2) dynamical environmental variables (analysis and forecasts) come the latest/greatest ECMWF reanalysis –ERA5 –that has the same resolution as the NWP global models circa 2015
3) satellite precipitation analyses

The initial version of the SBT covers a 13-year period 2007-2019 and after a short summary of SBT properties, the talk gives one application example for TC genesis. Version 2.0 will include the entire ERA5 period 1979-2020.

Keywords: TC forecasting, reanalysis, TC activity, TC genesis

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Direct Multi-class AUC Maximization for Forecasting Rapidly Intensifying Tropical Cyclones

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Intense tropical cyclones (TCs) have caused tremendous damage to human society. Most intense TCs experience rapid intensification (RI, Kaplan and DeMaria 2003). To predict TC intensification, the Statistical Hurricane Intensity Prediction System (SHIPS; DeMaria et al., 2005) has been developed and run in operational centers. SHIPS utilizes a multivariate regression model that predicts future intensity changes, i.e., the central pressure and maximum wind speed, for each time-window with predictors calculated from numerical models and observations.
Although SHIPS has been improved with lots of efforts (Shimada et al., 2018, DeMaria et al., 2014), it is essentially difficult to predict RI since the number of RI training samples is very small (~5%). More technically, in the training of regression models with imbalanced data, e.g., between rapid and moderate intensifications, the contribution of minor events, i.e., RI, would be vanished in the squared or absolute error due to the dominance of the majority events, i.e., moderate intensification.
To tackle such imbalanced problems in the TC forecast, we propose to formulate it as a classification problem where the time-window is classified into five future intensity levels, i.e., rapid weakening, moderate weakening, neutral, moderate intensification and RI. The direct maximization of Area Under Curve (AUC; Ueda and Fujino, 2018) is known to be a theoretically grounded approach to the imbalanced classification problem. Since AUC is the sum of true positive rates, to maximize AUC, the positive class, e.g., RI, has to be selected correctly. To apply the direct AUC maximization to the multiple intensity-level-classification, we originally introduce a multi-class variant of AUC, called “One-versus-the-Rest-AUC, ORAUC) where at each class, the class is treated as “positive” and the rest as “negative” to compute true-positive rates.
We show the effectiveness of our proposed method, ORAUC, through the forecast of five-intensity-level of TCs using the sequences of 48-hour-window-SHIPS-feature generated from TCs occurred between 1987 and 2017. We split the window-based data into the training (1987-2010), validation (2011-2013), and evaluation (2014-2017) data. The label of each window is annotated based on the thresholds of the change of central pressure in 48-hour; thresholds are statistically determined as 5-, 25-, 75- and 95-percentiles of data (see the top-left of Fig.).
We compare three methods: SHIPS (linear regression), neural network with cross-entropy loss (CE), and neural network with ORAUC (proposed method). The figure depicts the distribution of central pressure changes, the overview of the entire flow of our proposed method, and the experimental evaluation. As for the evaluation metric, we use precision and recall for each class and mean F1 score over classes. As the table (see the bottom-right of Fig.) shows, our proposed method improves the recall (true positive rates) for the class of rapid weakening and intensification where there are only 5% of data since the AUC of each class is maximized. Above all, our proposed method obtains the best mean F1 score over classes, indicating that our proposed method, ORAUC, could improve the performance of RI prediction by handling the imbalanced data problem well.

Keywords: Intense tropical cyclones , intensity classification, AUC maximization

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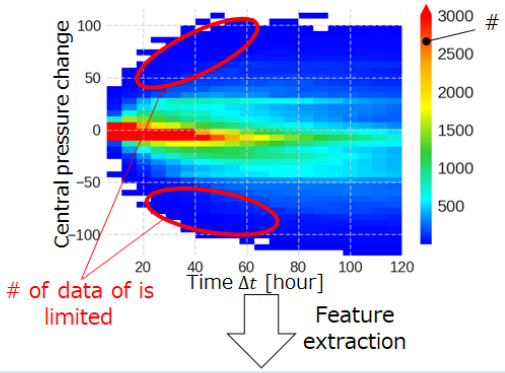
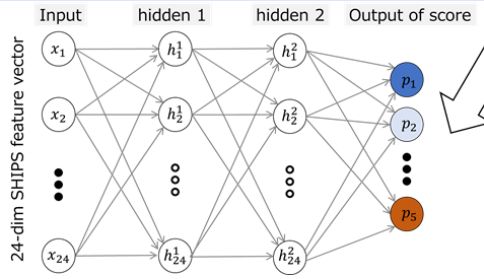
Distribution of central pressure change, 1987-2017



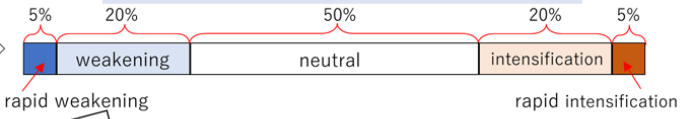
Feature extraction

Training neural network with data 1987-2011



Stats

Label annotation based on percentiles



Maximizing AUC

Evaluation with data 2014-2017

Precision/recall for each class

	Rapid weakening	weakening	neutral	intensification	Rapid intensification	Mean F1
SHIPS	0.70/0.63	0.63/0.62	0.69/0.71	0.43/0.40	0.20/0.22	0.52
CE	0.78/0.65	0.65/0.69	0.69/0.80	0.47/0.37	0.40/0.02	0.52
ORAUC	0.57/0.89	0.61/0.65	0.78/0.62	0.42/0.43	0.29/0.62	**0.57**

Recall (true positive rate) is improved for the class with minor data by proposed method, ORAUC

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Warm ocean conditions and increased typhoon intensity in 2019

*Akiyoshi Wada[1]

1. Department of Typhoon and Severe Weather Research, Meteorological Research Institute

It is sometimes pointed out that the increase in the upper-ocean temperature, particularly sea surface temperature, is one of the factors that cause stronger landfalling typhoons such as FAXAI and HAGIBIS in 2019.Since these landfalling typhoons cause serious disasters, it is necessary to explore the effects of increases in the upper-ocean temperature on the typhoons. First, an empirical orthogonal function (EOF) analysis method was applied for tropical cyclone thermal potential (TCHP) data from 1982 to 2019 to investigate upper ocean temperature variations. From the EOF analysis, we can find the correlation map that TCHP increased in almost all areas in the North Pacific as the second mode, while the first mode shows the variation corresponding to the El Nino-Southern Oscillation. In 2019, we find that the second mode is dominant. In order to investigate the impact of the increase in the upper-ocean temperature on typhoons in 2019, numerical simulations were conducted for Typhoons FAXAI and HAGIBIS with a nonhydrostatic atmosphere model and the atmosphere-wave-ocean coupled model, and with two different oceanic initial conditions. One oceanic initial condition is the average from 1982 to 2019, while the other is the daily operational oceanic analysis data in the Japan Meteorological Agency. The simulation results show that the difference in track predictions between the four simulations was very small although all simulated tracks showed the westward errors. However, the simulated central pressures and the simulated maximum wind speeds show that the simulated typhoon intensity became weak when both the coupled model and the average from 1982 to 2019 were used. In some experiments, there was no systematic difference between the four experiments as to the accumulated precipitation distribution over the Japanese archipelago. Therefore, the effect of the increase in the upper-ocean temperature on landfalling typhoons can be found only in the intensity.

Keywords: Typhoon, TCHP, Numerical simulation

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Simulated atmosphere-ocean-biogeochemical interaction under the passage of tropical cyclone Trami (2018)

*Kosuke Ito[1], Jaedeok Lee[1], Takahiro Toyoda[2], Kei Sakamoto[2]

1. University of the Ryukyus, 2. Meteorological Research Institute

In the subtropical ocean, tropical cyclones (TCs) play an important role on oceanic ecosystem because nutrients that limit the activity of phytoplanktons are sometimes mixed up to the ocean surface due to the strong wind forcing. However, it is also known that the accurate reproduction of a TC structure and intensity requires a high-resolution atmosphere-ocean coupled model. To aim at the accurate reproduction, a coupled atmosphere-ocean-biogeochemical model has been developed. The system consists of the JMA-NHM, MRI.COM mesh and a NPZD model as a high-resolution atmospheric, oceanic, and biogeochemical component, respectively. As a first trial of the coupled system, an observed enhancement of the primary production after the passage of TC Trami (2018) was simulated. The simulated results indicate that TC intensity is better reproduced in the coupled system. The NO3 rapidly increases to the passage of TC Trami in the mixed layer through the supply from the subsurface water. In contrast, the densities of phytoplankton and zooplankton firstly decreased just beneath the TC Trami (2018) presumably due to the shortage of the sunlight under TC-related clouds. However, their densities become about ten times in the next few days following the abundant NO3 and sufficient short wave radiation. The simulated increase of the density of phytoplankton is comparable to the satellite-based estimate of the phytoplankton at the ocean surface. The reasonable reproduction suggests the possibility of forecasting the enhancement of the ecosystem activity and may help the understanding of the relationship among atmosphere, ocean, and biogeochemical systems when a TC moves over the subtropical ocean.

Keywords: tropical cyclone, plankton bloom

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Binary Tropical Cyclones in a Three-Dimensional Idealized Framework

Jaedeok Lee[1], *Kosuke Ito[1], Johnny Chan[2]

1. University of the Ryukyus, 2. City University of Hong Kong

In the real atmosphere, the interaction of binary tropical cyclones (TCs), generally referred to as the *Fujiwara effect*, can causes large uncertainties of TC forecasts, particularly on the track. These binary TCs could have much complex interaction depending on the environment, TC size, or separation distance. For a better understanding of the binary TCs, we have carried out several numerical simulations with the structure adjustable balanced vortex in the three-dimensional idealized framework. As consistent with many previous studies, the simulated binary TCs show a high-dependency on separation distances. From the potential vorticity (PV) tendency, the results show many interesting features. First of all, the maximum-positive PV anomaly (advection+diabatic heating) area is typically consistent with the subsequent TC movement. This maximum-positive PV area may be useful to diagnose the subsequent movement of binary TCs. Second, the vertical wind shear induced by binary TCs, e.g., TC’s outflow, can cause asymmetry of the diabatic heating profile. Perhaps, this asymmetric diabatic heating could be regarded as a “*three-dimensional Fujiwhara effect*”.

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS06] Advances in Tropical Cyclone Research: Past, Present, and Future

convener:Yoshiaki Miyamoto(Faculty of Environment and Information Studies, Keio University), Sachie Kanada(Nagoya University), Akiyoshi Wada(Department of Typhoon and Severe Weather Research, Meteorological Research Institute), Kosuke Ito(University of the Ryukyus)

Tropical cyclones (TC) cause severe disasters in many countries by torrential rainfall and destructive winds. Strong TCs caused severe damages in many areas of Japan in this couple years; a record-breaking heavy rainfall occurred in western Japan due partly to Typhoon Prapirooon (2018), Kansai airport was forced to be closed by Typhoon Trami (2018), and Typhoon Faxai (2019) caused a long-term shut-down in Chiba prefecture. As the surface temperature of ocean, - the energy source of TC -, increases with global warming, TCs are expected to intensify in the future. Therefore, it is an urgent problem to obtain deeper understanding of mechanisms on TC intensity, structure, and motion, more accurate mid- to long-term projections of the TC parameters, and better forecast of TC. The TC researches are important for disaster prevention as well as the academic development, and hence do contribute to the future progress of earth and planetary science. In this session, we welcome papers on various aspects of TC studies. We hope that the session will provide a new direction for future TC researches.

[AAS06-13] Tropical cyclone activity in South China Sea and the link with ENSO events

*Chun Lei Liu[1] (1.Guangdong Ocean University)

[AAS06-14] **A comprehensive analysis of North Indian Ocean cyclonic activity and rainfall contribution over India during current and pre-warming climate**

*KASTURI SINGH[1], JAGABANDHU PANDA[1] (1.National Institute of Technology Rourkela, Odisha, India)

[AAS06-17] **Ageostrophic Winds Associated with a Tropical Cyclone and Northward Moisture Fluxes**

*Kazuo Saito[1,2,3], Takumi Matsunobu[4] (1.Atmosphere and Ocean Research Institute, the University of Tokyo, 2.Meteorological Research Institute, Japan Meteorological Agency, 3.Japan Meteorological Business Support Center, 4.University of Tsukuba)

Tropical cyclone activity in South China Sea and the link with ENSO events

*Chun Lei Liu[1]

1. Guangdong Ocean University

The occurrence and development of tropical cyclones (TC) in South China Sea over last 50 years have been investigated, and the links with ENSO events have been studied. The occurrence frequency of TCs varies with the ENSO index, and there is a positive correlation before 2007 with the ENSO index leading TC frequency about 6 months, and an anti-phase correlation after 2007. The mechanism behind these relations has been studied by investigating the sea surface temperature and ocean heat content variations.

Keywords: Tropical cyclone, South China Sea, ENSO

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A comprehensive analysis of North Indian Ocean cyclonic activity and rainfall contribution over India during current and pre-warming climate

*KASTURI SINGH[1], JAGABANDHU PANDA[1]

1. National Institute of Technology Rourkela, Odisha, India

This work provides an overview on climatology of cyclonic disturbances (CDs) and associated rainfall, with primary emphasis to North Indian Ocean (NIO). For this purpose, TC best track data provided by India Meteorological Department (IMD) over NIO region and rainfall product from IMD, several parameters like sea surface temperature (SST), air temperature (AT), surface level relative humidity (RH), mid-troposphere relative humidity (RH500), surface level wind (SW), evaporation factor from International Comprehensive Ocean-Atmosphere Data Set (ICOADS), NOAA CIRES, and Hadley centre considered. Robustness analysis of the best track data indicates that there is improvement over the years in terms of quality and availability over NIO. The determination of location and proper track of the CDs over NIO has improved during satellite era and the frequency of looping, southward moving, recurving CDs increased.

Based on annual SST anomaly variation, the period of study is divided into pre-warming (PWP; during 1880–1946) and current warming (CWP; 1947 onwards) with negative and positive anomalies respectively. A decreasing trend observed in total storms, cyclones and severe cyclones frequency during CWP for NIO region. CD activity over southern and northern BOB is decreasing sharply during CWP. Southern sector of BOB hosts mostly severe systems and middle sector most tropical cyclones. CD activity over the eastern sector of AS shows considerable enhancement during CWP. An increasing SST, SW, RH500 and potential evaporation factor are helpful in the formation of intensified storms during CWP. The activities during PWP were reverse compared to that of CWP. A large temperature anomaly difference between atmosphere and ocean also perceived to play a key role in modulating the enhanced intensity of CDs during CWP.

The impact of warming climate on landfall activity reveals that Bangladesh (BD), Andhra Pradesh (AP), and Tamil Nadu (TN) are more vulnerable to severe cyclones formed over BOB during the CWP. Among western coastal states, Gujrat (GJ) is prone to severe cyclones and Arabian Peninsula countries are vulnerable to cyclonic storms formed over the AS during the current warming climate as well. During CWP, BD and Myanmar are more vulnerable to CD landfall in pre-monsoon season, whereas in post-monsoon months, AP, TN and BD are more prone coastal areas of BOB. Gujrat is more vulnerable coastal area of AS. The enhanced genesis over southern and middle sector of BOB is mainly responsible for more landfall over AP, TN and BD. Changes in wind direction and increased meridional SST over BOB found to be encouraging the landfall activity near AP and TN coasts. The W-SW wind and zonally distributed SST supports landfall over Gujrat.
The rainfall rate associated with CDs (CDR) found to be increasing during post-monsoon season with a decreasing CD frequency both in PWP and CWP scenario (refer to the figure). During pre-monsoon, the CDR was increasing with CD frequency during both the epochs considered. Mostly eastern Indian states experienced heavy rainfall contribution by CDs during PWP. During CWP, the accumulated rainfall is higher over eastern and western coastal states during pre-monsoon and during post-monsoon season. Among eastern coastal states, the accumulated rainfall is higher over AP, TN, Odisha (OD) and southern West Bengal (WB) during both the seasons of PWP and CWP. Among western coastal states, Gujarat (GJ),

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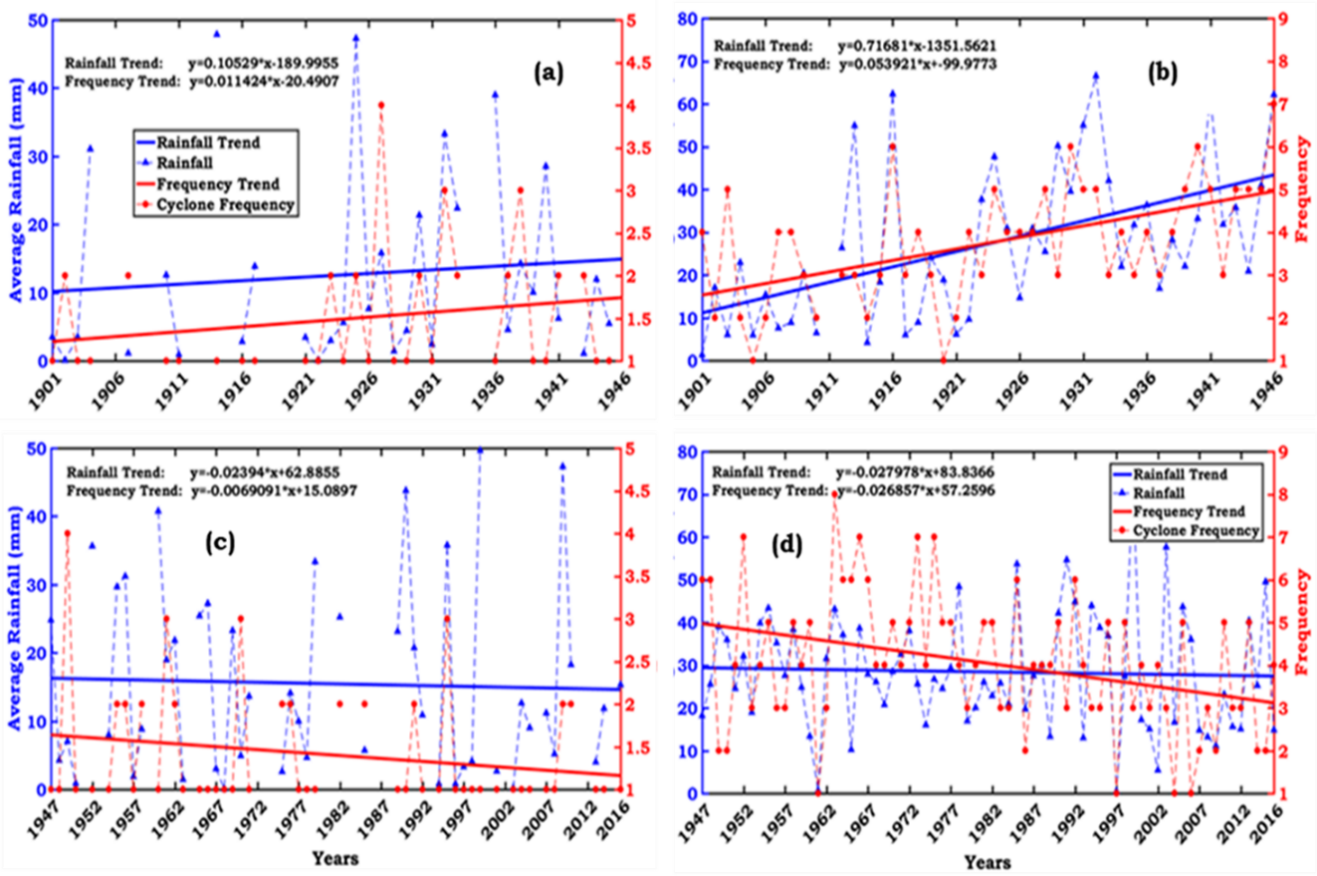
Karnataka (KA) and Kerala (KL) suffer maximum rainfall from CDs for the considered scenario. The overall rainfall contribution by CDs is observed to have a decreasing trend during both seasons of CWP and PWP. Owning to the stable rainfall trend along with decreasing CD frequency during post-monsoon season, the results indicate an increased amount of rainfall by CDs during CWP and PWP.

Keywords: North Indian Ocean, Cyclonic Disturbances, Warming Climate, Rainfall



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Ageostrophic Winds Associated with a Tropical Cyclone and Northward Moisture Fluxes

*Kazuo Saito[1,2,3], Takumi Matsunobu[4]

1. Atmosphere and Ocean Research Institute, the University of Tokyo, 2. Meteorological Research Institute, Japan Meteorological Agency, 3. Japan Meteorological Business Support Center, 4. University of Tsukuba

In Japan, heavy rainfalls often occur when a typhoon exists off the south coast of Japan. This phenomenon is often explained by northward moisture transport by a typhoon, however, ‘northward’ emission from a typhoon violates the relationship of geostrophic wind. These pre-typhoon rainfalls are also known in other countries and called as ‘PRE’, which is enhanced by deep poleward moisture transport ahead of the recurving TC. Saito (2019) examined the origin of the northward winds and explained that the ageostrophic winds are dynamically induced by the acceleration vectors.
In this presentation, based on the numerical experiment by Saito (2019), we show vertical profiles of ageostrophic winds and the associated northward moisture fluxes over a region off the south coast of western Japan.

References:
Saito, K., 2019: On the northward ageostrophic winds associated with a tropical cyclone. *SOLA*, **15**, 222-227.

Keywords: Tropcal Cyclone, Ageostrophic wind, pre-typhoon rainfalls (PRE), moisture flux

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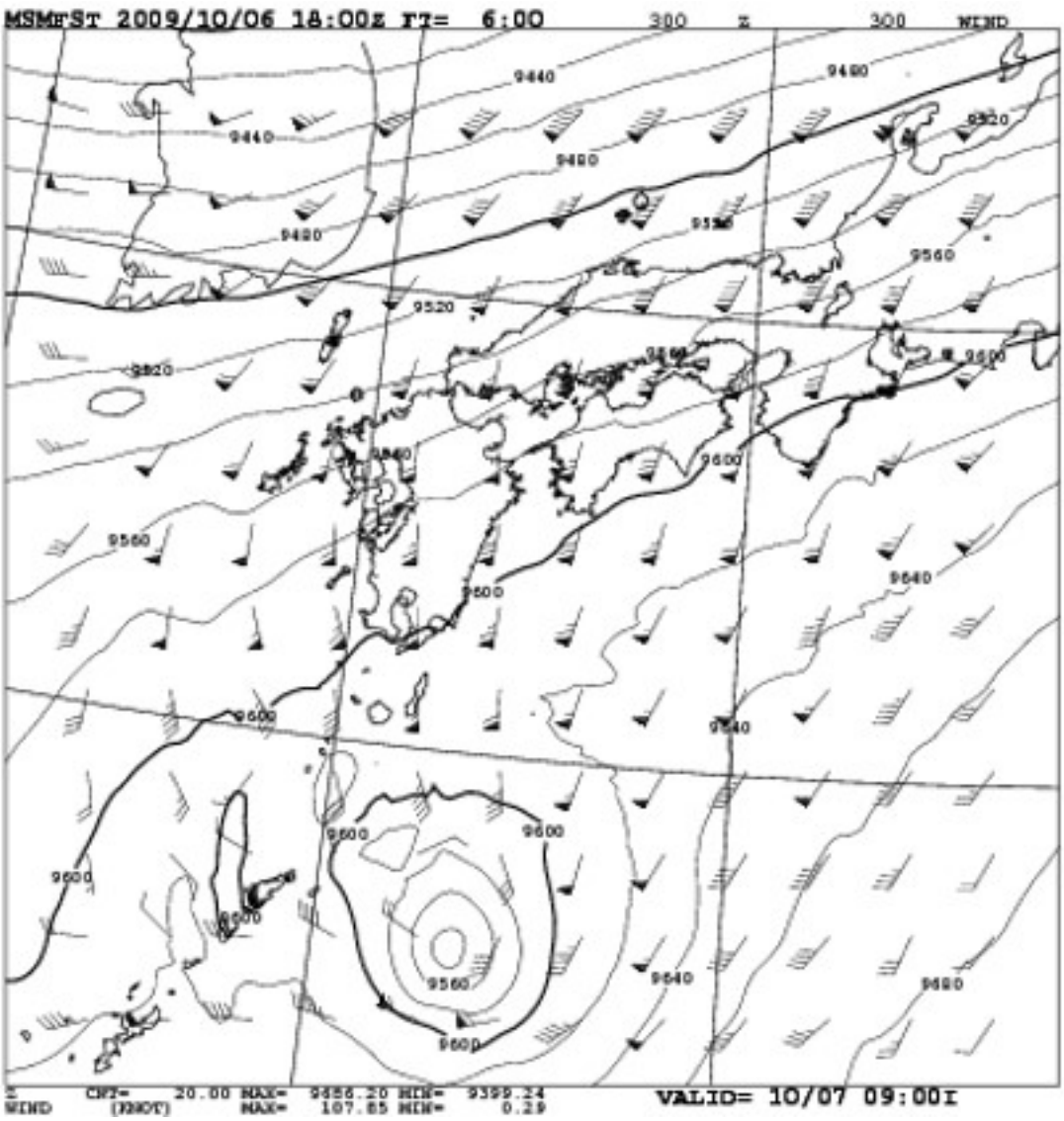

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS07] Atmospheric Chemistry

convener:Naoko Saitoh(Center for Environmental Remote Sensing), Tomoki Nakayama(Graduate School of Fisheries and Environmental Sciences, Nagasaki University), Sakae Toyoda(Department of Chemical Science and Engineering, Tokyo Institute of Technology), Risa Uchida(Japan Automobile Research Institute)

This session provides a forum for the presentation of the broad spectrum of tropospheric and stratospheric chemistry, including various research topics (e.g., dynamical processes, air quality and climate), approaches (modeling, field measurements, remote sensing, and laboratory studies), and species (gas and aerosol). This session also provides an opportunity for discussing possible future collaboration with other research fields relevant to atmospheric chemistry.

[AAS07-01] Recent research trends in airborne microplastics (AMPs)

★Invited Papers

*Hiroshi Okochi[1], Norihisa Yoshida[1], Somei Yanagitani[1], Yasuhiro Niida[2], Naoki Umezawa[2], Yohei Itaya[3], Hiroko Ogata[3], Naoya Katsumi[4], Hideshige Takada[5] (1.School of Science and Engineering, Waseda University,, 2.PerkinElmer Japan, 3.Shibata Scientific Technology LTD,, 4.Ishikawa Prefectural University, 5.Tokyo University of Agriculture and Technology)

[AAS07-03] Analysis of sources of carbon monoxide at Tsukuba with observed vertical profile

*Daisike Suzuki[1], Hideaki Nakajima[2,1], Isao Murata[1], Isamu Morino[2] (1.Graduate school of Environmental Studies, Tohoku University, 2.National Institute for Environmental Studies)

[AAS07-04] **Multi-Spectral/Multi-Sensor Satellite Retrievals and Cross-Sensor Validation of Ozone and Carbon Monoxide within the TROPESS Framework**

*thomas p kurosu[1], Kevin bowman[1], John Worden[1], Vijay Natraj[1], Kazuyuki Miyazaki[1], James McDuffie[1], Ming Luo[1], Susan Kulawik[2], Elva Kuai[1], Kristen Fahy[1] (1.NASA Jet Propulsion Laboratory/California Institute of Technology, Pasadena, CA 91109, 2.Bay Area Environmental Research Institute, Moffett Field, CA 94035)

[AAS07-05] Atmospheric Trace Gas Retrievals from Hyperspectral Satellite Remote Sensors

*Xu Liu[1] (1.NASA Langley Research Center)

Recent research trends in airborne microplastics (AMPs)

*Hiroshi Okochi[1], Norihisa Yoshida[1], Somei Yanagitani[1], Yasuhiro Niida[2], Naoki Umezawa[2], Yohei Itaya[3], Hiroko Ogata[3], Naoya Katsumi[4], Hideshige Takada[5]

1. School of Science and Engineering, Waseda University,, 2. PerkinElmer Japan, 3. Shibata Scientific Technology LTD,, 4. Ishikawa Prefectural University, 5. Tokyo University of Agriculture and Technology

1. Introduction

The total production of plastics is estimated to reach 2 million tons per year in 1950, 300 million tons in 2012, and 40 billion tons in 2050 (Zalasiewicz, et al., 2016). As a result, a large amount of marine plastic waste is generated through rivers. Microplastics (MPs), which are plastic debris with a diameter of 5 mm or less, are mistakenly eaten as food by marine organisms to cause physical obstacles. In addition, MPs include various additives and the adsorbed harmful organic compounds, which probably affect the living body.

2. Current status of airborne microplastics (AMPs)

In recent years, MPs have been detected in rivers, tap water, plastic bottled water, road dust, and indoor air. According to estimates from the United States, MPs are taken up into the body as food and inhalation with about 60,000 particles per year, respectively (Cox et al., 2019). In addition, 90,000 MPs are intaken from bottled water each year. However, reports on airborne microplastics (AMPs) are limited and the current status of AMPs is poorly understood. Previous studies on AMPs have been conducted in the suburban of Paris, France (Dris et al., 2016, 2017) and in Guangdong, China (Cai et al., 2017). However, most research focused on AMPs not in atmospheric aerosols but in fallout. The shape of AMPs in urban areas is mostly fibrous, with few films, fragments, and foams. The identified materials are mainly polypropylene, polyethylene and polyethylene terephthalate (Dris et al., 2016, 2017; Cai et al., 2017, Liu et al., 2019). Although only a few research on AMPs in atmospheric aerosol have been reported, in Paris (France), indoor air contains 1to 60 fibers/m^3, 66% of which were natural fibers such as cellulose (Dris et al., 2017). On the other hand, the number concentration in the outdoor air was 0.3 to 1.5 fibers/m^3 (50 to 1650 μm). The majority of AMPs in urban air in Assaluyeh on the southern coast of Iran were fibers with 0.3 to 1.1 fibers/m^3 (2 to 100 μm), but it is unknown whether they were natural or synthetic fibers (plastics) (Abbasi et al., 2019). In the urban air in Shanghai (China), the number concentration of AMPs was 0 to 4.18 particles/m^3 (23 to 9555 μm), and 67% of them were fibrous (Liu et al., 2019a). At the same point, it was also reported to be 0.05 to 0.07 particles/m^3 (12 to 2191 μm), 43% of which were fibrous (Liu et al., 2019b).

Most of the AMPs studies were performed in urban areas. However, it has been recently reported that deposition fluxes of AMPs were estimated to be 365 particles/m^2/day (> 65 μm) in the French Pyrenees (Allen et al., 2019), which were almost the same levels in urban areas. This suggests that contamination of microplastics through the atmosphere may occur over a wide area. The shapes of AMPs in mountainous areas were very different from those in urban areas, with many fragments and films and low fibrous. These findings were broadcast by NHK last April, and AMPs have also attracted attention from atmospheric chemists in Japan. AMPs have also been detected in snowfall in the Swiss Alps and from ice floes in Fram Strait (Bergmann et al., 2019).

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3. Issues in research on airborne microplastics (AMPs)

Up to now, researchers reported their results of AMPs in their unique method, making it difficult to simply compare them, and a unified method is needed for AMPs. In my presentation, I will give the findings on sampling, pretreatments, and identification of AMPs. Based on the standard method we propose, I would like to introduce some of the results, i.e. the aerodynamic particle size distribution, number concentration, shapes, and materials of AMPs in urban and free tropospheric atmospheres.

Keywords: μFTIR, ATR imaging, purification to remove organics, density separation, aerodynamic particle size distribution, number concentration

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Analysis of sources of carbon monoxide at Tsukuba with observed vertical profile

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Carbon monoxide (CO) is an atmospheric pollutant that is mainly produced by incomplete combustion of fossil fuels, biomass burning, and the oxidation of hydrocarbons. CO plays an important role in atmospheric chemistry by contributing to the generation of tropospheric ozone and influences on various atmospheric trace gases via its reaction with OH. As CO’ s lifetime varies from a few weeks to two months, CO show regional differences in atmospheric concentration, therefore, observation at several locations is desirable. Particularly in the Asian region, which has large impact on global CO concentrations in recent years, it is necessary to understand the behavior of CO more accurately, and observations of CO in Japan is crucial. At Tsukuba (36.05˚N, 140.12˚E), we have been observing atmospheric trace gases using a high-resolution ground-based Fourier transform infrared (FTIR) spectrometer. By utilizing high wavenumber resolution (0.0035cm-1), we can retrieve vertical distribution of CO abundances from the line shape of the observed absorption spectrum. In this study, in order to clarify the source and seasonal variation of CO over Tsukuba, we analyzed the CO source using the vertical distribution of CO and hydrogen cyanide (HCN). HCN is mainly produced by biomass burning and has lifetime of a few years. HCN was used as a tracer for biomass burning in this analysis.

For the period from April 2010 to May 2019 the vertical profiles of CO and HCN were derived from the FTIR spectra taken at Tsukuba. An inversion analysis program <SFIT4> developed based on optimal estimate method (Rodgers, 2000) was used for the analysis.
The vertical distribution of CO was decomposed into two layers, i.e. altitude ranges of 0-5 km and 5-18 km, and correlation analysis with the HCN partial column corresponding to the same date and altitude was performed. As a result of the analysis, a significant correlation was confirmed at 5-18 km altitude between the partial column of CO and HCN in autumn, and no correlation was found at 0-5km altitude From the CO / HCN ratio obtained from the correlation analysis, the ratio of biomass-burning-origin CO abundance to total CO abundance in the atmosphere was calculated for partial column at 5-18 km altitude in autumn. From September to November at altitude of 5-18 km, the proportion of biomass-burning-origin CO was estimated to be 52% on average. From this analysis, it is guessed that CO from biomass burning is dominant due to distant forest fires in upper troposphere and lower stratosphere in Tsukuba in autumn. On the other hands at lower troposphere, it is considered that CO from biomass burning is not dominant than that in upper layer because CO from combustion of fossil fuels from urban atmosphere is mixed, in addition to CO from biomass burning.

Keywords: atmosphere, remote sensing

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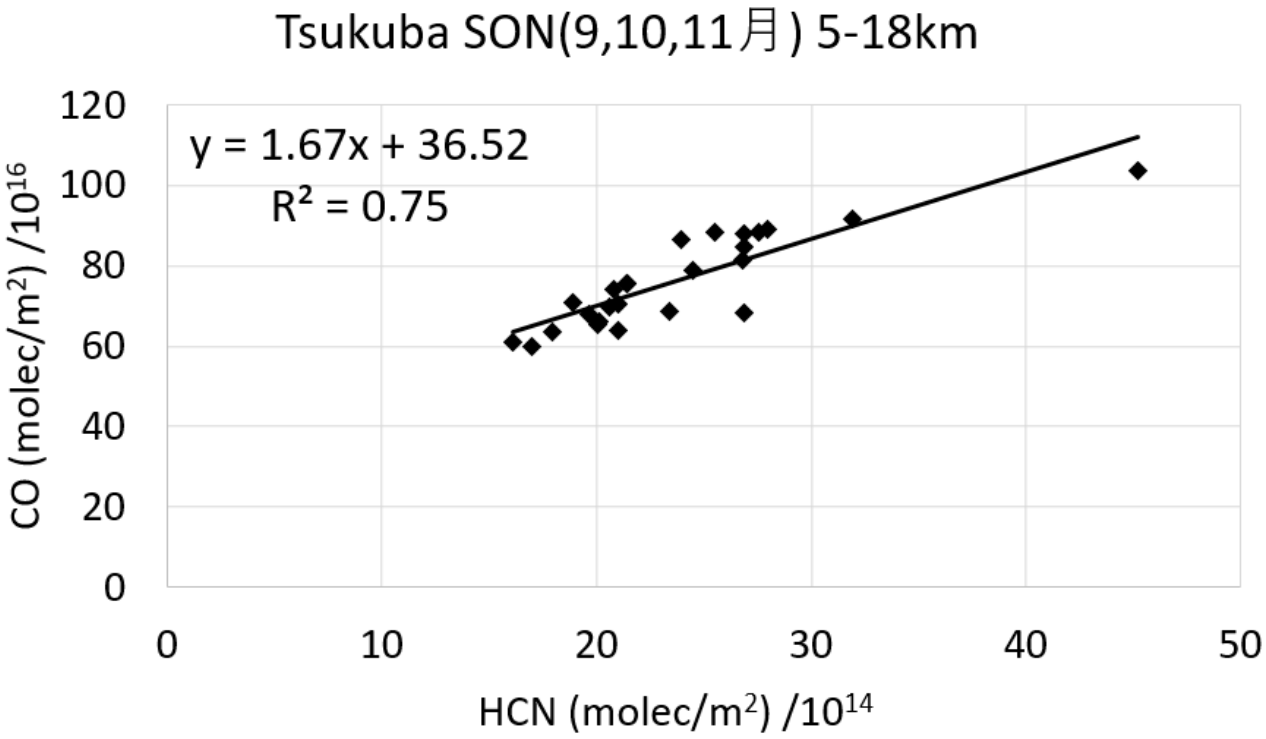

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Multi-Spectral/Multi-Sensor Satellite Retrievals and Cross-Sensor Validation of Ozone and Carbon Monoxide within the TROPESS Framework

*thomas p kurosu[1], Kevin bowman[1], John Worden[1], Vijay Natraj[1], Kazuyuki Miyazaki[1], James McDuffie[1], Ming Luo[1], Susan Kulawik[2], Elva Kuai[1], Kristen Fahy[1]

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Satellite-based monitoring of carbon monoxide and ozone is an integral part of the 2019 NOAA/NASA FIREX-AQ campaign. Key satellite sensors for FIREX-AQ are CrIS and OMPS on Suomi NPP, as well as the Sentinel 5P/TROPOMI: CrIS and OMPS observe ozone from the same platform but in different spectral regions (IR and UV) with different vertical sensitivities, and TROPOMI covers all major fire emission products in the UV to near-IR with high spatial resolution.

Differences in retrieval approach usually pose a challenge when combining and comparing retrieval products from different sensors. The TRopospheric Ozone and its Precursors from Earth System Sounding (TROPESS) framework is being developed at JPL as a continuation of atmospheric composition retrieval and validation tools developed for Aura/TES. Key elements of TROPESS are Reusable Framework for Atmospheric Composition (ReFRACtor), an extensible multi-instrument retrieval framework that facilitates data fusion of radiance measurements from different instruments (UV to thermal IR spectrum); and Multi-Spectral, Multi-Species, Multi-Sensors (MUSES), a retrieval code based on optimal estimation that has been applied successfully to joint AIRS/OMI observations. ReFRACtor/MUSES is designed to retrieve trace gas vertical profile concentrations and total column amounts in a consistent manner across spectral regions, by combining fast and accurate radiative transfer code with a non-linear optimal estimation solver. Inclusion of instrument-specific information allows the application of the same code base to different sensors for a consistent retrieval methodology across platforms, facilitating retrieval comparison across platforms. The goal is to extend single-instrument retrieval capabilities to joint multi-spectral retrievals like AIRS/OMI and CrIS/OMPS.

We present results on the concentration and vertical distribution of O_3 and CO, derived from the application of ReFRACtor/MUSES to AIRS/OMI and CrIS observations during 2019 FIREX-AQ, including comparisons with standard data products from OMPS and TROPOMI, pixel-matched OMPS/TROPOMI radiance calibration, and OMPS/TROPOMI tropospheric ozone comparisons with GEOS-Chem profiles.

Keywords: Satellite Air Quality Monitoring, Ozone, Carbon Monoxide

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Atmospheric Trace Gas Retrievals from Hyperspectral Satellite Remote Sensors

*Xu Liu[1]

1. NASA Langley Research Center

Satellite-based hyperspectral observations provide high information content for the Earth’s atmospheric and surface properties. We have developed two method for retrieving atmospheric trace gases from hyperspectral satellite sounders such as AIRS and CrIS. The first method performs an optimal estimation retrievals using single field of view (SFOV) hyperspectral satellite data. The second method performs a spectral fingerprinting on spatiotemporally averaged hyperspectral data. The retrieved geophysical parameters include atmospheric temperature and moisture profiles, CO_2, CO, CH_4, N_2O, and O_3 profiles, cloud optical depth, size, phase, and height. Surface properties such as surface emissivity spectra and surface skin temperatures are also retrieved simultaneously. The key to our retrieval algorithm is a a Principal Component-based Radiative Transfer Model (PCRTM), which can simulate radiance or reflectance spectra in the cloudy atmosphere from far IR to visible and UV spectral regions (50 wavenumber to 30000 wavenumber) quickly and accurately. Multi-scatterings of multiple layers of clouds/aerosols are included in the model. The PCRTM has a very good accuracy relative to reference line-by-line radiative transfer models and it saves orders of magnitude computational time. Results of applying both the SFOV PCRTM retrieval and spectral fingerprinting methods to CrIS and AIRS data will be presented.

Keywords: Trace gas retrievals, hyper spectral remote sensing, inversion algorithm, satellite data

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS07] Atmospheric Chemistry

convener:Naoko Saitoh(Center for Environmental Remote Sensing), Tomoki Nakayama(Graduate School of Fisheries and Environmental Sciences, Nagasaki University), Sakae Toyoda(Department of Chemical Science and Engineering, Tokyo Institute of Technology), Risa Uchida(Japan Automobile Research Institute)

This session provides a forum for the presentation of the broad spectrum of tropospheric and stratospheric chemistry, including various research topics (e.g., dynamical processes, air quality and climate), approaches (modeling, field measurements, remote sensing, and laboratory studies), and species (gas and aerosol). This session also provides an opportunity for discussing possible future collaboration with other research fields relevant to atmospheric chemistry.

[AAS07-06] Cobenefits and Tradeoffs in Reducing Short-Lived Climate Forcers and Air Pollutants by Deep Decarbonization in Asia

★Invited Papers

*Tatsuya Hanaoka[1], Tomoki Hirayama[2], Go Hibino[2], Toshihiko Masui[1] (1.National Institute for Environmental Studies, 2.Mizuho Information and Research Institute)

[AAS07-08] Utilizing continuous multi-component MAX-DOAS observations for the near-surface ozone sensitivity diagnosis at Tsukuba and Chiba, Japan for 2013-2019

*Hitoshi Irie[1], Daichi Yonekawa[1] (1.Center for Environmental Remote Sensing, Chiba University)

[AAS07-09] Model Evaluation of NO_2 horizontal distribution with MAX-DOAS ground measurement during Chiba-Campaign 2015

*Syuichi Itahashi[1], Hitoshi Irie[2] (1.Central Research Institute of Electric Power Industry, 2.Center for Environmental Remote Sensing, Chiba University)

[AAS07-10] A routine 24-hour measurement of total column NO_2 using direct solar and lunar spectra over Table Mountain Facilities, California

*King-Fai Li[1], Thomas J. Pongetti[2], Ryan Khoury[1], Stanley P. Sander[2], Yuk L. Yung[3] (1.University of California, Riverside, California, USA, 2.Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA, 3.California Institute of Technology, Pasadena, California, USA)

Cobenefits and Tradeoffs in Reducing Short-Lived Climate Forcers and Air Pollutants by Deep Decarbonization in Asia

*Tatsuya Hanaoka[1], Tomoki Hirayama[2], Go Hibino[2], Toshihiko Masui[1]

1. National Institute for Environmental Studies, 2. Mizuho Information and Research Institute

1. Introduction

In the Paris Agreement adopted by the United Nations Framework Convention on Climate Change (UNFCCC) Parties, it is required for all UNFCCC parties to reduce GHG emissions, in order to achieve the international target to “hold the increase in the global average temperature to well below 2˚C above pre-industrial levels” (so-called “2˚C target”). However, due to the rapid growth over the past decades in Asian developing countries, Asia became major emitters of CO2 in the world; in addition, they have been facing with serious air pollution. Thus, Asian developing countries need to take much further efforts than the current mitigation measures on greenhouse gases and air pollutants.

The objective of this study is to analyze emissions projections of CO2, air-pollutants and short-lived climate forcers (SLCFs) in Asia and the world, by considering various combinations of decarbonization measures and air pollutants control measures, and also to evaluate mitigation costs and cobenefits or tradeoffs in reducing air pollutants in response to decarbonization measures for achieving the 2˚C target.

2. Method

In order to analyze future emissions projections, mitigation potentials and costs by combinations of various kinds of technologies, this study uses a technology bottom-up model with a detailed technology selection framework, named the AIM/Enduse model. The AIM/Enduse model is a partial equilibrium, recursive dynamic optimization model, to minimize the total system costs including initial cost, operation and management cost, energy cost, carbon tax, energy tax, subsidy.

AIM/Enduse[Global] covers 32 of the world's geographical regions, especially focusing on Asia in detail such as Japan, China, India, ASEAN. As for the target gases, this study covers not only long-lived GHGs (CO2, N2O, HFCs, PFCs, SF6) but also SLCPs (CH4, BC) and air pollutants (SO2, NOx, PM2.5, PM10, OC, CO, NH3, NMVOC), in major multiple sectors such as energy supply, industry, residential & commercial, transport, agriculture, waste, industrial process, and fuel mining. Based on mitigation option database of realistic and currently existing technologies, mitigation potentials and costs can be analyzed.

3. Result and discussions

CO2 emission pathways toward the global 2˚C target can be projected in various ways by considering different combinations of decarbonization measures. However, even if features of CO2 emission pathways are the similar or same, emission projections of non-CO2 emissions are widely different depending on combinations of decarbonization measures and end-of-pipe measures.

Figure 1 shows an example result about emissions projections and sector-wise mitigation potentials in China, India, and ASEAN, regarding CO2, SLCFs (BC, CH4), and major air pollutants (SO2, NOx, CO, etc), when comparing between the reference and the 2˚C target scenarios. Major emission sources of air pollutants and SLCFs are diverse in different technologies in different sectors. Thus, major sectors with large mitigation potentials differ in each gas, which will induce various different levels of cobenefits and tradeoffs.

Large mitigation potentials are found in power and industry sectors for CO2 and SO2; transport, power, and industry sectors for NOx; residential and transport sectors for BC; and transport, industry and residential sectors for CO. It is also important to note is that, emissions of CO2, BC, SO2, NOx, CO are

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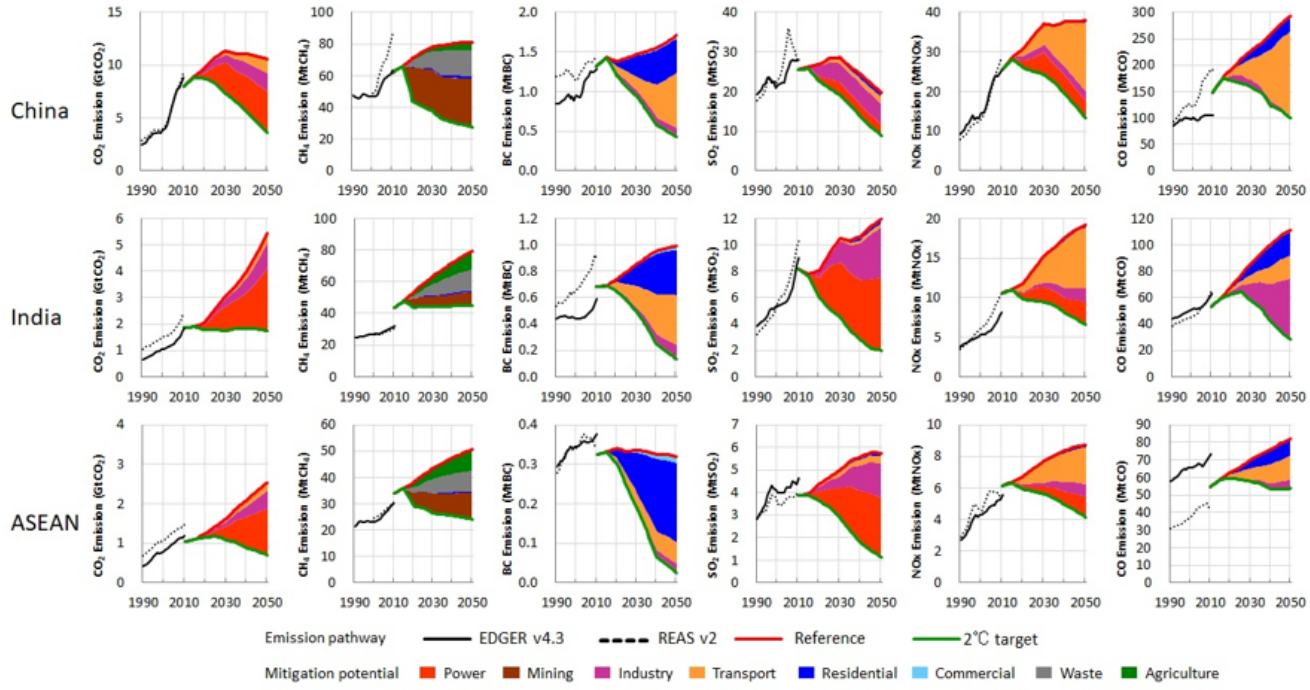
mainly from energy sources, but major sources of CH4 are non-energy related sectors such as agriculture, waste and fuel mining sectors. Thus, cobenefits in reducing CH4 are not expected in response to decarbonization measures.
This study also analyzed required mitigation costs and cost cobenefs. The larger decarbonization measures are taken, the more energy shifting occurs from fuel to renewables and the more additional investments are required than end-of-pipe measures.

Keywords: SLCFs, Air Pollutants, Decarbonization, Mitigation Scenarios



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Utilizing continuous multi-component MAX-DOAS observations for the near-surface ozone sensitivity diagnosis at Tsukuba and Chiba, Japan for 2013-2019

*Hitoshi Irie[1], Daichi Yonekawa[1]

1. Center for Environmental Remote Sensing, Chiba University

In the troposphere, ozone (O_3) plays a critical role not only as a critical photochemical oxidant but also as the third most important greenhouse gas. In recent years, its importance has been more widely recognized as a major short-lived climate pollutant. However, recent trends of concentrations of the near-surface O_3 and its major precursors, namely nitrogen oxides (NOx ≡NO + NO_2) and volatile organic compounds (VOCs), and the relationship among them have not been fully understood yet. Here, we utilized the multi-axis differential optical absorption spectroscopy (MAX-DOAS) to conduct continuous simultaneous observations of NO_2 (as a proxy for NOx), formaldehyde (HCHO; as a proxy for VOC), and O_3 concentrations in the retrieved lowermost troposphere (0-1 km) at Tsukuba (36.06ºN, 140.13ºE, 35 m asl) and Chiba (35.63ºN, 140.10ºE, 21 m asl), Japan for seven years from 2013 to 2019. For a spatially-representative analysis around Chiba situated in an urban area, four MAX-DOAS instruments directed to four different azimuth directions (north, east, west, and south) were operated simultaneously. The seven-year-long period was a unique target as satellite observations indicated an abrupt improvement in the tropospheric NO_2 concentration level over East Asia, including China. Considering this with other observational evidence from literatures, the transboundary transport of ozone originating from the Asian continent was likely suppressed or unchanged. Over such a unique time period, MAX-DOAS observations at both Tsukuba and Chiba showed almost-constant variations or rather an increasing tendency in the near-surface O_3 concentration, although reductions in NO_2 and HCHO concentrations by as much as 30% were observed simultaneously. These results provide observation evidence that decreasing NOx concentration significantly reduced the amount of O_3 quenched through the NOx titration.

Keywords: Tropospheric ozone, NO2, O3, MAX-DOAS

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Model Evaluation of NO_2 horizontal distribution with MAX-DOAS ground measurement during Chiba-Campaign 2015

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In this study, the horizontal distribution of nitrogen dioxide (NO_2) simulated by the chemical transport model (CTM) has been extensively evaluated with Multi-Axis Differential Optical Absorption Spectroscopy (MAX-DOAS). Although the ground-based observation network (i.e., AEROS system) in Japan can provide the hourly NO_2 concentration, its horizontal coverage is sparse, especially over rural or remote sites. The space-based satellite measurement can provide the spatial distribution of air pollutants; however, measured values are vertically integrated concentrations. To overcome these disadvantages in existing observations, we used MAX-DOAS measurement to evaluate the model performance. The scattered sunlight observations in the UV/visible at several elevation angles between the horizon and zenith, so-called MAX-DOAS technique, can retrieve both trace gases and aerosol profiles. Total of four MAX-DOAS measurement systems located at Chiba University (35.63˚N, 140.10˚E, 21 m a.s.l.) are allocated to cover north, east, west, and south, and provide the horizontal distributions for the lower troposphere. By targeting the period of Chiba-Campaign 2015 conducted from 9 to 23 November 2015, here we present the detailed model evaluations on NO_2 spatial and vertical distribution, and temporal variation.

Keywords: Chemical Transport Model, MAX-DOAS, NO2

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A routine 24-hour measurement of total column NO_2 using direct solar and lunar spectra over Table Mountain Facilities, California

*King-Fai Li[1], Thomas J. Pongetti[2], Ryan Khoury[1], Stanley P. Sander[2], Yuk L. Yung[3]

1. University of California, Riverside, California, USA, 2. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA, 3. California Institute of Technology, Pasadena, California, USA

The first 24-hour measurement of total column NO_2 has been made over the Jet Propulsion Laboratory's Table Mountain Facilities (TMF) located in a suburban area of Los Angeles, California, USA (2.286 km above mean sea level, 34.38˚N, 117.68˚W) during a 1-week campaign in October, 2018 using a grating spectrometer that measures the telluric NO_2 absorptions in the direct solar and lunar spectra. The measured 24-hour cycle of total column NO_2 on clean days agrees well with a 1-D photochemical model calculation, including the monotonic changes during daytime and nighttime due to the exchange with the N_2O_5 reservoir and the abrupt changes at sunrise and sunset due to the activation or deactivation of the NO_2 photodissociation. In our photochemical model, we find that the Arrhenius constant $A = 6.7\times10^{-11}$ cm^3 $molecule^{-1}$ s^{-1} and the activation energy $E/R = 0.0$ for the bimolecular reaction $N_2O + O(^1D) \rightarrow 2O$ from previous recommendation are adequate to well simulate the observed 24-hour cycle of the total column NO_2. The resulting rate constant is ~15% less than that obtained using more recent recommended values of A and E/R, and it lies in the lower end of the suggested uncertainty. While the model is able to reproduce the observed rate of increase of daytime total column NO_2, it overestimates the rate of decrease of nighttime total column NO_2, implying that a lower nighttime temperature is required for a more accurate simulation. The total column NO_2 in one of the afternoons during the campaign was much higher than the model simulation, implying the influence of urban pollution from nearby cities. A 24-hour back-trajectory analysis shows that the wind first came from inland in the northeast and reached the southern Los Angeles before it turned northeast and finally arrived TMF, allowing it to pick up pollutants from Riverside County, Orange County, and Downtown Los Angeles.

Keywords: grating spectrometer, modified Langley method, back-trajectory, urban pollution

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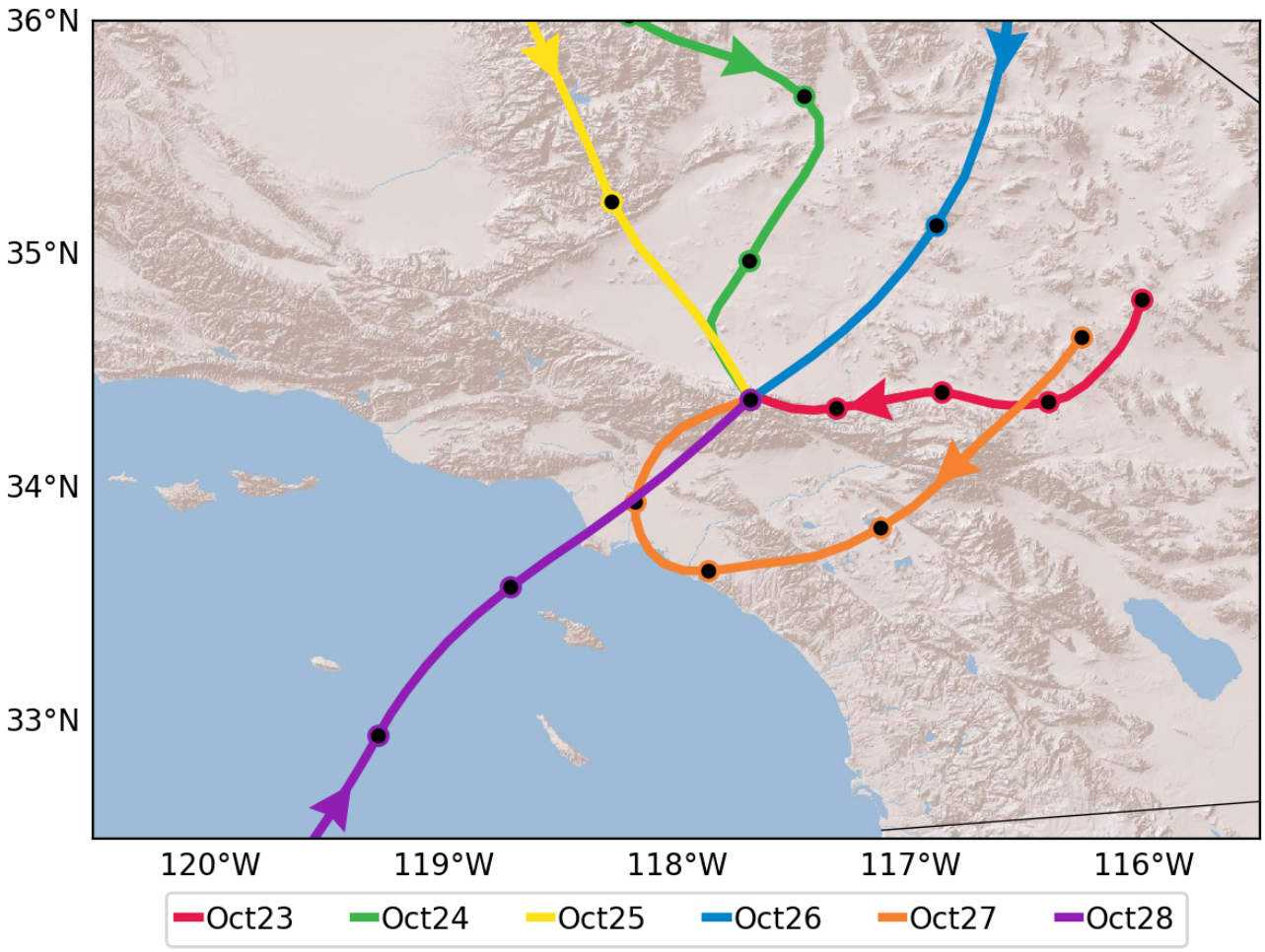

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS07] Atmospheric Chemistry

convener:Naoko Saitoh(Center for Environmental Remote Sensing), Tomoki Nakayama(Graduate School of Fisheries and Environmental Sciences, Nagasaki University), Sakae Toyoda(Department of Chemical Science and Engineering, Tokyo Institute of Technology), Risa Uchida(Japan Automobile Research Institute)

This session provides a forum for the presentation of the broad spectrum of tropospheric and stratospheric chemistry, including various research topics (e.g., dynamical processes, air quality and climate), approaches (modeling, field measurements, remote sensing, and laboratory studies), and species (gas and aerosol). This session also provides an opportunity for discussing possible future collaboration with other research fields relevant to atmospheric chemistry.

[AAS07-11] Monitoring anthropogenic and natural sources and sinks of GHGs: Challenges in Asia and Oceania

★Invited Papers

*Nobuko Saigusa[1], Toshinobu Machida[1], Tsuneo Matsunaga[1], Hiroshi Tanimoto[1], Yosuke Niwa[1], Yukio Terao[1], Akihiko Ito[1] (1.National Institute for Environmental Studies)

[AAS07-12] Greenhouse gases and air quality monitoring system for urban anthropogenic emission estimation around Jakarta megacity

*Masahide Nishihashi[1], Hitoshi Mukai[1], Yukio Terao[1], Shigeru Hashimoto[1], Rizaldi Boer[2], Muhammad Ardiansyah[2], Bregas Budianto[2], Adi Rakhman[2], Gito Sugih Immanuel[2], Rudi Nugroho[3], Nawa Suwedi[3], Anies Marufatin[3], Muhammad Agus Salim[3], Dodo Gunawan[4], Eka Suharguniyawan[4], Asep Firman Ilahi[4], Muharam Syam Nugraha[4], Ronald Christian Wattimena[4], Bayu Feriaji[4], Qoriana Maulani[4], Tomohiro Oda[5], Thomas Lauvaux[6] (1.National Institute for Environmental Studies, 2.IPB University, Indonesia, 3.Agency for the Assessment and Application of Technology (BPPT), Indonesia, 4.Meteorological, Climatological, and Geophysical Agency (BMKG), Indonesia, 5.Universities Space Research Association/NASA Goddard Space Flight Center, USA, 6.Laboratory for Sciences of Climate and Environment (LSCE), France)

[AAS07-13] Methane vertical profiles over the Indian subcontinent derived from the GOSAT/TANSO-FTS thermal infrared sensor

*Dmitry Belikov[1], Naoko Saitoh[1], Prabir Patra[1,2], Naveen Chandra[2] (1.Center for Environmental Remote Sensing, Chiba University, 2.Research Institute for Global Change, JAMSTEC)

[AAS07-14] Quantifying thermal power plant CO_2 emissions from CO_2 total column measurements with portable FTIR spectrometers

*Hirofumi Ohyama[1], Kei Shiomi[2], Nobuhiro Kikuchi[2], Isamu Morino[1], Akihiro Hori[1], Tsuneo Matsunaga[1] (1.National Institute for Environmental Studies, 2.Japan Aerospace Exploration Agency)

[AAS07-15] Satellite Cloud Assimilation and its Impact on Air Quality Simulations

*Arastoo Pour Biazar[1], Andrew White[1,5], Maudood Khan[6,4], Richard T. McNider[1,2,3] (1.University of Alabama in Huntsville (UAH), 2.UAH/Earth System Science Center (ESSC), 3.National Space Science and Technology Center (NSSTC), 4.National Aeronautics and Space Administration (NASA), 5.NASA/Short-term Predication, Research and Transition (SPoRT) Center, 6.Booz Allen Hamilton)

Monitoring anthropogenic and natural sources and sinks of GHGs: Challenges in Asia and Oceania

*Nobuko Saigusa[1], Toshinobu Machida[1], Tsuneo Matsunaga[1], Hiroshi Tanimoto[1], Yosuke Niwa[1], Yukio Terao[1], Akihiko Ito[1]

1. National Institute for Environmental Studies

The Paris Agreement established a long-term goal of keeping the global average temperature well below 2 degrees Celsius above the pre-industrial level by achieving a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases (GHGs) in the second half of this century. To monitor and evaluate the impacts of climate change measures for implementing the Paris Agreement, accurate knowledge of emission trends and reliable GHG inventories are essential. Emission reporting from developing countries is particularly important.

Asia, as one of the world's largest GHG emitters, has a responsibility to play an important role to turn the goals of Paris Agreement into reality. Urgent needs in Earth observations for GHGs are to reduce uncertainties in their source and sink estimations and to identify current knowledge gaps and requirement for further international collaboration. The reliability of evaluations of natural and anthropogenic sources and sinks has been improved in recent years, however, due to uncertainties in modelling tools, and limited observational data coverage, high uncertainty still remains, particularly for CO2. Discussions will be focused on current status and challenges from NIES's relevant GHG observation and analysis to improve up-to-date analysis systems and data coverage particularly in Asia–Oceania for better estimation of the distribution of anthropogenic and natural sinks and sources with sufficient accuracy in time with such activities as the Global Stocktake Process under the Paris Agreement.

Keywords: greenhouse gas emissions, source and sink estimation, Asia and Oceania

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Greenhouse gases and air quality monitoring system for urban anthropogenic emission estimation around Jakarta megacity

*Masahide Nishihashi[1], Hitoshi Mukai[1], Yukio Terao[1], Shigeru Hashimoto[1], Rizaldi Boer[2], Muhammad Ardiansyah[2], Bregas Budianto[2], Adi Rakhman[2], Gito Sugih Immanuel[2], Rudi Nugroho [3], Nawa Suwedi[3], Anies Marufatin[3], Muhammad Agus Salim[3], Dodo Gunawan[4], Eka Suharguniyawan[4], Asep Firman Ilahi[4], Muharam Syam Nugraha[4], Ronald Christian Wattimena[4], Bayu Feriaji[4], Qoriana Maulani[4], Tomohiro Oda[5], Thomas Lauvaux[6]

1. National Institute for Environmental Studies, 2. IPB University, Indonesia, 3. Agency for the Assessment and Application of Technology (BPPT), Indonesia, 4. Meteorological, Climatological, and Geophysical Agency (BMKG), Indonesia, 5. Universities Space Research Association/NASA Goddard Space Flight Center, USA, 6. Laboratory for Sciences of Climate and Environment (LSCE), France

National Institute for Environmental Studies (NIES) has implemented an international joint research project for greenhouse gases (GHGs) and air quality monitoring with three institutes in Indonesia, IPB, BPPT, and BMKG since 2015/2016. The purpose of this project is to quantify anthropogenic emissions from Jakarta megacity and characterize them in terms of socioeconomic activities in the city. In order to respond to the Paris Climate Agreement, it is important for a monitoring project like ours not only to be capable of monitoring the increasing anthropogenic emissions by rapid economic growth in a developing country, but also to assess future those reduction impacts resulted from mitigation strategies implemented. It is also important to observe GHGs and related air pollutants with high accuracy in Indonesia because such kinds of observations are very limited in Southeast Asia.

We have maintained continuous monitoring systems of CO_2, CH_4, CO, NO_x, SO_2, O_3, aerosol concentrations ($PM_{2.5}$, PM_{10}, BC) and the chemical components (NO_3^-, SO_4^{2-}) of $PM_{2.5}$ and PM_{10}, and meteorological parameters at three sites: Serpong (Jakarta suburb), Bogor (center of Bogor city), and Cibeureum (mountainous area, background-like site) since 2016/2017. We have also performed automatic flask sampling of ambient air once a week. The air samples are used to analyze N_2O, SF_6, and carbon isotopes (^{13}C, ^{14}C) in CO_2 at NIES and to validate CO_2, CH_4, and CO data obtained from the continuous measurement.

We have also conducted high-resolution atmospheric CO_2 simulations using the Weather Research and Forecasting model coupled to Chemistry (WRF-Chem). We used two emission inventories to prescribe the surface emissions: ODIAC (Open-source Data Inventory for Anthropogenic CO_2) as fossil fuel CO_2 ($ffCO_2$) and MsTMIP (Multi-scale Synthesis and Terrestrial Model Intercomparison Project) as biogenic CO_2 ($bioCO_2$).

We analyzed the intersite differences of daytime CO_2 mole fractions (dCO_2) between the urban sites (Serpong, Bogor) and the background-like site (Cibeureum) in the dry season (July-August 2017) and the rainy season (January-February 2018). The observed dCO_2 at Serpong was 8.7 and 0.9 ppm in the dry and rainy seasons, respectively. The simulated dCO_2 at Serpong shows similar decreasing trend, which is 8.5 and 3.1 ppm in the dry and rainy seasons, respectively. While the simulated CO_2 values at Serpong are slightly overestimated in the rainy season possibly due to the poor reproducibility of meteorological fields (wind environment near the surface), the simulation indicates two main factors of the seasonal differences in dCO_2: one is the reduction of $ffCO_2$ at Serpong in the rainy season (3.3 ppm) and another one is the reduction of $bioCO_2$ uptake by photosynthesis at Cibeureum in the rainy season (2.9 ppm). The seasonal

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differences in dCO_2 observed and simulated at Bogor are similar to those of Serpong, but smaller. In our presentation, we will also present the relationship between CO_2 and the other species.

Keywords: greenhouse gases, air quality, urban monitoring, CO2 simulation, Indonesia

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Methane vertical profiles over the Indian subcontinent derived from the GOSAT/TANSO-FTS thermal infrared sensor

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We examine CH_4 variability over different parts of India and the surrounding oceanic regions using thermal infrared (TIR) band observations by the Thermal And Near-infrared Sensor for carbon Observation-Fourier Transform Spectrometer (TANSO-FTS) onboard the Greenhouse gases Observation SATellite (GOSAT). GOSAT/TANSO-FTS TIR (hereafter referred to as “GOSAT-TIR”) band provides data coverage and density that captures detailed features of CH_4 distributions even in the cloudy conditions, which is very common for the region with a monsoon climate.

The vertical profiles of CH_4 observed from GOSAT-TIR were compared to results of simulations by the Model for Interdisciplinary Research on Climate (MIROC, version 4.0) based atmospheric chemistry-transport models (ACTM) referred to as MIROC4-ACTM. The ACTM runs are conducted at a horizontal resolution of T42 spectral truncations (≈2.8˚×2.8˚) with 67 sigma-pressure vertical levels. The ACTM CH_4 was simulated with two combinations of inverted fluxes:
1) $ACTM_{Cao}$: EDGAR432 + GFED4s + Termite + … + VISIT wetland (Cao scheme),
2) $ACTM_{WH}$: EDGAR432 + GFED4s + Termite + … + VISIT wetland (WH (Walter&Heimann) scheme).
A comparison of modeled and observed CH_4 shows that the GOSAT-TIR retrievals at 22 vertical levels provide critical information about CH_4 transport from the top of the boundary layer to the upper troposphere and lower stratosphere in the region. Even if no averaging kernel incorporated, the mean ACTM-GOSAT misfit is within 50 ppb, except for the level of 150 hPa and upward, where the GOSAT-TIR sensitivity becomes very low. The GOSAT-ACTM misfit above the level of 150 hPa is likely to arise from a priori model for TIR retrievals. Convolution of the modeled profiles with retrieval a priori and averaging kernels reduces the misfit to below uncertainty. However, the weight of the a priori profiles becomes too large with such smoothing.

Overall, the ACTM simulations of CH_4 in the Indian regions compare favorably with the GOSAT-TIR samplings, in terms of seasonality and regional variability. However, the GOSAT-ACTM inconsistencies indicate opportunities for further flux optimization and emission uncertainty reduction by inverse modeling methods.

Fig. 1. **Center**: The map of the regional divisions for the analysis –the high mountain range on the northern sides and oceans in the southern boundaries form a unique monsoonal flow in the region. The Indian regions from Southwest to Northeast are following: the Arabian Sea (AS), Southern India (SI), the Bay of Bengal (BB), Western India (WI), Central India (CI), Eastern India (EI), Arid India (AI), Western IGP (WIGP), Eastern IGP (EIGP), and Northeast India (NEI). **(a-l)** Averaged CH_4 vertical profiles: **left panel**) pre-monsoon season (April-June), **right panel**) monsoon season (July-September) of 2011 over the considered Indian regions. The black line with error bars shows the GOSAT-TIR data with uncertainty (1-σ STD). Blue and red lines with shaded areas correspond to the $ACTM_{CAO}$ and $ACTM_{WH}$ data with uncertainty. Magenta and cyan lines represent the CH_4 from the $ACTM_{CAO}$ and $ACTM_{WH}$ after the averaging kernel implementation [Belikov et al., in preparation].

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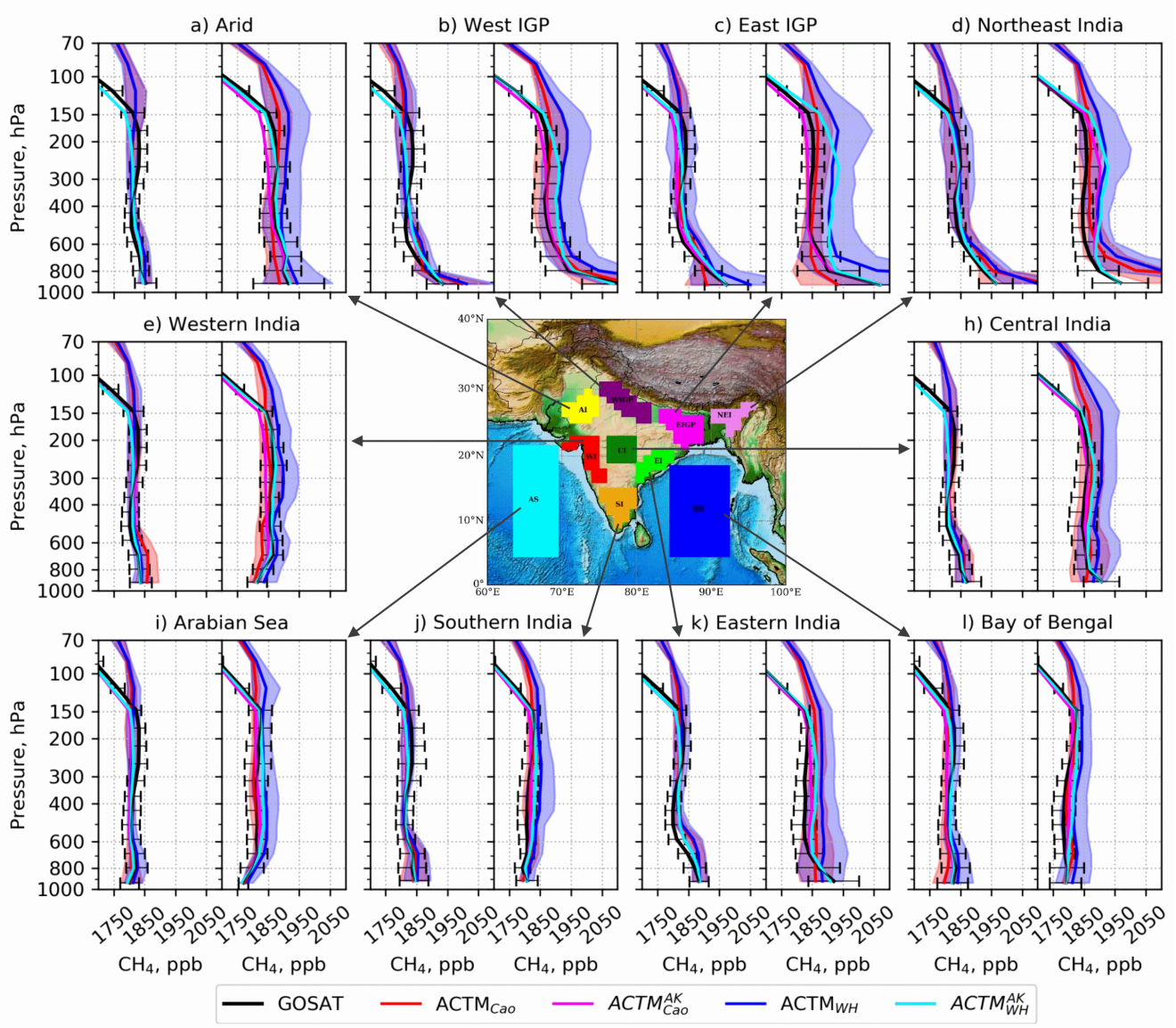
Keywords: methane, carbon cycle, asian summer monsoon anticyclone



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Quantifying thermal power plant CO_2 emissions from CO_2 total column measurements with portable FTIR spectrometers

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Emissions of carbon dioxide (CO_2) from large point sources such as thermal power plants and steel plants account for approximately 40% of the world’ s energy-related CO_2 emissions. Nowadays, the CO_2 emissions from thermal power plants have been quantified based on CO_2 column abundances obtained by airborne and satellite-borne remote sensing. In the present study, we evaluated precisions in CO_2 emission estimates from simpler and more inexpensive ground-based CO_2 column measurements. To this end, we conducted two measurement campaigns for one month each during October 2018 and October–November 2019 to measure CO_2 column abundances using two portable Fourier transform infrared (FTIR) spectrometers (EM27/SUN) around a thermal power plant in Japan. In addition, wind profiles in the planetary boundary layer and meteorological parameters at the ground were observed by a Doppler lidar and a meteorological observation system, respectively. We assumed that the CO_2 plume rises by a certain height depending on heat emission rate and wind speed at the stack top, and that the horizontal distribution of CO_2 column enhancement relative to the background can be represented by a Gaussian plume model. Because the shape of the plume is disturbed by turbulence, the observed CO_2 column and meteorological data were averaged into 10 min bins to mitigate that effect. The wind speeds at an effective plume height and the plume widths necessary for CO_2 emission estimates were obtained or estimated from the observed values, and highly variable wind directions were retrieved simultaneously with the CO_2 emission. We compared the CO_2 emissions estimated from the observed data with those converted from hourly fuel consumptions, and it was found that the standard deviation (1 σ) of the differences was ~20%.

Keywords: carbon dioxide, thermal power plant, emission amount, remote sensing

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Satellite Cloud Assimilation and its Impact on Air Quality Simulations

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Clouds have a significant role in tropospheric chemistry as they modulate photolysis rates, affect biogenic hydrocarbon emissions, impact boundary-layer development, lead to deep vertical mixing of pollutants and precursors, and induce aqueous phase chemistry. Numerical meteorological models have difficulty in creating clouds in the right place and time compared to observed clouds. This is especially the case when synoptic-scale forcing is weak, as often is the case during air pollution episodes. Consequently, poor representation of clouds affects the photochemical model's ability in reproducing the tropospheric chemical state. One way to improve model cloud simulation is data assimilation. Since satellites provide the best observational platform for defining the formation and location of clouds, satellite observations can be of great value in retrospective simulations.

In this study, a new technique is used to assimilate derived cloud fields from the Geostationary Operational Environmental Satellite (GOES) in the Weather Research and Forecasting (WRF) model. The improved meteorological fields, including simulated clouds, are subsequently used for emissions estimates and to drive the Community Multiscale Air Quality (CMAQ) photochemical model. Based on GOES observations, the assimilation technique dynamically supports cloud formation/dissipation within WRF. The technique uses observations to identify model cloud errors, estimates a target vertical velocity and moisture needed to create/remove clouds, and adjusts the flow field accordingly. The technique was tested in air quality simulation over the period of August-September 2013 (NASA’s Discover-AQ field campaign). The cloud assimilation on the average improved model cloud simulation by 15% over this period. The cloud correction not only improved the spatial and temporal distribution of clouds, but it also improved boundary layer temperature, humidity, and wind speed. These improvements in meteorological fields substantially improved the air quality simulations by altering the biogenic VOC emissions and by correcting the photolysis rates. Cloud correction reduced isoprene and monoterpene emissions over the southeastern U.S. by 10-20% and improved ozone predictions. Ozone bias over the southeastern United States was reduced by 63%. Preliminary results from this activity will be presented.

Keywords: Air Quality, Satellite Cloud Assimilation, WRF/CMAQ, Biogenic VOC Emission, Ozone Chemistry, Numerical Modeling

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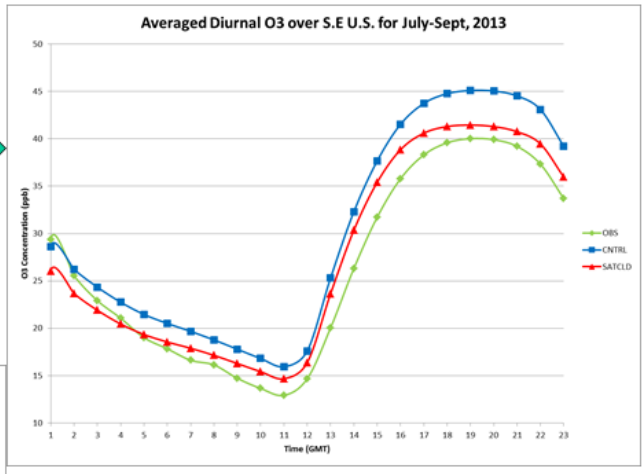
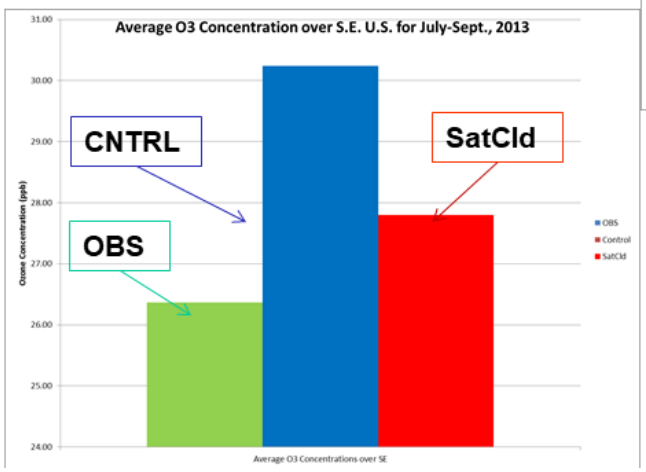
Impact of Cloud assimilation on Ozone Concentration

Significant daytime improvement for O3 over S.E. U.S. during summer of 2013.





63% reduction in bias for ozone over S.E. U.S.

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS07] Atmospheric Chemistry

convener:Naoko Saitoh(Center for Environmental Remote Sensing), Tomoki Nakayama(Graduate School of Fisheries and Environmental Sciences, Nagasaki University), Sakae Toyoda(Department of Chemical Science and Engineering, Tokyo Institute of Technology), Risa Uchida(Japan Automobile Research Institute)

This session provides a forum for the presentation of the broad spectrum of tropospheric and stratospheric chemistry, including various research topics (e.g., dynamical processes, air quality and climate), approaches (modeling, field measurements, remote sensing, and laboratory studies), and species (gas and aerosol). This session also provides an opportunity for discussing possible future collaboration with other research fields relevant to atmospheric chemistry.

[AAS07-16] The NICAM–SPRINTARS simulations of the transport and wetdeposition of the black carbon emitted from a Siberian forest fire in September 2016

*Yousuke Yamashita[1,2], Masayuki Takigawa[1], Daisuke Goto[2], Hisashi Yashiro[2,3], Masaki Satoh[4,1], Yugo Kanaya[1], Fumikazu Taketani[1], Takuma Miyakawa[1] (1.Japan Agency for Marine-Earth Science and Technology, 2.National Institute for Environmental Studies, 3.RIKEN Center for Computational Science (R-CCS), 4.Atmosphere and Ocean Research Institute, The University of Tokyo)

[AAS07-17] Spherical tarballs form through chemical and physical evolution of primary organic particles in biomass-burning smoke

*Kouji Adachi[1] (1.Meteorological Research Institute)

[AAS07-18] Concentrations and Size Distributions of Black Carbon in the Surface Snow at Syowa station in Eastern Antarctica in 2011

*Takeshi Kinase[1,2], Kouji Adachi[1], Naga Oshima[1], Kumiko Goto-Azuma[3,4], Yoshimi Ogawa-Tsukagawa[3], Yutaka Kondo[3], Nobuhiro Moteki[5], Sho Ohata[6], Tatsuhiro Mori[7], Masahiko Hayashi[8], Keiichiro Hara[8], Hiroto Kawashima[9], Kazuyuki Kita[2] (1.Meteorological Research Institute, 2.Ibaraki University, 3.National Institute of Polar Research, 4.SOKENDAI, 5.The University of Tokyo, 6.Nagoya University, 7.Tokyo University of Science, 8.Fukuoka University, 9.Akita Prefectural University)

[AAS07-20] Enhanced new particle formation above the marine boundary layer over the Yellow Sea: Potential impacts on cloud condensation nuclei

*Nobuyuki Takegawa[1], Takafumi Seto[2], Nobuhiro Moteki[3], Makoto Koike[3], Naga Oshima[4], Kouji Adachi[4], Kazuyuki Kita[5], Akinori Takami[6], Yutaka Kondo[7] (1.Tokyo Metropolitan University, 2.Kanazawa University, 3.The University of Tokyo, 4.Meteorological Research Institute, 5.Ibaraki University, 6.National Institute for Environmental Studies, 7.National Institute of Polar Research)

[AAS07-21] Enhanced Sulfate Production During Nitrate Photolysis in the Presence of Halide Ions in Atmospheric Particles

*Masao Gen[1], Chak Chan[2], Ruifeng Zhang[2], DanDan Huang[3], Yongjie Li[4] (1.Faculty of Frontier Engineering, Institute of Science and Engineering, Kanazawa University, 2.School of Energy and Environment, City University of Hong Kong, 3.Shanghai Academy of Environmental Sciences, 4.Department of Civil and Environmental Engineering, Faculty of Science and Technology, University of Macau)

The NICAM–SPRINTARS simulations of the transport and wetdeposition of the black carbon emitted from a Siberian forest fire in September 2016

*Yousuke Yamashita[1,2], Masayuki Takigawa[1], Daisuke Goto[2], Hisashi Yashiro[2,3], Masaki Satoh[4,1], Yugo Kanaya[1], Fumikazu Taketani[1], Takuma Miyakawa[1]

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The black carbon (BC) affects absorption/scattering of solar radiation, precipitation, and snow/ice cover. In areas of low human activity such as the Arctic and oceans, even a small inflow of natural or anthropogenic aerosols can directly and indirectly influence solar radiation, clouds, and precipitation, making it important to better understand aerosol transport to such areas. However, the limited number of spatial and temporal observations is available in such areas, and it is useful to use a global chemistry transport model aimed at estimating the transport to such areas and projecting its influence on the climate.

The Nonhydrostatic Icosahedral Atmospheric Model (NICAM)–SPRINTARS is the global aerosol transport model, which has been developed to calculate global aerosol transport and its influences on radiation and precipitation incorporated with the NICAM. The latest model is developed to include the forest fire emission with daily timescales and has fine horizontal resolution with 56 km, which is capable of simulating fine scales transport processes of aerosols such as the accumulation of BC behind the cold front, and the wetdeposition process around the low-pressure system.

A large and continuous forest fire was burning near Lake Baikal, Russia in September 2016. At the same time that the observation of BC was performed by observational cruise of R/V Mirai (MR16-06) possessed by Japan Agency for Marine-Earth Science and Technology (JAMSTEC), and the R/V Mirai observed BC peaks near the Aleutians in 25th–26th September. For evaluating the capability of simulating the long-range transport to the low human activity area, we used NICAM–SPRINTARS to simulate the transport pathways, deposition process, and their resolution dependency of observed major forest fire event using the recent fine horizontal resolution (56 km) comparing to low horizontal resolution (220 km), which is still used in recent climate simulations.

The experiments with Siberian forest fire emissions showed that the column BC amount around Siberia is exponentially deposited from Siberia to the Aleutians. These BC was deposited by precipitation associated with a low-pressure system, exponentially decreasing along the transport pathway from Siberia to Kamchatka. The wetdeposition flux in 220 km model along the transport pathway is large in magnitude than that in 56 km model due to the patchy peak areas of deposition, causing the relatively larger maximum of BC in 56 km mode along with the R/V Mirai path.

Some additional deposition in Arctic for the 56 km experiment is much larger than that for 220 km experiment in the 27th–28th September. We found that in the 56 km experiments, the BC emitted from the Siberian forest fire was transported as far as the Arctic with a filamental structure of high-BC area around the Bering and Chukchi Seas from the 27th–28th with the ascending motion around the developed low-pressure system. In contrast, the 220 km experiments produced the widespread high-BC area with

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relatively smaller amount of maximum concentration, especially around 8 km, associated with the weak ascending motion around the low-pressure system.

These results suggest that the 56 km resolution was required to reproduce the inflow of BC to the Arctic due to the high-resolution transport process of developed low-pressure system around the Bering and Chukchi Seas as well as the high-resolution wetdeposition process near Siberia. Thus, the future climate simulations and the transport and budget analysis need to be performed with fine horizontal resolution (~56 km) using the global chemistry transport models.

Keywords: black carbon, aerosol transport model, wetdeposition

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Spherical tarballs form through chemical and physical evolution of primary organic particles in biomass-burning smoke

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Biomass burning is an urgent issue for the regional environment and global climate. Recently, large-scale wildfires have occurred in Australia, Brazil, the United States, and elsewhere, and large amounts of gases and aerosol particles have been released into the atmosphere. Organic matter is dominant in aerosol particles from biomass burning and influence the climate by scattering/absorbing light and becoming cloud condensation nuclei. Within relatively aged smoke (a few hours after emission), the spherical organic particles, named “tarball”, are of interest because of their abundance and optical property. Tarballs can be identified based on their spherical shapes on the substrate observed using, for example, transmission electron microscopy (TEM). Studies assumed various tarball formation processes but have not yet confirmed them. This study aims to understand the occurrence and formation of tarballs in biomass burning smoke using TEM.

Biomass burning samples were collected on TEM grids during the BBOP campaign 2013 using the G-1 aircraft in the northwestern United States. During the BBOP campaign, the mass fraction of tarballs was estimated to be ~30% in smoke from biomass burning, and the refractive index of tarball was estimated to be 1.56-0.02i (Sedlacek et al., 2018). The mode diameter of tarball was 223nm (Adachi et al., 2019). In addition, chemical and physical evolution of organic matter from biomass-burning smoke and the formation of tarball particles were observed. When organic particles were fresh, less than 1 hour from the emissions, organic matters had low viscosity and surface tension, resulting in spread on the substrate due to the impact when collected. Fresh organic matters contained potassium salts as inclusions. Within samples collected several hours after the emissions, organic particles increased their viscosity and become rounded on the substrate. In addition to the increase in sphericity, the weight percentage of nitrogen and oxygen relative to potassium, which is a conserved tracer, was increased. The observation suggested that chemical reactions involving O and N within primary organic maters change the particle viscosity and surface tension, resulting in tarballs. Currently, the tarball formation hypothesis is being tested using biomass burning samples collected during the FIREX-AQ campaign. The campaign was conducted from July to September 2019 in the United States using a NASA DC-8 aircraft. During the campaign, both biomass burning smokes from wildfire and agricultural fire were observed. Tarball particles had similar appearances with those from the BBOP, and further TEM analyses are being processed.

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Keywords: biomass burning, aerosol, observation

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Concentrations and Size Distributions of Black Carbon in the Surface Snow at Syowa station in Eastern Antarctica in 2011

*Takeshi Kinase[1,2], Kouji Adachi[1], Naga Oshima[1], Kumiko Goto-Azuma[3,4], Yoshimi Ogawa-Tsukagawa[3], Yutaka Kondo[3], Nobuhiro Moteki[5], Sho Ohata[6], Tatsuhiro Mori[7], Masahiko Hayashi[8], Keiichiro Hara[8], Hiroto Kawashima[9], Kazuyuki Kita[2]

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Aerosol particles are emitted from both natural and anthropogenic sources and travel across the globe. They influence the climate through becoming cloud condensation and ice nuclei and absorbing and scattering solar radiation both in air and on snow/ice surfaces. Black carbon (BC) is one of the most important aerosol particle for the climate and absorbs light as an impurity in surface snow/ice. As the result, BC exhibits positive radiative forcing and contributes to global warming. However, the climate effect by BC in snow still has large uncertainties because observations of BC concentrations and size distributions within surface snow are limited, especially in Antarctica. This study measured the concentrations and size distributions of BC and inorganic ions in snow samples collected at the Syowa station in Antarctica from April 2011 to December 2011 and along a traverse route to an inland (Mizuho) station during the 52nd Japanese Antarctic Research Expedition (JARE52).

The modified single particle soot photometers (SP2) were used for analyses of BC concentrations and size distributions between 70 nm and 4170 nm in snow. The average mass and number concentrations of BC (C_{MBC} and C_{NBC}) between April and November were 288.2 ng L^{-1} and 101.5 particle μL^{-1}, respectively, and those during December increased to 2117.3 ng L^{-1} and 812.7 particle μL^{-1}, respectively. The C_{MBC} and C_{NBC} of the Mizuho traverse route samples were 727.7–1153.2 ng L^{-1} and 249.6–454.6 particle μL^{-1}, respectively and were 1.7–2.7 times higher than those of the Syowa samples during the same period. The C_{MBC} values were consistent with those in previous studies observed in other areas of Antarctica. The size distributions of BC in snow were bimodal with MMD values of ~140 nm (fine) and ~690 nm (coarse). The MMD estimated by single lognormal functions in our study (149–191 nm) were smaller than those in other areas of Antarctica, and the average mass of BC particle (m_{BC}) was 2.8 (1.8–5.8) fg particle^{-1}, which is smaller than typical values in the Arctic. Inorganic ions in snow in Syowa mainly originated from sea salt and did not correlate with C_{MBC} and C_{NBC}. The Na^+ and Cl^- concentrations in snow largely decreased with increasing distance from the coastal area.

The BC concentrations in the ground-level atmosphere did not correlate with those of snow; i.e., the BC concentrations increased in December when the ambient temperature increased above 0 ˚C with strong solar irradiance. This result indicates that the BC concentrations in snow are largely influenced by postdeposition processes such as sublimation, snow melting and evaporation. Inorganic ion concentrations away from the coastal area were lower than those at the Syowa station (coastal area), suggesting that small contributions of snow transported from the ocean in the inland region. Relatively high BC concentrations away from the coastal area suggest the transport from the upper atmosphere and the less snow accumulation in inland. BC size distributions in our samples were smaller than those in other regions with neighboring BC sources. This result suggests that the BC in the Antarctic snow originated through a long-range transport, resulting in decrease in m_{BC} values by the removal of large BC particles during the transport.

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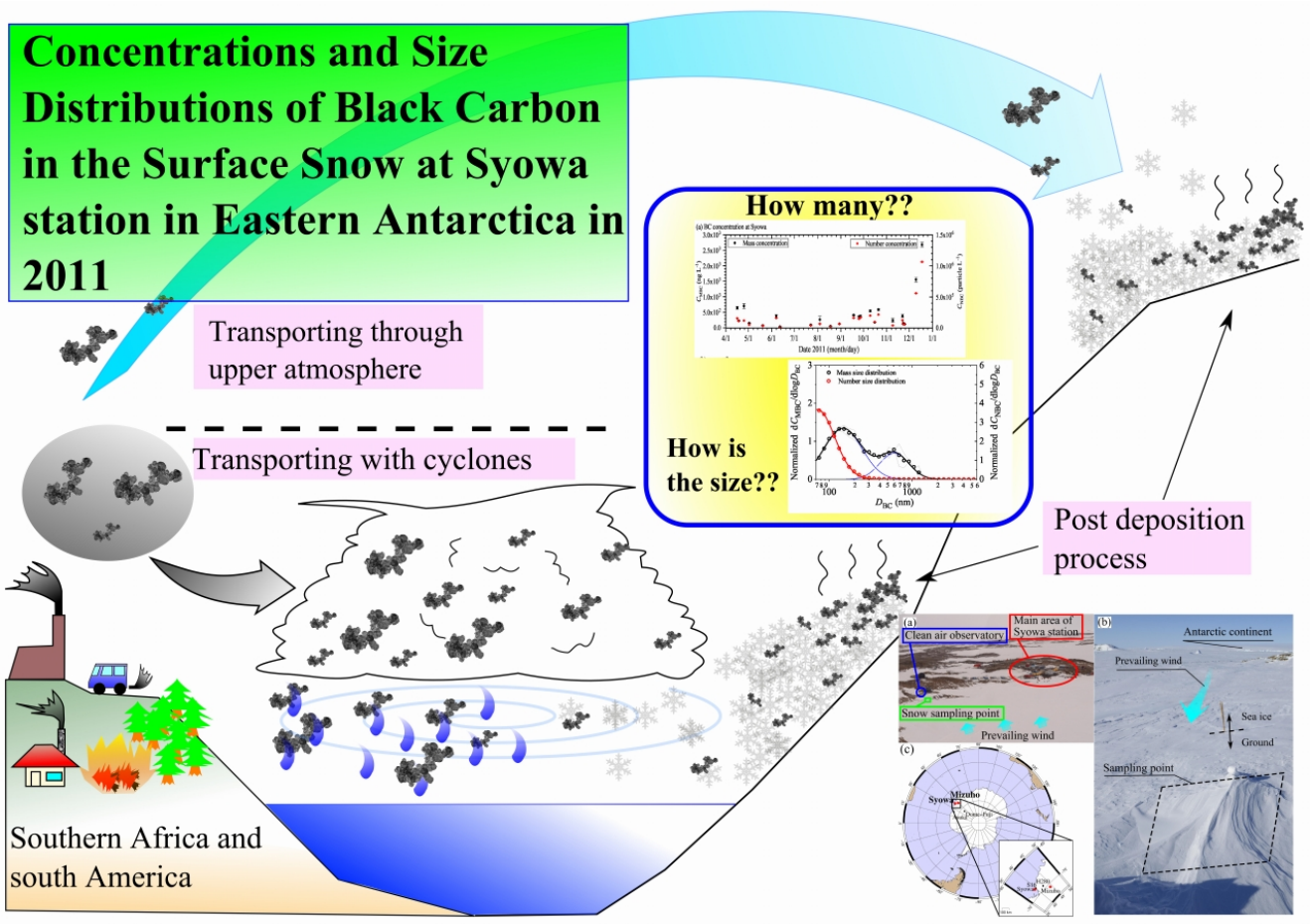
Keywords: Black carbon, BC in snow, Antarctica, Albedo, Snow, Climate



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Enhanced new particle formation above the marine boundary layer over the Yellow Sea: Potential impacts on cloud condensation nuclei

*Nobuyuki Takegawa[1], Takafumi Seto[2], Nobuhiro Moteki[3], Makoto Koike[3], Naga Oshima[4], Kouji Adachi[4], Kazuyuki Kita[5], Akinori Takami[6], Yutaka Kondo[7]

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Aircraft measurements of aerosols were conducted over the Yellow Sea and East China Sea from February 14 to March 10, 2013, during the Aerosol Radiative Forcing in East Asia 2013 Winter campaign. Ground-based measurements of aerosols were also conducted on Fukue Island, Japan. The aircraft measurements revealed large increases in particle number concentrations in the nucleation mode at altitudes of ~0.5-3 km over the Yellow Sea. This feature was attributed to enhanced new particle formation (NPF) above the marine boundary layer over the Yellow Sea. The number ratio of Aitken-mode (10-90 nm) or accumulation-mode (> 90 nm) particles to black carbon particles (tracer of primary emissions) was used to quantify the effects of NPF on particle number concentrations. We estimated that NPF increased Aitken-mode particle number concentrations by an order of magnitude at altitudes of ~1-2.5 km over the Yellow Sea. Synchronized aircraft and ground-based data suggest that vertical transport of Aitken-mode particles formed over the Yellow Sea led to large variability in the particle growth events observed on Fukue Island. A shift of sea surface temperature near Fukue Island and the resultant promotion of vertical mixing are likely the key mechanisms for this complex feature. Potential impacts of NPF on cloud condensation nuclei over the East China Sea are also discussed.

Keywords: Aerosol, New particle formation, East Asia

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Enhanced Sulfate Production During Nitrate Photolysis in the Presence of Halide Ions in Atmospheric Particles

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1. Faculty of Frontier Engineering, Institute of Science and Engineering, Kanazawa University, 2. School of Energy and Environment, City University of Hong Kong, 3. Shanghai Academy of Environmental Sciences, 4. Department of Civil and Environmental Engineering, Faculty of Science and Technology, University of Macau

Heterogeneous oxidation of SO_2 is an effective production pathway of sulfate in the atmosphere. We recently reported a novel pathway for the heterogeneous oxidation of SO_2 by in-particle oxidants (OH, NO_2 and NO_2^-/HONO) produced from particulate nitrate photolysis (Environ. Sci. Technol. 2019, 53, 8757–8766). Particulate nitrate is often found to coexist with chloride and other halide ions, especially in aged sea-salt aerosols and combustion aerosols. Reactive uptake experiments of SO_2 with UV-irradiated nitrate particles showed that sulfate production rates were enhanced by a factor of 1.4, 1.3 and 2.0 in the presence of Cl^-, Br^- and I^-, respectively, compared to those in the absence of halide ions. The larger sulfate production was attributed to enhanced nitrate photolysis promoted by the increased incomplete solvation of nitrate at the air-particle interface due to the presence of surface-active halide ions. Modeling results based on the experimental data show that the nitrate photolysis rate constants increase by a factor of 2.0, 1.7, and 2.1 in the presence of Cl^-, Br^- and I^-, respectively. The present study demonstrates that the presence of halide ions enhances sulfate production produced during particulate nitrate photolysis and provides insights into the enhanced formation of in-particle oxidants that may increase atmospheric oxidative capacity.

Keywords: Enhanced nitrate photolysis, Halide ions, Sulfate production, Heterogeneous photochemistry

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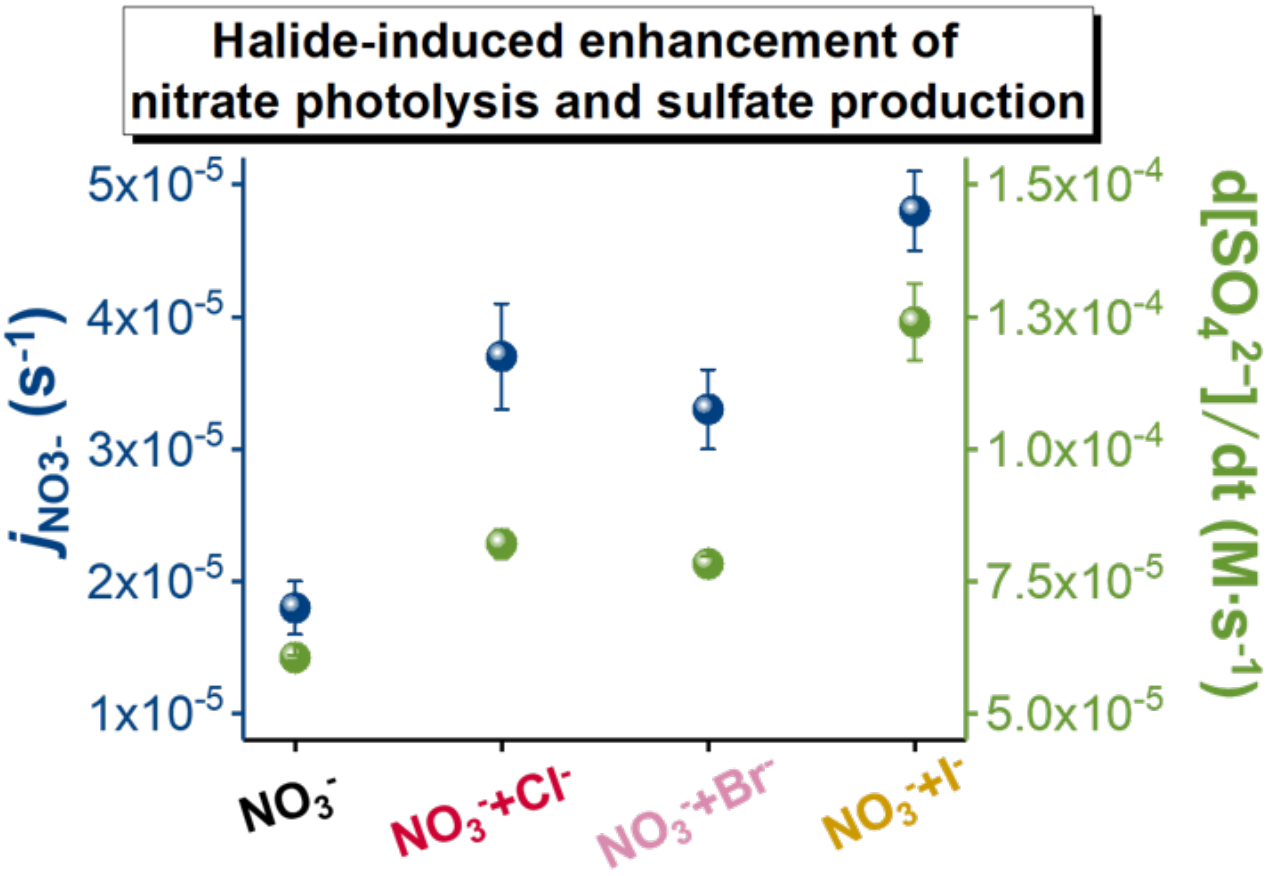

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS07] Atmospheric Chemistry

convener:Naoko Saitoh(Center for Environmental Remote Sensing), Tomoki Nakayama(Graduate School of Fisheries and Environmental Sciences, Nagasaki University), Sakae Toyoda(Department of Chemical Science and Engineering, Tokyo Institute of Technology), Risa Uchida(Japan Automobile Research Institute)

This session provides a forum for the presentation of the broad spectrum of tropospheric and stratospheric chemistry, including various research topics (e.g., dynamical processes, air quality and climate), approaches (modeling, field measurements, remote sensing, and laboratory studies), and species (gas and aerosol). This session also provides an opportunity for discussing possible future collaboration with other research fields relevant to atmospheric chemistry.

[AAS07-22] Investigation on new particle formation competing against the growth of pre-existing particles during isoprene ozonolysis

*Satoshi Inomata[1], Jun Hirokawa[2] (1.National Institute for Environmental Studies, 2.Hokkaido University)

[AAS07-23] **Assessment of the role of saltingout effect on the hygroscopicity of urban atmospheric aerosol**

*Phuong Nguyet Phung[1], Michihiro Mochida[1,2], Sho Ohata[2], Yuzo Miyazaki[3], Eri Tachibana[3] (1.Graduate School of Environmental Studies,Nagoya University, Nagoya 464-8601, Japan, 2.Institute for Space-Earth Environmental Research, Nagoya University, Nagoya 464-8601, Japan, 3.Institute of Low Temperature Science, Hokkaido University, Sapporo, 060-0819, Japan)

[AAS07-24] **Investigation on temperature- and acidity-dependence of the formation of secondary organic aerosol from α-pinene ozonolysis**

*Yange Deng[1], Satoshi Inomata[1], Kei Sato[1], Sathiyamurthi Ramasamy[1], Yu Morino[1], Shinichi Enami[1], Hiroshi Tanimoto[1] (1.National Institute for Environmental Studies)

[AAS07-25] Accurate Identification of Dimers from α-Pinene Oxidation Using High-Resolution Collision-Induced Dissociation Mass Spectrometry

*Kanako Sekimoto[1,2], Daisuke Fukuyama[1], Satoshi Inomata[3] (1.Yokohama City University, 2.Osaka University, 3.National Institute for Environmental Studies)

[AAS07-26] **Application of SERS on the chemical speciation of individual nanoparticles**

Ryota Kunihisa[1], Ayumi Iwata[2], Masao Gen[3,4], Chak Keung Chan[4], *Atsushi Matsuki[5] (1.Graduate School of Natural Science and Technology, Kanazawa University, 2.Faculty of Science and Technology, Keio University, 3.Institute of Science and Engineering, Kanazawa University, 4.School of Energy and Environment, City University of Hong Kong, 5.Institute of Nature and Environmental Technology, Kanazawa University)

[AAS07-27] Development of a Novel Particle Mass Spectrometer for Online Measurements of Refractory Sulfate Aerosols

*Yuya Kobayashi[1], Yu Ide[1], Nobuyuki Takegawa[1] (1.Graduate School of Science, Tokyo Metropolitan University)

Investigation on new particle formation competing against the growth of pre-existing particles during isoprene ozonolysis

*Satoshi Inomata[1], Jun Hirokawa[2]

1. National Institute for Environmental Studies, 2. Hokkaido University

Atmospheric aerosols scatter and absorb incoming solar radiation, which directly impact the global radiative balance of the atmosphere. If these aerosols are hydrophilic, they can act as cloud condensation nuclei (CCN) and have an indirect effect on the climate by modifying the properties of clouds. New particle formation (NPF) through nucleation is believed to contribute up to half of the global CCN concentrations. The nucleation and growth mechanisms of new particles in the atmosphere have therefore been topics of study in atmospheric research. Recently, we observed NPF during ozonolysis of small alkenes such as isoprene and ethene even in the presence of seed aerosol. We proposed that oligomeric hydroperoxides originated from stabilized Criegee intermediates (sCIs) that were generated during the ozonolysis of the small alkenes potentially contribute to the NPF while competing with the uptake into pre-existing particles. To evaluate quantitatively whether this type of NPF is important in real atmosphere, we have tried to estimate an “yield of the NPF (y^{NPF}) competing against the growth of pre-existing particles”. For this purpose, we carried out two groups of experiments with same initial conditions except the relative humidity (RH): one group was under less humid conditions (including dry conditions, RH < 20 %) and the other group was under high humid conditions (RH > 20 %). The number concentration of the NPF (N^{NPF}) was defined as the concentration difference between two groups of experiments. The number concentration of the particles related to the growth of pre-existing particles (N^{uptake}) was defined as the concentration under high humid conditions from which the concentration of the seed particles was subtracted. The value of y^{NPF} was determined by $N^{NPF}/(N^{NPF} + N^{uptake})$. In this study, isoprene ozonolysis was tested with this method. The influence of the number concentration and acidity of pre-existing particles, temperature, relative humidity (RH), the presence of OH radical scavenger, and the concentration of the reactants on the NPF yield was investigated. The formation of new particles with the diameters of less than 30 nm was observed in the presence of seed particles whose mean diameter was ~90 nm. Strong dependence of the NPF yield on RH was obtained: i.e., the yield decreased substantially with the increase of RH. In addition, the yield of the NPF was sensitive to the number concentration of the pre-existing particles. The NPF was dominant when the number concentration of the pre-existing particles was less than 10^4 cm^{-3} in our experimental conditions. The yield was low when the concentrations of the reactants were low. The acidity of seed particles and temperature did not affect the yield of the NPF obviously. This methodology can be used for the prediction of NPF in real atmosphere where extremely low volatility organic compounds (ELVOCs) act as the main nucleation agents in real atmosphere. We thank Ms. Sumiko Komori for her technical support. This work was supported by Steel Foundation for Environmental Protection Technology (FY2018–FY2020).

Keywords: New particle formation, Nucleating agent, Isoprene ozonolysis, Criegee intermediates, Oligomeric hydroperoxide

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Assessment of the role of saltingout effect on the hygroscopicity of urban atmospheric aerosol

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Atmospheric aerosols are complex mixtures consisting of inorganic and organic compounds [Jing et al., 2017], where water-soluble matter accounts for a large portion of the total mass [Wang et al., 2003; Almeida et al., 2005]. For cloud condensation nucleus (CCN) activation ofaerosol particles, inorganic salts could influence on the surface tension and thus the CCN activation by so-called salting out effect [Prisle et al., 2010]. In this study, the surface tension of water-soluble matter collected in Nagoya, with and without addition of ammonium sulfate, was investigated to assess whether salting out effect should be taken into account for the prediction of the CCN activation of aerosol particles.

Water soluble matter in aerosol samples collected using a high volume sampler with a cascade impactor was extracted using water, and the extract solutions were concentrated. The solutions and those diluted from the original solutions were subjected to the surface tension measurements using a pendant drop tensiometer (DM-301, Kyowa Interface Science Co., Ltd). The surface tension of the extract solutions with addition of ammonium sulfate was also measured in the same manner.

When the concentrations of water-soluble organic matter were relatively low (0.004 and 0.010 mol-C L^{-1}), the reduction in surface tension by adding ammonium sulfate was found to be small regardless of up to 0.1 M ammonium sulphate. By contrast, the clear decrease in surface tension was found for a higher concentration of water-soluble organic matter with the higher concentration of ammonium sulfate. The surface tension lowered gradually during 2 min of measurements for all samples. The result suggests that the surface tension of atmospheric aerosol particles could be lower than prediction if longer residence times in the real atmosphereis not considered appropriately. The cloud-forming potential of inorganic/organic mixed particles should be further investigated by taking into account the possible importance of the salting out effect by inorganic salts.

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Investigation on temperature- and acidity-dependence of the formation of secondary organic aerosol from α-pinene ozonolysis

*Yange Deng[1], Satoshi Inomata[1], Kei Sato[1], Sathiyamurthi Ramasamy[1], Yu Morino[1], Shinichi Enami[1], Hiroshi Tanimoto[1]

1. National Institute for Environmental Studies

Secondary organic aerosol (SOA) accounts for 20–90 % of submicrometer aerosol mass and is thus of great importance in affecting human health and the prediction of climate change. The formation of SOA in ambient atmosphere is influenced by both the environment temperature and the acidity of precursor reactants. However, these factors are not embodied in current atmospheric chemistry models mainly because our understanding on them is insufficient. In this study, a new Teflon atmospheric simulation chamber, in which reactions in atmospheric pressure conditions can be performed with controlled temperature, humidity, light, and seed particles (with/without, and different acidity), is developed. α-Pinene ozonolysis is simulated under temperatures of 278 K, 288 K, and 298 K with neutral/acidic seed aerosol particles. In each experimental run, excess ozone was introduced to the chamber and α-pinene was almost fully consumed by the end of the experiment. SOA were collected onto Teflon filters and were analyzed using negative electrospray ionization liquid-chromatography time-of-flight mass spectrometry (LC-TOF-MS). SOA yield increased with the decrease of temperature. While this could be caused by the shifting of the partition of semi-volatile organic vapors (SVOC) between gas and aerosol phases toward the aerosol phase at the low temperature, the low enthalpy of vaporization might indicate the large contribution of water to SOA yield at the low temperature. Volatility distribution of SOA components, which is represented by the vapor saturation concentration in logarithmic scale ($\log_{10}C^*$) in unit interval, was derived under different experimental conditions in order to see chemical changes macroscopically. Compared with neutral seed conditions, the mass fraction of SOA at $\log_{10}C^*$=-1 decreased and that at $\log_{10}C^*$=-4, -3 increased in the condition of acidic seed particles (~200 μmol m^{-3}) at 298 K. Chemical composition analyses indicated that the difference was probably caused by the formation of organosulfate, which could lead to increased SOA yield under acidic seed conditions. Under acidic seed conditions, mass fraction of SOA at $\log_{10}C^*$=-9, -8 (m/z range: 411-453) increased with the decrease of temperature, which might suggest that the formation of products by acid-catalyzed heterogeneous reactions were more effective at the low temperature.We thank Dr. Tomoharu Sano and Ms. Sumiko Komori for their technical supports. This research is supported by the NIES Research Funding (Type A).

Keywords: Secondary organic aerosol, Acidity of seed aerosol, α-Pinene ozonolysis, Temperature dependence of SOA yield, Volatility distribution

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Accurate Identification of Dimers from α-Pinene Oxidation Using High-Resolution Collision-Induced Dissociation Mass Spectrometry

*Kanako Sekimoto[1,2], Daisuke Fukuyama[1], Satoshi Inomata[3]

1. Yokohama City University, 2. Osaka University, 3. National Institute for Environmental Studies

Highly oxidized dimers from α-pinene oxidation are essential to the atmospheric chemistry field because they are efficient precursors of secondary organic aerosols. Here we apply high-resolution collision-induced dissociation (CID) mass spectrometry with an atmospheric pressure ionization (API) source to accurately identify the origin of dimers from α-pinene + O_3/OH/NO_x reactions. The CID spectra and specific fragmentation patterns suggest that (i) a large fraction of dimer ions detected in full-scan mass spectra can be hydrogen-bonded clusters, which are instrument artifacts; these clusters form owing to the adiabatic expansion between the API source inside a mass spectrometer, and (ii) the residual small fraction includes covalently-bonded dimers, such as hydroperoxide-type dimers, that are formed from reactions between a stabilized Criegee Intermediate (sCI) and oxidized monomers. This work highlights the importance of accurate identification and quantification of dimers for mechanistic and kinetic studies of α-pinene-derived dimer formation using ion intensities detected by mass spectrometry.

Keywords: α-Pinene, Oxidation, Dimer, High-resolution collision-induced dissociation mass spectrometry, Hydrogen-bonded artifact cluster

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Application of SERS on the chemical speciation of individual nanoparticles

Ryota Kunihisa[1], Ayumi Iwata[2], Masao Gen[3,4], Chak Keung Chan[4], *Atsushi Matsuki[5]

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The smallest of atmospheric particles are less than 100 nm in diameter and also termed as nanoparticles. The subset of particles in this size range can also act as cloud condensation nuclei and have significant impact on the regional and global climate. Also, human exposure to anthropogenic nanoparticles is an emerging health concern since their impact maybe overlooked by the conventional regulatory measures such as $PM_{2.5}$. However, the chemical speciation of nanoparticles is technically challenging because of the minute particle mass. There is a constant need for more effective collection method and sensitive chemical analysis, which can detect and resolve the evolution of the chemical compounds of nanoparticles in the atmosphere. In this study, we examined the applicability of surface enhanced Raman spectroscopy (SERS) on the rapid and sensitive chemical analysis of nanoparticles. SERS provides a drastic enhancement of the scattering efficiency over traditional Raman spectroscopy. The novelty of the proposed technique is that a SERS substrate was directly used as a sampling substrate of nanoparticles in the condensation growth tube (CGT) sampler (Series 110 Liquid Spot Sampler, Aerosol Device Inc.), which can activate nanoparticles into water droplets (~3 μm) and ensures their inertial impaction on the SERS substrate. Additional advantage is that while the SERS substrate requires the analyte in the form of water solution but Spot Sampler can activate nanometer-sized particles into large liquid droplets (~3 μm). Using the SERS method, we investigated laboratory generated ammonium sulfate and levoglucosan particles of 20 nm, 50 nm, and 100 nm, as well as ambient nanoparticles. Based on the successful detection of the peaks corresponding to sulfate $\nu(SO_4^{2-})$ and organics ν(C-H) modes, our proposed method of combined CGT sampler and SERS technique showed sensitivity high enough for detecting major chemical components from nanoparticles as small as 20 nm. Furthermore, comparison of chemical composition inferred both from current method and that from hygroscopicity of ambient particles showed consistent results.

Keywords: nanoparticle, droplet activation, Raman spectroscopy, SERS

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Development of a Novel Particle Mass Spectrometer for Online Measurements of Refractory Sulfate Aerosols

*Yuya Kobayashi[1], Yu Ide[1], Nobuyuki Takegawa[1]

1. Graduate School of Science, Tokyo Metropolitan University

Sulfate aerosols are ubiquitous in the atmosphere. Ammonium sulfate (AS) is generally the dominant form of sulfate aerosols in urban air, whereas potassium sulfate (PS), sodium sulfate (SS), magnesium sulfate (MS), and calcium sulfate (CS) may have large contributions in remote areas. Currently available methods for online measurements of sulfate aerosols, which are based on ion-chromatography (IC) or thermal desorption aerosol mass spectrometry, cannot separately quantify nonrefractory and refractory sulfate compounds. We have developed a new particle mass spectrometer to measure nonrefractory and refractory sulfate compounds based on a laser-induced, high-temperature thermal desorption method (hereafter referred to as HT-LDMS). Aerosol particles are introduced into a vacuum chamber via an aerodynamic lens unit, and are collected on a U-shaped graphite target (graphite collector). A focused CO_2 laser coupled with the graphite collector enables high desorption temperature (black-body equivalent temperature of ~950˚C) for detecting AS, PS, SS, and MS aerosols. The gas molecules evolved from these compounds are detected using a quadrupole mass spectrometer. The performance of the HT-LDMS has been tested in the laboratory. Preliminary data indicate that the HT-LDMS can separately quantify AS, PS, SS, and MS particles.

Keywords: Aerosol, Refractory, Sulfate, Online measurement, Thermal desorption aerosol mass spectrometer

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS08] Stratosphere-troposphere interaction

convener:Takatoshi Sakazaki(Graduate School of Science, Kyoto University), Takenari Kinoshita(Japan Agency for Marine-Earth Science and Technology), Pu Lin(Princeton University/NOAA Geophysical Fluid Dynamics Laboratory), Peter Hitchcock(Cornell University)

The dynamical, radiative, and chemical processes involved in the interactions between the stratosphere and troposphere are essential for understanding the present and future climate. Both observed data and high-resolution models have now clearly demonstrated that stratospheric processes can affect various tropospheric phenomena. Recently, processes coupling the troposphere and stratosphere in the tropical region have become a new focus.
 It has also been shown that the accuracy of tropospheric sub-seasonal and seasonal scale forecasts can be improved by more accurate representations of the stratosphere. As a result, interest is increasing in the predictability and reproducibility of specific stratospheric phenomena, including the Quasi-Biennial Oscillation (QBO) and its recent disruption as well as Stratospheric Sudden Warmings (SSW).
 This session will highlight recent progress in our understanding of stratosphere-troposphere interaction. We welcome studies of these and related phenomena in the troposphere and stratosphere (and mesosphere) based on observation, models and theory. Further, this session builds upon the middle atmosphere session traditionally held at the JpGU annual meetings and aims to provide a platform for sharing recent findings and promoting international collaborations on this topic.

[AAS08-01] Influences on the timing of Sudden Stratospheric Warmings

★Invited Papers

*Lesley J Gray[1], Matt Brown[1], Jeff Knight[2] (1.University of Oxford, 2.Met Office)

[AAS08-02] Hindcast Experiment of the 2009 Sudden Stratospheric Warming and Following Elevated Stratopause Event by Using a High-Top Gravity Wave Resolving Model

★Invited Papers

*Shunsuke Noguchi[1], Shingo Watanabe[1], Dai Koshin[2], Kaoru Sato[2] (1.Japan Agency for Marine-Earth Science and Technology, 2.The University of Tokyo)

[AAS08-03] **Seasonal Prediction Skill of Northern Extratropical Surface Temperature Driven by the Stratosphere**

*Liwei Jia[1,2], Xiaosong Yang[1,2], Gabriel Vecchi[3], Richard Gudgel, Thomas Delworth[1], Stephan Fueglistaler[3], Pu Lin[3], Adam Scaife[4], Seth Underwood[1], Shian-Jiann Lin (1.NOAA Geophysical Fluid Dynamics Laboratory, 2.University Corporation for Atmospheric Research, 3.Princeton University, 4.Met Office Hadley Centre)

[AAS08-04] Persisted negative Antarctic oscillations after sudden stratospheric warming in the Southern Hemisphere in 2019

*Chiaki Kobayashi[1], Shuhei Maeda[1] (1.Meteorological Research Institute)

[AAS08-05] Probabilistic skill in seasonal forecasts of stratospheric extreme events

*Peter Hitchcock[1], Daniela Domeisen[2], Mikhail Dobrynin[3], Johanna Baehr[4] (1.Department of Earth and Atmospheric Sciences, Cornell University, Ithaca, NY, USA, 2.Institute for Atmospheric and Climate Science, ETH Zürich, Switzerland, 3.Deutscher Wetterdienst (DWD), Hamburg, Germany, 4.Institute of Oceanography, Center for Earth System Research and Sustainability (CEN), University of Hamburg, Germany)

Discussion

Influences on the timing of Sudden Stratospheric Warmings

*Lesley J Gray[1], Matt Brown[1], Jeff Knight[2]

1. University of Oxford, 2. Met Office

Extreme stratospheric polar events, in the form of sudden stratospheric warmings (SSWs) have been shown to impact weather at the surface in the Northern Hemisphere, so an ability to accurately forecast them would improve forecast skill. Many studies have shown that statistical skill can be gained from knowledge of the QBO, ENSO and solar cycle phase, but only in general terms of whether a warming is likely sometime during the winter season. More accurate forecasts of the timing within the winter is desirable but current forecast models perform poorly in this respect. This study examines the factors that influence the timing of SSWs using several case studies of both displaced and split vortex winters. Using the Met Office Unified Model experiments are performed in which various regions of the atmosphere are nudged towards observations to explore their importance in determining the timing of the SSW evolution. Results from experiments will be described, with particular emphasis on the role of the upper equatorial stratosphere.

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Hindcast Experiment of the 2009 Sudden Stratospheric Warming and Following Elevated Stratopause Event by Using a High-Top Gravity Wave Resolving Model

*Shunsuke Noguchi[1], Shingo Watanabe[1], Dai Koshin[2], Kaoru Sato[2]

1. Japan Agency for Marine-Earth Science and Technology, 2. The University of Tokyo

A series of hindcast experiments on the 2009 Sudden Stratospheric Warming (SSW) and following Elevated Stratopause (ES) event is conducted by using a high-top model named Japanese Atmospheric General circulation model for Upper Atmospheric Researches (JAGUAR). A comparative examination of hindcasts by JAGUAR in both a Gravity Wave (GW) resolving setting and a low-resolution setting with GW parametrizations reveals a superior performance of the former on reproducing detailed features of the SSW-ES event. In particular, the ES-related residual circulation in the polar mesosphere-lower thermosphere tends to show different behavior despite some effort of tuning parameters in the later. This talk will present details of such a benefit of the explicit simulation of GWs and discuss some challenges in the predictability study of the middle atmosphere.

Keywords: Sudden Stratospheric Warming, Elevated Stratopause, Gravity Wave Resolving Model

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Seasonal Prediction Skill of Northern Extratropical Surface Temperature Driven by the Stratosphere

*Liwei Jia[1,2], Xiaosong Yang[1,2], Gabriel Vecchi[3], Richard Gudgel, Thomas Delworth[1], Stephan Fueglistaler[3], Pu Lin[3], Adam Scaife[4], Seth Underwood[1], Shian-Jiann Lin

1. NOAA Geophysical Fluid Dynamics Laboratory, 2. University Corporation for Atmospheric Research, 3. Princeton University, 4. Met Office Hadley Centre

Motivated by the fact that low seasonal prediction skill of surface climate over extratropical land, this study explores the role of the stratosphere as a source of seasonal predictability of surface climate over Northern Hemisphere extratropics both in the observations and climate model predictions. Using GFDL FLOR model, a suite of numerical experiments are set up to isolate the role of the stratosphere in seasonal predictive skill of extratropical near-surface land temperature. We found that most of the lead-0-month spring predictive skill of land temperature over extratropics, particularly over northern Eurasia, stems from stratospheric initialization. We further revealed that this predictive skill of extratropical land temperature arises from skillful prediction of the Arctic Oscillation (AO). The dynamical connection between the stratosphere and troposphere is also demonstrated by the significant correlation between the stratospheric polar vortex and sea level pressure anomalies, as well as the migration of the stratospheric zonal wind anomalies to the lower troposphere.

Keywords: seasonal skill, surface temperature, stratosphere

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Persisted negative Antarctic oscillations after sudden stratospheric warming in the Southern Hemisphere in 2019

*Chiaki Kobayashi[1], Shuhei Maeda[1]

1. Meteorological Research Institute

In the early September 2019, a sudden stratospheric warming (SSW) occurred in the southern hemisphere for the first time in 17 years. The impact extended downward to the Earth’s surface, and the negative-phase of the Antarctic Oscillation (AAO) in the troposphere persisted from mid-October to the end of December. In this study, the relationship between SSW and negative AAO persistence in the troposphere was investigated from the viewpoint of wave-mean flow interaction applying the mass-weighted isentropic zonal mean (MIM) method to the Japan Meteorological Agency's 55-year reanalysis dataset (JRA-55). With this method, it is possible to evaluate the divergence of E-P flux in the troposphere including near the surface, the anomalies of the meridional circulation in the troposphere and the outflow of cold air to mid-latitudes. The anomalies are deviation from climatology of the 30-year average of 1981-2010.

First, the time-altitude cross-section of the standardized anomalies of the zonal mean geopotential height field averaged from 60S to 90S is examined to see the temporal change in the strength of the polar vortex from the stratosphere to the troposphere due to the SSW. After the SSW in the early September, weak state of the polar vortex persisted in the upper stratosphere, and the center of the height anomalies descended to the lower stratosphere in the mid-October. At the same time, the positive anomalies exceeded one sigma in the troposphere and then the situation continued throughout the end of December. The zonally averaged 300 hPa geopotential height anomalies shows positive anomalies over high latitudes area (60S-90S) and negative anomalies over the area from 35S-60S, indicating that negative AAO phase persists corresponding to the weakening of the polar vortex from mid-October to December.

In order to investigate the tropospheric situation during the period of negative AAO phase (16Oct-31Dec), the zonal-mean zonal wind, E-P flux and meridional circulation are compared with climatology in terms of wave-mean flow interaction. The stratospheric polar night jet seen in the climatology lacks in 2019 in the zonal-mean zonal wind field. Associated to the lack, there is no waveguide along with the polar night jet that exists in the climatology. The analysis on the refractive index in 2019 indicates the region where planetary waves from the troposphere cannot (or hardly) propagate vertically above the tropopause region of 40S 70S. This situation resembles the situation in December after the final warming of the stratosphere in the climatology. Associated with the situation, the vertical propagation of the E-P flux of stationary waves from the troposphere to the stratosphere over the high-latitudes is weak and converges more in the upper troposphere. In addition, the meridional distribution of the E-P flux of transient waves shifts to the low latitude side, and contributes to the persisted southward shift of the subtropical jet. The convergence anomalies of the E-P flux of these waves over the 40S-70S in the troposphere induce the direct circulation anomalies in the high-latitude. As a result, high-latitude cold air flow to mid latitudes and is likely to contribute to the maintenance of negative AAO.

Keywords: sudden stratospheric warming, Antarctic Oscillation, persisted tropospheric zonal-mean anomaly

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Probabilistic skill in seasonal forecasts of stratospheric extreme events

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Deterministic forecasts of major mid-winter sudden stratospheric warmings are generally thought to be reliable about two weeks prior to the wind reversal at 60 N, 10 hPa. However, the probability of their occurrence in a given year is thought to be influenced by various slowly-evolving components of the climate system, including the phase of the QBO or of ENSO. This suggests the potential for some predictability in the system at seasonal timescales. Given the importance of such extreme events for surface weather and climate, particularly the subset of sudden warmings known as Polar-night Jet Oscillation events that are associated with extended recovery periods, accurately identifying and exploiting any such predictability would be of value. We report here on the study of a 30-ensemble set of seasonal forecasts from the MPI-ESM seasonal prediction model, initialized each November 1st. This ensemble provides clear statistical evidence that information does exist in the initial conditions of the combined atmosphere, ocean, land-surface system regarding the likelihood of PJO events during the upcoming winter. Moreover, this information is skillful, in that years which were forecast to have an increased likelihood of a stratospheric extreme event are in fact more likely to have exhibited such an event. This skill in forecasting stratospheric events can also be demonstrated to lead to enhanced skill at the surface.

Keywords: Seasonal prediction, Stratospheric sudden warmings

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS08] Stratosphere-troposphere interaction

convener:Takatoshi Sakazaki(Graduate School of Science, Kyoto University), Takenari Kinoshita(Japan Agency for Marine-Earth Science and Technology), Pu Lin(Princeton University/NOAA Geophysical Fluid Dynamics Laboratory), Peter Hitchcock(Cornell University)

The dynamical, radiative, and chemical processes involved in the interactions between the stratosphere and troposphere are essential for understanding the present and future climate. Both observed data and high-resolution models have now clearly demonstrated that stratospheric processes can affect various tropospheric phenomena. Recently, processes coupling the troposphere and stratosphere in the tropical region have become a new focus.
 It has also been shown that the accuracy of tropospheric sub-seasonal and seasonal scale forecasts can be improved by more accurate representations of the stratosphere. As a result, interest is increasing in the predictability and reproducibility of specific stratospheric phenomena, including the Quasi-Biennial Oscillation (QBO) and its recent disruption as well as Stratospheric Sudden Warmings (SSW).
 This session will highlight recent progress in our understanding of stratosphere-troposphere interaction. We welcome studies of these and related phenomena in the troposphere and stratosphere (and mesosphere) based on observation, models and theory. Further, this session builds upon the middle atmosphere session traditionally held at the JpGU annual meetings and aims to provide a platform for sharing recent findings and promoting international collaborations on this topic.

[AAS08-06] Investigating the missing gravity wave drag in the Southern Hemisphere via satellite observations

★Invited Papers

*Laura Angelina Holt[1], M Joan Alexander[1], Colby M Brabec[1] (1.NorthWest Research Associates)

[AAS08-07] Gravity waves parameterized by a transient gravity-wave model coupled with convective sources: Wave intermittency

★Invited Papers

*Young-Ha Kim[1], Gergely Bölöni[1], Sebastian Borchert[2], Hye-Yeong Chun[3], Ulrich Achatz[1] (1.Goethe-Univ. Frankfurt, Germany, 2.DWD, Germany, 3.Yonsei Univ., Korea)

[AAS08-08] Formation of the double stratopauses and elevated stratopause associated with the major stratospheric sudden warming in 2018/19

*Haruka Okui[1], Kaoru Sato[1], Dai Koshin[1], Shingo Watanabe[2] (1. Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo , 2.Japan Agency for Marine-Earth Science and Technology)

[AAS08-09] **A tropospheric pathway of the stratospheric QBO impact on the boreal winter polar vortex**

*Koji Yamazaki[1], Tetsu Nakamura[1], Jinro Ukita[2], Kazuhira Hoshi[2] (1.Hokkaido University, 2.Niigata University)

[AAS08-10] Do sudden stratospheric warmings boost convective activity in the tropics?

*Kohei Yoshida[1] (1.Meteorological Research Institute)

Discussion

Investigating the missing gravity wave drag in the Southern Hemisphere via satellite observations

*Laura Angelina Holt[1], M Joan Alexander[1], Colby M Brabec[1]

1. NorthWest Research Associates

Recent assessments of chemistry-climate models (CCMs) reveal biases in temperatures and winds in, especially but not limited to, the Southern Hemisphere stratosphere, where winds are generally too strong and temperatures too cold. The reasons for these biases are not completely understood, but it is thought that missing gravity wave drag in models is a major culprit. Understanding the sources of the missing drag and correcting the deficiencies in modeled gravity wave effects is a high priority since the resulting model biases in wind and temperature hinder our ability to realistically model the ozone hole and its recovery, which also has implications for our ability to model tropospheric climate change. However, observational constraints on gravity wave parameterizations have remained difficult to establish. In this presentation we show results using the High Resolution Dynamic Limb Sounder (HIRDLS) to investigate the missing drag in the Southern Hemisphere. We derive detailed gravity wave properties and obtain new observational estimates of the gravity wave drag in the stratosphere to guide gravity wave parameterizations in CCMs.

Keywords: gravity waves, ozone, satellite observations

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Gravity waves parameterized by a transient gravity-wave model coupled with convective sources: Wave intermittency

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1. Goethe-Univ. Frankfurt, Germany, 2. DWD, Germany, 3. Yonsei Univ., Korea

Gravity waves (GWs) transport a large amount of momentum throughout the deep atmosphere, which is crucial for large-scale circulations in the middle atmosphere. Due to the scales of GWs and their sources, down to about 1-10 km, they are not fully resolved in large-scale models, so that their effects are parameterized in a simplified framework. Such simplications include, among others, the steady-state assumption by which the vertical profiles of GW properties are diagnosed instantaneously throughout the model-grid column at each time step. Thus, in the steady-state representation, GWs are modeled as if they propagate to the model top within one time step, and the interaction between GWs and the mean flow is ignored unless waves dissipate. In the real atmosphere, it can take a long time for GWs to propagate to, e.g., the mesosphere (~10 hours or more, depending on the wave characteristics), and the mean flow may evolve substantially during the time, which can induce both non-dissipative and dissipative GW-mean-flow interactions. In this regard, a prognostic GW model, Multi-Scale Gravity-Wave Model (MS-GWaM), has been developed, fully representing the transient GW dynamics.

In this presentation, we show the application of MS-GWaM to a global model as a subgrid-scale parameterization and investigate the effects of transient GW dynamics. A particular interest is in the representation of GW intermittency, which can affect the vertical distribution of GW forcing (by determining wave-breaking altitudes). In order to include the wave sources' intermittency and variability, MS-GWaM is coupled to convective sources, diagnosed by cumulus parameterization, based on an analytic formulation of GW response to a heat source. In addition to this, a spatio-temporally uniform, persistent source is prescribed in the extratropics to take into account other non-orographic sources. Orographic sources are currently not coupled to MS-GWaM, so that the intermittency is assessed only for the non-orographic GWs. The GW intermittency is investigated by probability distributions of GW pseudomomentum flux as well as by the Gini index of the flux. The modeled intermittency is found to be quite high in the tropics, compared to that in the extratropics. In both regions, the Gini index has faily similar values to those observed by superpressure balloons reported in previous studies. A control simulation is performed using GW parameterization based on the steady-state assumption, but coupled to the same wave sources, in order to assess the effects of transient GW modeling on the simulated intermittency. In comparison with the control simulation, it is found that the transient GW modeling leads to increase in the intermittency of GWs from the persistent source but mitigates the intermittency from convective sources.

Keywords: gravity wave, transient parameterization, wave intermittency

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Formation of the double stratopauses and elevated stratopause associated with the major stratospheric sudden warming in 2018/19

*Haruka Okui[1], Kaoru Sato[1], Dai Koshin[1], Shingo Watanabe[2]

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In some major stratospheric sudden warming (SSW) events, the stratopause once disappears after the warming and reforms at an elevated height (e.g., Siskind et al., 2007; Manney et al., 2008, 2009), which is called the “elevated stratopause” (ES). Tomikawa et al. (2012) showed that the ES forms and descends to the climatological height of the stratosphere due to the westward gravity wave forcing (GWF), while some studies indicated that planetary wave (s=1) forcing (PWF) is important for the initial formation of the ES (e.g., Limpasuvan et al., 2012). However, details are not well understood. Clarifying how the middle atmosphere is modulated responding to the SSW, it is effective to conduct a quantitative study by using a GW-resolving GCM that covers from the troposphere to the mesosphere and lower thermosphere (MLT). In this study, using the outputs of the simulation of the 2018/2019 SSW event carried out by a GW-resolving GCM containing the MLT region, we analyzed dynamical phenomena occurred in the whole middle atmosphere. As a result, we found that the ES formed after the major warming on January 1 and a significant temperature maximum appeared in the polar upper mesosphere around December 28 prior to the ES formation, which is referred to as the “double stratopause” (DS). Then we focused on the formation of the DS and ES and analyzed the role of wave forcing in these phenomena.
First, the cause of the DS formation is described. A eastward jet existed at a latitude/height of ~30˚N/~70km since 7 days before the DS formation, and the GWF is positive above and negative below the jet. On the polar side of this GWF>0, negative latitudinal gradient of potential vorticity (PV) is observed. Subsequently, PWF>0 and PWF<0 appeared, which act to eliminate the anomalous PV gradient. Therefore, plausible processes of the DS formation are that 1) the GWF makes a weak temperature maximum at higher latitudes, 2) the mean field becomes unstable, 3) and then PWs are generated and exert forcing which intensifies the temperature maximum in the polar upper mesosphere.
Second, the formation process of the ES is discussed. On January 10 when the ES formed, GWF was strongly negative in the polar upper mesosphere. The eastward jet is reformed in the polar mesosphere on that day. This means that critical level filtering by the jet causes GWF<0, which is important for the ES formation, as Tomikawa et al. (2012) suggested. Thus, we examined the recovery mechanism of this jet. Before the warming, stratospheric PWF was strongly negative, as commonly observed in SSW events. Near the equator, the stratospheric temperature decreased and a westward jet near the stratopause was accelerated. Negative GW and synoptic-scale wave forcing appeared at the bottom of and around the peak of this jet, respectively. On the polar side of this, the temperature increased at ~20˚N. Around January 6, a eastward jet with its axis at ~40˚N/~55 km formed on the polar side of this warming region. Meanwhile, the westward jet in the polar stratosphere and mesosphere was accelerated in association with SSW around January 8. GWFs above the two jets took large negative/positive values at lower/higher latitudes than 60˚N. The temperature increased significantly at ~60˚N/50–90 km corresponding the latitudinal boundary of GWF>0 and GWF<0. These results suggest that the recovery mechanism of the eastward jet is explained by following processes: 1) wave forcings become negative near the equator related to the temperature decrease and acceleration of the westward jet there associated with SSW, 2) the temperature increases at ~20˚N due to the wave-induced residual downwelling and then the eastward stratospheric jet forms at mid-latitudes keeping the thermal wind balance, and 3) GWF<0 above this jet and GWF>0 above the westward polar jet associated with SSW cause strong downwelling at ~60˚N and

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reinforce the negative latitudinal gradient of the temperature in the high latitude region.

Keywords: Middle atmosphere, Stratospheric sudden warming

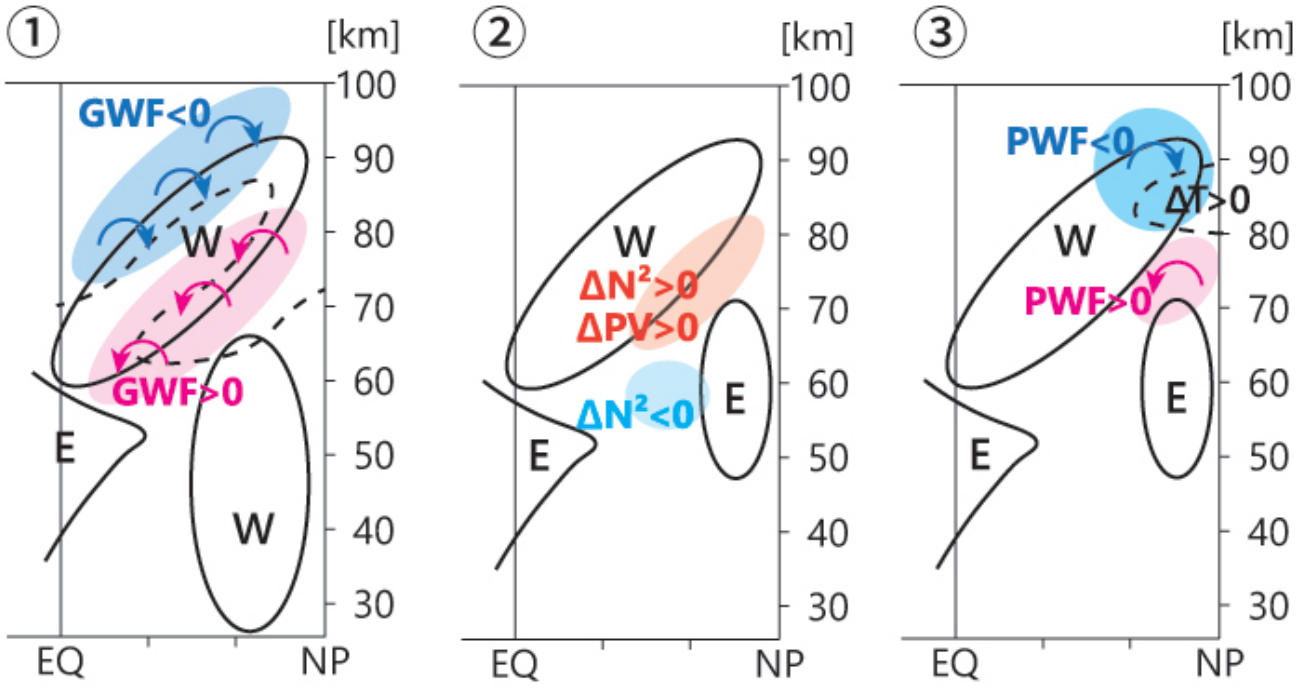

Figure 1 Schematic of the formation process of the DS.

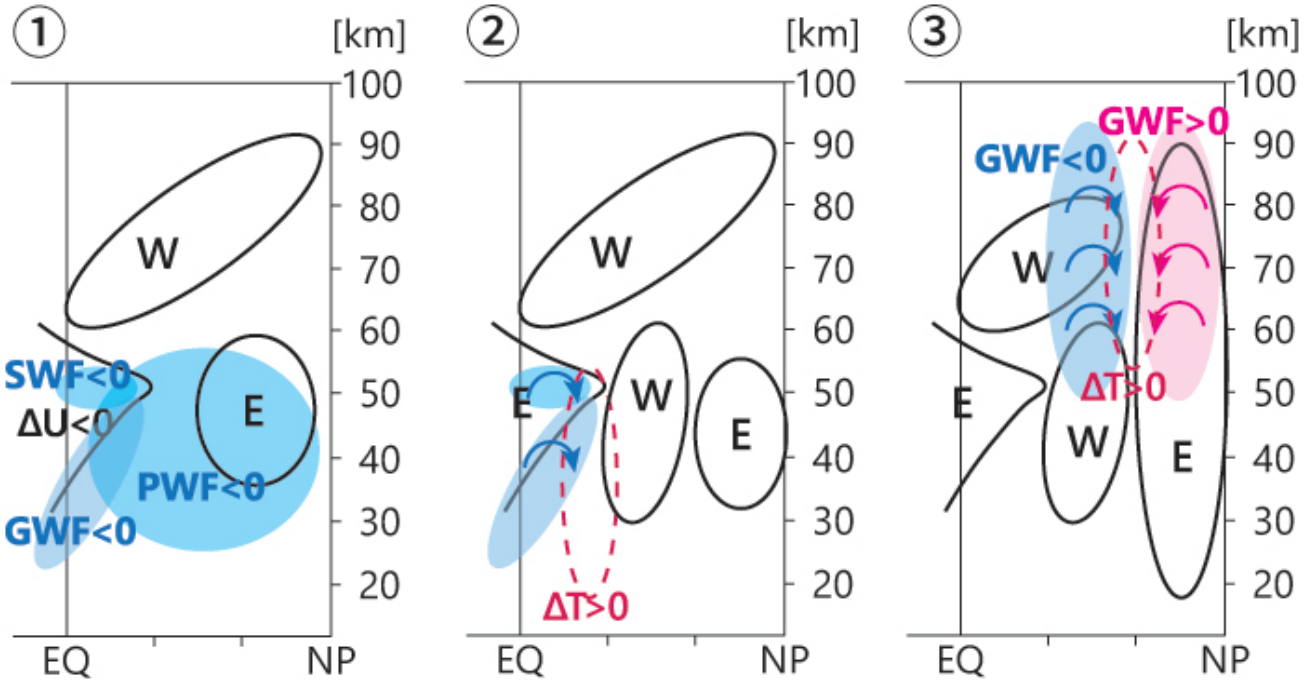

Figure 2 Schematic of the recovery mechanism of the eastward jet in the polar mesosphere.

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A tropospheric pathway of the stratospheric QBO impact on the boreal winter polar vortex

*Koji Yamazaki[1], Tetsu Nakamura[1], Jinro Ukita[2], Kazuhira Hoshi[2]

1. Hokkaido University, 2. Niigata University

The quasi-biennial oscillation (QBO) is quasi-periodic oscillation of the tropical zonal wind in the stratosphere. When the tropical lower stratospheric wind is easterly (westerly), the winter Northern Hemisphere (NH) stratospheric polar vortex tends to be weak (strong). This relation is known as Holton-Tan relationship. Several mechanisms for this relationship have been proposed, especially linking the tropics with high-latitudes through stratospheric pathway. Although QBO impacts on the troposphere have been extensively discussed, a tropospheric pathway of the Holton-Tan relationship has not been explored previously. We here propose a tropospheric pathway of the QBO impact, which may partly account for the Holton-Tan relationship in early winter, especially in the November-December period. The study is based on analyses on observational data and results from a simple linear model and atmospheric general circulation model (AGCM) simulations. The mechanism is summarized as follows: the easterly phase of the QBO is accompanied with colder temperature in the tropical tropopause layer, which enhances convective activity over the tropical western Pacific and suppresses over the Indian Ocean, thus enhancing the Walker circulation. This convection anomaly generates Rossby wave train, propagating into the mid-latitude troposphere, which constructively interferences with the climatological stationary waves, especially in wavenumber 1, resulting in enhanced upward propagation of the planetary wave and a weakened polar vortex.

Keywords: Tropical convection, Planetary wave, stratospheric QBO, polar vortex, tropospheric pathway

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Do sudden stratospheric warmings boost convective activity in the tropics?

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1. Meteorological Research Institute

Influence of stratospheric circulation changes related to sudden stratospheric warmings (SSW) on the tropical troposphere have been examined in many previous studies. However, due to small sample size of SSW and large internal variability in the tropical troposphere, influence of the SSW on the tropical troposphere is still uncertain. We examine impact of the stratospheric circulation changes related to SSW on the tropical troposphere using 5,000-year scale ensemble simulations with a 60 km horizontal resolution global atmospheric model MRI-AGCM3.2. Thousands of SSW-like circulation change events are extracted thanks to the large ensemble simulations. A composite analysis of the SSW-like events shows significant stratospheric upwelling and cooling in the tropics. Synchronized with the upwelling, statistically robust tropospheric signals such as raised temperature and enhanced convective activity including tropical cyclone are found. Although the mean tropospheric signals tend to be small in the view of S/N ratio (~0.1), relative probability of their extreme events significantly increases.

Keywords: Stratosphere-Troposphere coupling in the tropics, Sudden Stratospheric Warming, Tropical convection, Tropical cyclone, Large ensemble simulation

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS08] Stratosphere-troposphere interaction

convener:Takatoshi Sakazaki(Graduate School of Science, Kyoto University), Takenari Kinoshita(Japan Agency for Marine-Earth Science and Technology), Pu Lin(Princeton University/NOAA Geophysical Fluid Dynamics Laboratory), Peter Hitchcock(Cornell University)

The dynamical, radiative, and chemical processes involved in the interactions between the stratosphere and troposphere are essential for understanding the present and future climate. Both observed data and high-resolution models have now clearly demonstrated that stratospheric processes can affect various tropospheric phenomena. Recently, processes coupling the troposphere and stratosphere in the tropical region have become a new focus.
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 This session will highlight recent progress in our understanding of stratosphere-troposphere interaction. We welcome studies of these and related phenomena in the troposphere and stratosphere (and mesosphere) based on observation, models and theory. Further, this session builds upon the middle atmosphere session traditionally held at the JpGU annual meetings and aims to provide a platform for sharing recent findings and promoting international collaborations on this topic.

[AAS08-11] The Coupling between the Troposphere and Stratosphere at Middle and High Latitudes

★Invited Papers

*Wenshou Tian[1], Jinlong Huang[1], Ruhua Zhang[1], Jiankai Zhang[1], Shiyan Zhang[1] (1. College of Atmospheric Sciences, Lanzhou University,China)

[AAS08-12] A pause in Southern Hemisphere circulation trends due to the Montreal Protocol

★Invited Papers

*Antara Banerjee[1,2], John C. Fyfe[3], Lorenzo M. Polvani[4], Darryn Waugh[5,6], Kai-Lan Chang[1,2] (1.Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, USA, 2.Chemical Sciences Division, National Oceanic and Atmospheric Administration/Earth System Research Laboratory, Boulder, Colorado, USA, 3.Canadian Centre for Climate Modelling and Analysis, Environment and Climate Change Canada, Victoria, British Columbia, Canada, 4.Department of Applied Physics and Applied Mathematics, Columbia University, New York, NY, USA, 5.Department of Earth and Planetary Sciences, The John Hopkins University, Baltimore, Maryland, USA., 6.School of Mathematics and Statistics, University of New South Wales, Sydney, New South Wales, Australia)

[AAS08-13] Multi-year analysis using the data assimilation system in the middle atmosphere

*Dai Koshin[1], Kaoru Sato[1], Masashi Kohma[1], Shingo Watanabe[2], Kazuyuki Miyazaki[3] (1.Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, 2.Japan Agency for Marine-Earth Science and Technology, 3.National Aeronautics and Space Administration, Jet Propulsion Laboratory)

[AAS08-14] The response of extreme variability in the Arctic stratosphere to 4xCO_2 concentrations in CMIP6 models

*Blanca Ayarzaguena[1], Andrew J. Charlton-Perez[2], Amy H Butler[3], Peter Hitchcock[4], Isla R. Simpson[5], Lorenzo Polvani[6], Neal Butchart[7], Edwin Gerber[8], Lesley Gray[9], Birgit Hassler[10], Pu Lin[11], François Lott[12], Elisa Manzini[13], Ryo Mizuta[14], Clara Orbe[15], Scott Osprey[9], David Saint-Martin[16], Michael Sigmond[17], Masakazu Taguchi[18], Evgeny Volodin[19], Singo Watanabe[20] (1.Departamento de Física de la Tierra y Astrofísica, Universidad Complutense de Madrid, Spain, 2.Department of Meteorology, University of Reading, UK, 3.Cooperative Institute for Environmental Sciences (CIRES)/National Oceanic and Atmospheric Administration (NOAA) Chemical Sciences Division, USA, 4.Department of Earth and Atmospheric Sciences, Cornell University, USA, 5.Climate and Global Dynamics Laboratory, National

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[AAS08-15] UTLS aerosol measurements over Japan within eastward shedding vortices coming from the Asian summer monsoon anticyclone

*Masatomo Fujiwara[1], Tetsu Sakai[2], Koichi Shiraishi[3], Masahiko Hayashi[3], Noriyuki Nishi[3], Shin-Ya Ogino[4], Prabir Patra[4], Taku Umezawa[5], Yoichi Inai[6], Masato Shiotani[7], Nawo Eguchi[8], Takashi Shibata[9], Sergey Khaykin[10], Laura L. Pan[11] (1.Faculty of Environmental Earth Science, Hokkaido University, 2.Meteorological Research Institute, JMA , 3.Faculty of Science, Fukuoka University, 4.JAMSTEC, 5.NIES, 6.Tohoku University, 7.RISH, Kyoto University, 8.Kyushu University, 9.Nagoya University, 10.LATMOS/IPSL, UVSQ, Sorbonne Universites, CNRS, 11.NCAR)

Discussion

The Coupling between the Troposphere and Stratosphere at Middle and High Latitudes

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1. College of Atmospheric Sciences, Lanzhou University,China

The stratosphere and the troposphere coupling is a hot topic in recent years while the stratospheric polar vortex plays a critical role in this coupling at middle and high latitudes. Up to date, the underlying mechanisms and key processes involved in this coupling are still under wide debate. In this work, the connections of tropospheric blockings, eddy driven jet, planetary waves with the stratospheric polar vortex strength and position are investigated. In addition, the role of the large scale BD circulation played in the stratosphere troposphere dynamical coupling at middle and high latitudes is also discussed. The analysis reveals that the blocking frequency has a close relationship with the stratospheric polar vortex strength and position. The connections between blockings and the polar vortex are controlled by the linear and nonlinear wave interference effects while the BD circulation induced airmass transport can significantly modulate stratosphere troposphere coupling at high latitudes at relatively longer time scales. The thermal-dynamical anomalies in the polar stratosphere can get into the polar troposphere under favorable conditions and we found that it is the duration of upward propagation of planetary waves in mid-high latitude upper troposphere, rather than the wave strength that controls the downward extension of the stratospheric anomalies.

Keywords: stratosphere-troposphere coupling, planetary waves, polar vortex, BD circulation

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A pause in Southern Hemisphere circulation trends due to the Montreal Protocol

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Observations show robust near-surface trends in the Southern Hemisphere tropospheric circulation towards the end of the 20th century, including a poleward shift in the midlatitude jet, a positive trend in the Southern Annular Mode, and an expansion of the Hadley cell. It is established that these trends have been driven by ozone depletion in the Antarctic stratosphere due to emissions of ozone-depleting substances. Here we show that these widely reported circulation trends have, in fact, paused, or slightly reversed, around the year 2000. Using a pattern-based detection and attribution analysis of atmospheric zonal wind, we show that the pause in circulation trends is forced by human activities, and has not occurred simply due to internal or natural variability of the climate system. Further, we demonstrate the essential role of stratospheric ozone recovery as a result of the Montreal Protocol in driving the pause through stratosphere-troposphere coupling. Since the pre-2000 circulation trends have impacted precipitation, and potentially, the ocean circulation and salinity, we anticipate that a pause in these trends will have wider impacts on the Earth system. Signatures of the Montreal Protocol and the associated stratospheric ozone recovery might therefore manifest, or might have already manifested, in other aspects of the Earth system.

Keywords: Atmospheric Dynamics, Chemistry-Climate Interactions, Stratosphere-Troposphere Interactions, Detection and Attribution

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Multi-year analysis using the data assimilation system in the middle atmosphere

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In the mesosphere, the roles of gravity waves, which are ageostrophic motions, are relatively important, compared with those in the troposphere and stratosphere. Recently, the presence of the interhemispheric coupling through the mesosphere has been suggested and the role of the gravity waves has been focused on. However, there are few observational evidences of the gravity wave modulation. In addition, the importance of in-situ generations of the gravity waves and Rossby waves in the mesosphere is recently indicated. Although the mesosphere is observed by satellites and radars, the observational frequency and density are not sufficient for the global analysis. Reanalysis data provided by meteorological organizations cover only up to the middle stratosphere thus, there are several attempts including the upper stratosphere and mesosphere, although they are developing and focus on short terms, several months at most. In this study, we are making the analysis data for about 15 years, when the Aura MLS data, which observes the mesosphere, are available.

We have improved the data assimilation system developed by Koshin et al. (GMDD, 2019), by applying the incremental analysis update (IAU). TIMED SABER (z=25–110 km) and DMSP SSMIS (z=25–80 km) data are added as the observation data for the assimilation. The GCM used for the data assimilation system has a horizontal resolution of T42 (~300 km) and a vertical resolution of about 1 km. The number of ensembles is taken 50. As the analysis becomes better through the consecutive analysis cycle, a continuous period should be as long as possible. However, as the assimilation needs much computational cost, thus the period for the assimilation was split into three: 13 August 2004–31 December 2008 (Stream 1), 15 November 2008–31 December 2013 (Stream 2), and the time period after 15 November 2013 (Stream 3).

Figure 1 shows the zonal mean temperature (70–80N) and zonal wind (60–70N) of Stream 2 for which the assimilation run was finished. Strong sudden stratospheric warming in January 2009 was nicely captured. The stratopause lowers to the height of z~30 km and the zonal wind turns to easterly above z~20 km in mid-January 2009. After that, the elevated stratopause appears at the height of z~85 km, then it lowers over two months. Figure 2 shows the vertical structure on the SSW, 24 January 2009. In the height range of about 30–80 km, the polar vortex splits into two, almost barotropically. It tilted westward with height for z=~80–100 km. Above z=~100 km, there are planetary waves whose phases are not continuous to those at the lower levels.

Using obtained global data, dynamics in the whole middle atmosphere such as interhemispheric coupling, and the effects of the middle atmosphere to the troposphere will be examined. By using the global data as

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the initial values, hindcasts using gravity wave resolving GCM are also planned.

Figure 1. Time-height cross section of the northern polar region. Color: T (70–80N) Contour: U (60–70N)

Figure 2. Geopotential heights for the height range of about 30–110 km on 12UTC, 24 January 2009. The contour interval is 500 m. The region where the anomaly from the zonal mean is larger than +500 m (-500 m) is shown by red (blue) shade. The longitude is 0 (180) degree at the front (back), The north pole and latitude circles of 30 and 60 degrees are shown by green.

Keywords: Middle atmosphere, Data assimilation, Interhemispheric coupling

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Figure 1

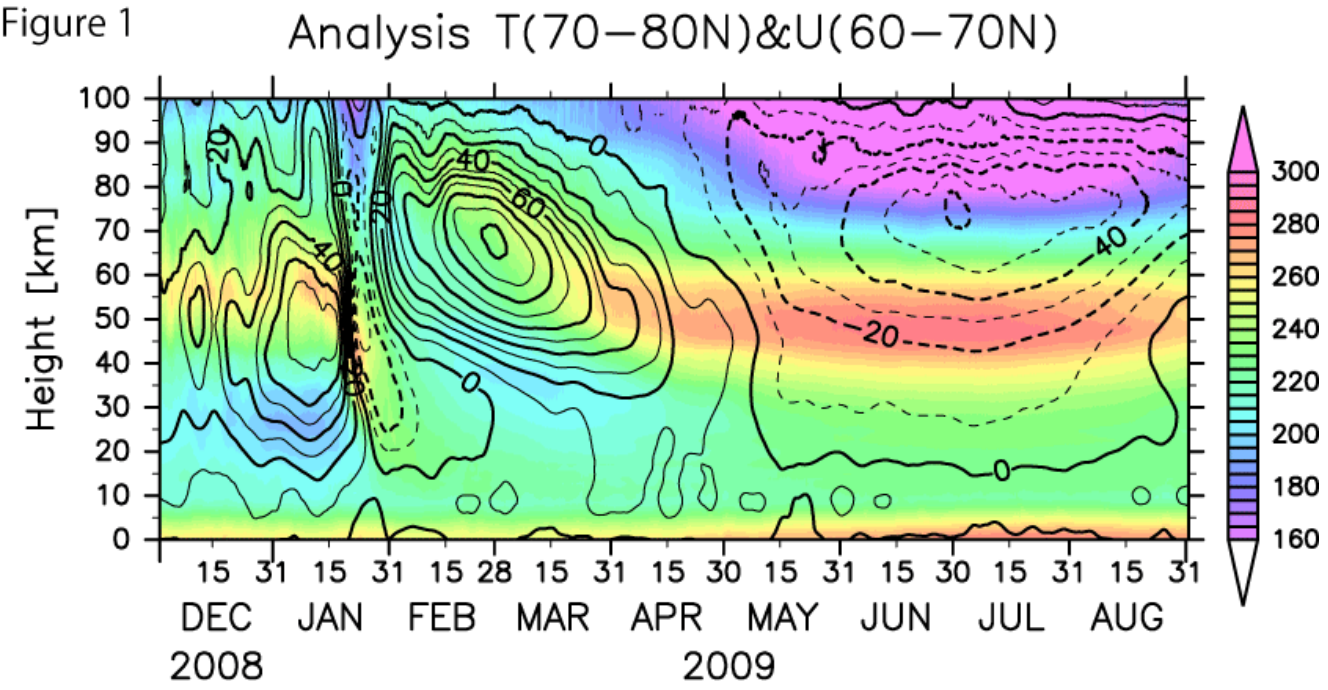
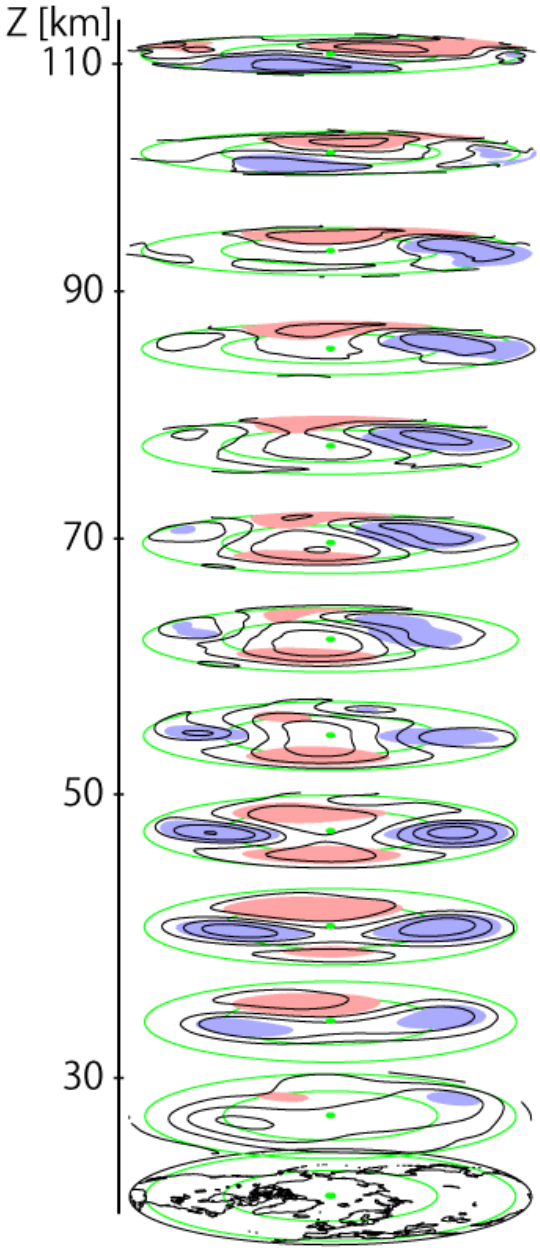


Figure 2



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The response of extreme variability in the Arctic stratosphere to 4xCO_2 concentrations in CMIP6 models

*Blanca Ayarzaguena[1], Andrew J. Charlton-Perez[2], Amy H Butler[3], Peter Hitchcock[4], Isla R. Simpson[5], Lorenzo Polvani[6], Neal Butchart[7], Edwin Gerber[8], Lesley Gray[9], Birgit Hassler[10], Pu Lin[11], François Lott[12], Elisa Manzini[13], Ryo Mizuta[14], Clara Orbe[15], Scott Osprey[9], David Saint-Martin[16], Michael Sigmond[17], Masakazu Taguchi[18], Evgeny Volodin[19], Singo Watanabe[20]

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Sudden stratospheric warmings (SSWs) and stratospheric final warmings (SFWs) are the most important phenomena of the wintertime Arctic stratosphere. They also constitute one of the clearest examples of stratosphere-troposphere coupling. Given their impact on the troposphere, several previous studies have focused on the possible impact of increasing CO_2 concentrations on these events, but without reaching a robust conclusion across them. Several factors might explain this lack of robustness in the results, notably the availability of short data record or the consideration of moderate CO_2 forcing. Part of these limitations may now be overcome thanks to the new simulations of the Coupled Model Intercomparison Project, Phase 6 and in particular, to the long daily data requirements of the DynVarMIP project in preindustrial and quadrupled CO_2 forcing simulations.

In this work, we use this new model output to investigate the response, if any, of extreme variability in the Arctic stratosphere to 4xCO_2 forcing. The results of many models predict that the SSW frequency is sensitive to increase in CO_2 loading, but there is a large disagreement across models on the sign of this change. Regarding the SSW impact on the troposphere, the response over the North Atlantic remain unchanged, but the signal over the Pacific is more uncertain, with some indications that there might be a larger mean response under 4xCO_2 scenario. Finally, the models show robust changes to the seasonal cycle in the stratosphere. Specifically, we find an earlier formation of the vortex in Autumn and a delay in the date of SFWs, resulting in a longer duration of the polar vortex and so, of the season of stratosphere-troposphere coupling.

Keywords: sudden stratospheric warmings, climate change

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UTLS aerosol measurements over Japan within eastward shedding vortices coming from the Asian summer monsoon anticyclone

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The Asian summer monsoon (ASM) anticyclone develops over the Tibetan Plateau and surrounding regions in the upper troposphere and lower stratosphere (UTLS). Various pollutants emitted from the Asian countries are convectively transported to and accumulated in the ASM anticyclone, before being transported quasi-horizontally and widely to the global UTLS. The eastward transport from the ASM anticyclone often takes a form of eastward shedding vortices covering the whole Japanese archipelago, with a frequency of ~3 times per month. We investigate the aerosol characteristics of these vortices by analyzing data from the lidar systems at Fukuoka (33.55N, 130.36E) and at Tsukuba (36.1N, 140.1E) during the summer of 2018.

We found several events of enhanced particle signals at Tsukuba at 16~17.5 km (at or above the tropopause) during August-September 2018, with averaged backscattering ratio of ~1.10 and particle depolarization of ~5%. Each event had a time scale of a few days. During the same period, we observed similar enhanced particle signals at Fukuoka as well.

Backward trajectory calculations from these two sites, starting on the days with enhanced particle signals observed and on the days without separately, showed tendency that the former airmass came more from the region within the anticyclone while the latter came more from the edge regions.

The particle characteristics obtained from the lidar measurements are consistent with the solid ammonium nitrate (NH4NO3) particles from the ASM anticyclone as suggested by Hoepfner et al. (2019). But, there still is a possibility that particles originated from Ambae/Aoba Island in Vanuatu (15.389S, 167.835E) which erupted during 11-17 July 2018 are mixed in the airmass.

Keywords: Asian summer monsoon anticyclone, aerosols , eastward shedding vortices

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS09] Cloud-Resolving Model Simulations for Climate and Weather Studies

convener:Toshihisa Matsui(NASA Goddard Space Flight Center), Masaki Satoh(Atmosphere and Ocean Research Institute, The University of Tokyo), Wei-Kuo Tao(NASA Goddard Space Flight Center)

Cloud-resolving models (CRMs) employs nonhydrostatic dynamic core, explicit microphysics and radiation processes to provide physically-realistic simulations of cloud structures, optical properties, and latent heat release, without parameterizing deep convection in coarse-resolution weather and climate models. CRMs can be run at a few km down to sub-km of horizontal grid spacing depending on science application and focused cloud systems. Over the past few decades, CRMs have been utilized in a variety of weather and climate studies; such as 1) understanding cloud-precipitation processes and interactions with aerosols, surface, radiation, and lightning processes, 2) evaluating and developing microphysics and convection with various in-situ and remote sensing observations, and 3) addressing climate issues to develop or replace convective-cloud parametrizations for global or regional atmospheric models. The goal of this session is to showcase the current efforts for these studies in the atmospheric community.

[AAS09-02] Importance of the cloud-altitude change to the high-cloud response to sea surface temperatures

*Tomoki Ohno[1], Akira T. Noda[1], Masaki Satoh[2,1] (1.Japan Agency for Marine-Earth Science and Technology, 2. Atmosphere and Ocean Research Institute, The University of Tokyo)

[AAS09-03] Climate effects of aerosol-cloud interaction investigated by a global cloud-resolving model.

*Hotta Haruka[1], Kentaroh Suzuki[1] (1.Atmosphere and Ocean Research Institute, Tokyo University)

[AAS09-04] **An intercomparison of tropical clouds using global storm resolving simulations over the Atlantic**

*Woosub Roh[1], Masaki Satoh[1], Cathy Hohenegger[2] (1.AORI, the university of Tokyo, 2.the Max Planck Institute for Meteorology)

[AAS09-05] Improvements in super-cooled liquid water simulations of low-level mixed-phase clouds over the Southern Ocean using a single-column box model

*Tatsuya Seiki[1], Woosub Roh[2] (1.Japan Agency for Marine-Earth Science and Technology, 2.The University of Tokyo)

[AAS09-06] **How well can the Multiscale Modeling Framework (MMF) simulate MCS-associated precipitation over the Central United States?**

*Guangxing Lin[1], Jiwen Fan[1], Zhe Feng[1] (1.Pacific Northwest National Laboratory)

Importance of the cloud-altitude change to the high-cloud response to sea surface temperatures

*Tomoki Ohno[1], Akira T. Noda[1], Masaki Satoh[2,1]

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Since it has been recognized that the uncertainty of cloud feedback is one of main contributors to the intermodel spread of climate sensitivity, the reduction of the uncertainties associated with cloud response to global warming has been one of central issues for robust projections and predictions of climate variability and change. High clouds have large impacts on the Earth’ s radiative energy budget, and the uncertainty of their response to global warming is known as one of large sources of the climate sensitivity spread. The conventional paradigm for high-cloud response to global warming attributes them to the change of the detrainment associated with the radiatively-driven circulation in the clear-sky region based on the so-called fixed anvil temperature hypothesis. This study examined the role of the cloud microphysics for the high-cloud response to sea surface temperatures (SSTs) based on radiative-convective equilibrium (RCE) simulations.

The RCE simulations were conducted using a nonhydrostatic global circulation model (the Nonhydrostatic Icosahedral Atmospheric Model; NICAM) with uniform SSTs of 300 and 304 K over the spherical domain for the Earth radius without rotation. The configuration with an explicit microphysics parameterization, and no cumulus was used.

It was determined that the tendency of ice cloud from cloud microphysical processes was dominated by the deposition growth and sublimation. It was also determined that the reduction of the time scale of these processes associated with the elevation of the altitude of clouds with higher SSTs reduce the high-cloud cover. Our results highlight the importance of the cloud-altitude change to the high-cloud response to global warming. It was also speculated the need for novel cloud-fraction diagnosis scheme considering the time scale of the sublimation processes, which is generally not accounted for schemes based on the saturation-adjustment approach.

Keywords: cloud feedback, high clouds, global warming

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Climate effects of aerosol-cloud interaction investigated by a global cloud-resolving model.

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Current general circulation models (GCMs) suffer from the uncertainty in representing aerosol-cloud interaction (ACI) because the relevant processes such as cloud microphysics occur at scales much smaller than typically resolved by a GCM grid. Such deficiencies in GCMs have prevented us from understanding the quantitative contribution of ACI to climate.

In this regard, the global cloud-resolving model coupled with the aerosol transport module, NICAM-SPRINTARS, is expected to represent ACI realistically with its explicit cloud dynamics and microphysics on the global scale. Previous studies investigated ACI by NICAM-SPRINTARS with 1-moment cloud microphysics and showed that aerosol effects on cloud water content is well-represented in the model consistent with satellite observations, as opposed to GCMs. The 1-moment scheme, however, is constrained in representing ACI because some important processes for ACI are not incorporated.

The purpose of the study is to reveal key processes for ACI in NICAM-SPRINTARS with 2-moment cloud microphysics scheme that predicts number and mass concentrations of hydrometeors to better represent ACI. Specifically, we compare the model with 1-moment and 2-moment schemes against satellite observations on the global scale to evaluate how different degrees of freedom in representing cloud microphysics influence ACI. The analysis is intended to isolate the aerosol effects on cloud from contamination of other factors such as meteorological impact and wet scavenging process to clarify quantitative contributions of microphysical processes to ACI. In particular, wet scavenging process is found to significantly contribute to the aerosol-cloud correlation, possiblyresulting an error in estimating the aerosol effects on cloud.

Keywords: aerosol-cloud interaction, global cloud-resolving model

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An intercomparison of tropical clouds using global storm resolving simulations over the Atlantic

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1. AORI, the university of Tokyo, 2. the Max Planck Institute for Meteorology

The representation of clouds has a large uncertainty in global climate models (GCMs). The results of GCMs depend on a cumulus parameterization. Several global storm resolving models (GSRMs) such as NICAM have developed to reproduce convections with a few kilometers horizontal resolution. It is important to intercompare GSRM simulations and investigate the characteristics for cloud and precipitation. One of the intercomparison projects for GSRMs is the DYAMOND (DYnamics of the Atmospheric general circulation Modeled On Non-hydrostatic Domains).
It is known the three typical cloud types like shallow cumulus, cumulonimbus, and congestus (e.g. Johnson et al. 1999). In this study, we investigate the vertical cloud structures over the Atlantic using DYAMOND data..
The purpose of this study is an intercomparison of GCRMs and an understanding of the characteristics of NICAM for the performance of tropical clouds.
The selected domain is over the Atlantic with 30˚W –50˚W and 0˚N –20˚N.
The cloud fraction of shallow, congestus, and deep clouds in DYAMOND data are intercompared and investigated. The resolution dependency on the vertical structure of cloud types is examined. The cloud fraction of DYAMOND data are evaluated using cloud mask data from CALIPSO and CloudSat.

Keywords: Intercomparison, Global storm resolving simulations, tropical clouds

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Improvements in super-cooled liquid water simulations of low-level mixed-phase clouds over the Southern Ocean using a single-column box model

*Tatsuya Seiki[1], Woosub Roh[2]

1. Japan Agency for Marine-Earth Science and Technology, 2. The University of Tokyo

A high-resolution global atmospheric model, NICAM (Nonhydrostatic ICosahedral Atmospheric Model), exhibited underestimation biases in low-level mixed-phase clouds in the midlatitudes and polar regions. Ice-cloud microphysics used in a single-moment bulk cloud microphysics scheme (NSW6) was evaluated and improved using a singlecolumn box model by reference to a double-moment bulk cloud microphysics scheme (NDW6). Budget analysis indicated that excessive action of the Bergeron-Findeisen and riming processes crucially reduced supercooled liquid water. In addition, the rapid production of rain directly reduced cloud water and indirectly reduced cloud water through the production of snow and graupel by riming. These biases in growth rates were found to originate from the number concentration diagnosis used in NSW6. The diagnosis based on the midlatitude cloud systems assumption was completely different from the one for low-level mixed-phase clouds. To alleviate underestimation biases, rain production, heterogeneous ice nucleation, vapor deposition by snow and graupel, and riming processes were revised. Either change in cloud microphysics alleviated the underestimation biases without parameter tuning. Finally, the lifetime of cloud layers
simulated by NSW6 was reasonably prolonged.

Keywords: supercooled liquid water, mixed-phase clouds, cloud microphysics

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How well can the Multiscale Modeling Framework (MMF) simulate MCS-associated precipitation over the Central United States?

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1. Pacific Northwest National Laboratory

Mesoscale convective systems (MCSs) are a major source of precipitation in many regions of the world. Traditional global climate models (GCMs) do not have adequate parameterizations to represent MCSs. In contrast, the Multiscale Modeling Framework (MMF), which explicitly resolves convection within the cloud resolving model (CRM) embedded in each GCM column, has been shown to be a promising tool for simulating MCSs, particularly over the Tropics. In this work, we use ground-based radar-observed precipitation, North American Regional Reanalysis (NARR) data, and a high-resolution Weather Research and Forecasting (WRF) simulation to evaluate in detail the MCS-associated precipitation over the central United States predicted by a prototype MMF simulation that has a 2° host-GCM-grid. We show that the prototype MMF with nudged winds fails to capture the convective initiation in three out of four major MCS events during May 2011, and under-predicts the precipitation rates for the remaining event, because the model cannot resolve the mesoscale drylines/fronts that are important drivers for initiating convection over the Southern Great Plains (SGP) region. By reducing the host-GCM-grid spacing to 0.25° in the MMF and nudging the winds, the simulation is able to better capture the mesoscale dynamics, which drastically improves the model performance. We also show that the MMF model performs better than the traditional GCM in capturing the precipitation intensity. Our results suggest that increasing resolution plays a dominant role in improving the simulation of precipitation in the MMF, and the CRM embedded in each GCM column further helps to boost precipitation rate.

Keywords: Precipitation, Mesoscale convective system, Multiscale Modeling Framework (MMF)

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS09] Cloud-Resolving Model Simulations for Climate and Weather Studies

convener:Toshihisa Matsui(NASA Goddard Space Flight Center), Masaki Satoh(Atmosphere and Ocean Research Institute, The University of Tokyo), Wei-Kuo Tao(NASA Goddard Space Flight Center)

Cloud-resolving models (CRMs) employs nonhydrostatic dynamic core, explicit microphysics and radiation processes to provide physically-realistic simulations of cloud structures, optical properties, and latent heat release, without parameterizing deep convection in coarse-resolution weather and climate models. CRMs can be run at a few km down to sub-km of horizontal grid spacing depending on science application and focused cloud systems. Over the past few decades, CRMs have been utilized in a variety of weather and climate studies; such as 1) understanding cloud-precipitation processes and interactions with aerosols, surface, radiation, and lightning processes, 2) evaluating and developing microphysics and convection with various in-situ and remote sensing observations, and 3) addressing climate issues to develop or replace convective-cloud parametrizations for global or regional atmospheric models. The goal of this session is to showcase the current efforts for these studies in the atmospheric community.

[AAS09-07] Numerical study of the lightning frequency in tropical cyclone using a metrological model coupled with a lightning component

*Yousuke Sato[1,2], Yoshiaki Miyamoto[3,2], Hirofumi Tomita[2] (1.Faculty of Science, Department of Earth and Planetary Sciences, Hokkaido University, 2.RIKEN Center for Computational Science, 3.Faculty of Environment and Information Studies, Keio University)

[AAS09-09] Development and applications of the process-tracking scheme based on bulk microphysics to determine the properties of snow particles

*Akihiro Hashimoto[1], Hiroki Motoyoshi[2], Narihiro Orikasa[1], Ryohei Misumi[2], Masashi Niwano[1] (1.Meteorological Research Institute, 2.National Research Institute for Earth Science and Disaster Resilience)

[AAS09-10] Evaluation of microphysical schemes in a meteorological model for winter snowfall events in Hokkaido

*Makoto Kondo[1], Yousuke Sato[2], Masaru Inatsu[2], Yuuta Katsuyama[1] (1.Graduate School of Science, Hokkaido University, 2.Faculty of science, Hokkaido University)

[AAS09-11] Characterizing Convective Cells Using Cloud-Resolving Simulations

*Xiaowen Li[1], Wei-Kuo Tao[2] (1.Morgan State Univ., 2.NASA/GSFC)

[AAS09-12] **BiLateral Operational Storm-Scale Observation and Modeling: BLOSSOM**

*Toshihisa Matsui[1,4], David B. Wolff[5], Karen Mohr[1], Stephen E. Lang[1,3], Minghua Zhang[2] (1.NASA GSFC , 2.Stony Brook University, 3.SCIENCE SYSTEMS AND APPLICATIONS INC, 4.ESSIC UMD, 5.NASA WFF)

Numerical study of the lightning frequency in tropical cyclone using a metrological model coupled with a lightning component

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The relationship between lifecycle of tropical cyclone (TC) and lightning frequency and effects of aerosols on the lightning frequency in TC were investigated using a meteorological model coupled with a bulk lightning model (Sato et al. 2019).

To investigate the relationship, an idealized experiment covering from initial to steady state (SS) of TC based on (Miyamoto and Takemi 2013) was conducted. The simulation was conducted with finer horizontal grid resolution (2 km) than our previous studies in JpGU. The results of the simulation indicate that the lightning frequency is maximum before rapid intensification (RI) of TC, which supports previous observational studies (e.g.,DeMaria et al. 2012; Stevenson et al. 2016). The frequency of lightning decreases after RI and it keeps small until the TC reaches SS. Our analyses indicate that the dependency of the lightning frequency upon the TC’ s lifecycle is originated from the difference in the mechanism triggering convective clouds. Convective clouds by convective available potential energy (CAPE) are dominant before RI. After the RI, in contrast, convective clouds are mainly triggered by the updraft along with the secondary circulation. Our analyses also indicate that the timing of the maximum lightning frequency is corresponding to the pre-conditioning stage of the TC, when the convective clouds by CAPE are generated most frequently during TC’ s lifecycle.

Effects of aerosols on lightning frequency in the TC were also investigated by sweptwing the number concentration of cloud condensation nuclei (N_{ccn}). Our results indicate that the lightning frequency is largely dependent upon N_{ccn} even though the strength of TC has small dependency upon N_{ccn}.

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Keywords: Lightning, Tropical Cyclone, Cloud resolving model

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Development and applications of the process-tracking scheme based on bulk microphysics to determine the properties of snow particles

*Akihiro Hashimoto[1], Hiroki Motoyoshi[2], Narihiro Orikasa[1], Ryohei Misumi[2], Masashi Niwano[1]

1. Meteorological Research Institute, 2. National Research Institute for Earth Science and Disaster Resilience

New method of diagnosing the characteristics of ice particles has been developed using a bulk microphysics model by Hashimoto et al. (2020). This method tracked the mass compositions of different classes of ice particles using their microphysical process of origin, such as water vapor deposition and riming.The mass composition from depositional growth was further divided into six components by the temperature and humidity ranges corresponding to the typical growth habits of ice crystals. In preliminary simulations with a two-dimensional domain, the new framework successfully revealed the influences of riming and depositional growths of ice particles within clouds and on surface snowfall. The new approach enables weather prediction models to provide much more information on the characteristics of ice particles regarding crystal habits and the extent of riming. Simulations were also performed in realistic three-dimensional atmospheric conditions regarding recent heavy snow events in Japan. Advantages and limitations of this approach will be discussed in the meeting.

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Keywords: Cloud microphysics, Crystal habit, Rimming, Avalanche

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Evaluation of microphysical schemes in a meteorological model for winter snowfall events in Hokkaido

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This study evaluated microphysical schemes implemented in a meteorological model SCALE (Nishizawa et al. 2015; Sato et al. 2015) targeting midwinter snowfall events in Hokkaido. Cloud microphysical schemes of a 2-moment bulk scheme (Seiki and Nakajima 2014: SN14), a 1-moment bulk scheme of Roh and Satoh (2014: RS14), and that of Tomita (2008: T08) were evaluated with the simulation for events, based on ground-based measurement by disdrometer. Our analysis elucidated that SN14 successfully simulated the measured relationship between the particle size and terminal velocity distribution (PVSD). On the other hand, T08 overestimated the frequency of graupel with fast fall velocity, and underestimated particle diameters. RS14 also overestimated the frequency of the graupel, but reproduced the fall velocity of graupel particles. Sensitivity experiments indicated that RS14 scheme can be improved by the modification for the slope parameter, mass-diameter(*m-D*) relationship, and PVSD relationship of graupel.

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Keywords: Cloud microphysics, Solid precipitation particle, Bulk microphysics scheme, Ground-based measurement

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Characterizing Convective Cells Using Cloud-Resolving Simulations

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Convection is a fundamental process in the atmosphere, driving global and regional circulations and producing the bulk of surface rainfall. Convective updraft cores, the engine of convective clouds, have a finite spatial scale of several kilometers, and temporal scale of less than one hour. Although convective cores are responsible for most of the heat and vertical mass transport in convective clouds, their structural and evolution characteristics are not well quantified due to the many difficulties in directly measuring updraft velocity in deep convection. Better convection parameterization remains one of the key factors in improving climate predictions. This study contributes to characterizing convection cells using ensembles of high-resolution, cloud-resolving model simulations.

The Goddard Cumulus Ensemble (GCE) model and the Weather Research and Forecast (WRF) model are used to conduct idealized ensemble simulations ranging from small-domain, single convective cells, to large-domain, case studies of convective systems. The emphasis is to build a large sample of individual convective cells through automatic feature identification and tracking algorithms. A k-mean clustering method is used to identify updraft cells with occasional human intervention. TrackPy toolkit is used to track the evolution of these cells through their lifecycle. We first present convective cell statistics derived from this database. The second part of the study explores how convective cell characteristics vary with environment variables (e.g., CAPE, wind shear, moisture) and model numerics (e.g., resolution, microphysics, radiation and turbulent mixing schemes). Lastly, applications of these statistics to understanding the global circulation, and to improving cumulus parameterization in GCMs will be discussed.

Keywords: Convection, Cells, Cloud-Resolving Model

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BiLateral Operational Storm-Scale Observation and Modeling: BLOSSOM

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1. NASA GSFC , 2. Stony Brook University, 3. SCIENCE SYSTEMS AND APPLICATIONS INC, 4. ESSIC UMD, 5. NASA WFF

Over the past several decades, cloud-resolving models (CRMs) have been advanced and utilized for many applications, such as the study of mesoscale convective systems, cloud microphysics, cloud latent heating, and cloud radiative forcing, all of which have been used to support the development of satellite algorithms for the Tropical Rainfall Measuring Mission (TRMM) and Global Precipitation Measurement (GPM) satellites. Yet, one of the long-standing uncertainties in CRMs is the spatial-temporal distribution of bulk hydrometeors, especially, mixed-phase and frozen precipitation. To continue to improve and advance these models in unison with the steady progression to finer grid resolutions, a robust evaluation is required that facilitates comprehensive comparisons between high-resolution, detailed cloud-process simulations and systematic routine storm-scale observations having sub-minute time-scale and sub-km spatial-scale sampling.

The NASA S-band dual-POLarimetric radar (NPOL) and Dual-frequency Dual-polarized Doppler Radar (D3R) are NASA’s signature ground-based polarimetric radars that have been deployed to many GPM ground validation (GV) sites and provide such vital storm-scale observations for CRM evaluation. Subsequent to these GV activities (https://gpm-gv.gsfc.nasa.gov/), N-POL and D3R have been operating at the NASA Goddard Space Flight Center Wallops Flight Facility (WFF) to continuously validate GPM satellite signals and retrievals over WFF sites. We briefly present concept and preliminary results of establishing routine polarimetric radar observations and cloud-process modeling at the NASA GSFC WFF in the following project entitled “**BiLateral Operational Storm-Scale Observation and Modeling (BLOSSOM)**”. Ultimately, the following ultimate goals are envisioned with BLOSSOM:
1) Establish a long-term super site to improve understanding of cloud and precipitation physical processes, particularly for mixed-phase and frozen precipitation over the WFF site, 2) Provide routine meteorological large-scale forcing input to drive different CRMs, large-eddy simulation (LES) models, and single-column models (SCMs) for improvement of cloud microphysics and convection parameterizations, 3) Provide routine storm-scale cloud-precipitation simulations as well as storm-scale measurements using ground-based polarimetric Doppler radar and in-situ data, and 4) collect Precipitation Measurement Mission (PMM) satellite data along with the CRM simulations and polarimetric radar observations to generate value-added BLOSSOM Bundled Data for the community.

Keywords: cloud and convection process, precipitation, polarimetric radar, cloud-resolving model

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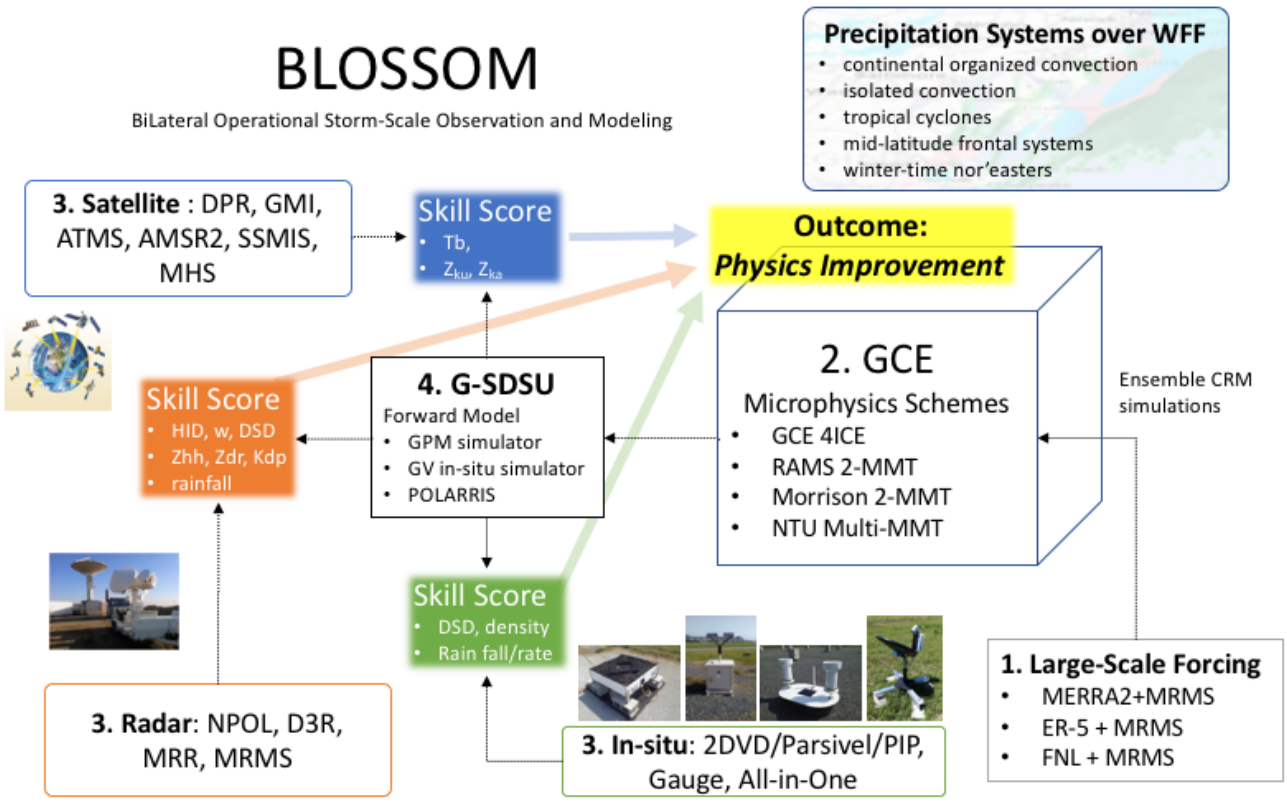

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS10] Land-Atmosphere interactions and precipitation variations over the Asian monsoon region.

convener:Hiroshi G. Takahashi(Department of Geography, Tokyo Metropolitan University), Hirokazu Endo(Meteorological Research Institute, Japan Meteorological Agency), Shiori Sugimoto(JAMSTEC Japan Agency for Marine-Earth Science and Technology), Hatsuki Fujinami(Nagoya University)

This session aims to discuss land-atmosphere interaction over the Asian monsoon region because this interaction is one of the essential components of the Asian monsoon system. Precipitation characteristics and cloud-precipitation processes are closely tied with land-atmosphere interactions, which are also a key target. Over Asia, climate are various, which produces various land-atmosphere-precipitation interactions. Influences of complex topography on precipitation characteristics are also considered. It may be interesting that the interactions can vary with scales in space and in time.
In addition, monsoon precipitation variability is a target of this session, which can be also associated with land surface conditions. We would like to approach the mechanism behind the precipitation/precipitation characteristics variability. In addition, to understand past and future precipitation variability, impacts of land-use changes and/or global warming should be considered. A large variety of observation, numerical modeling and their combined analyses are encouraged.

[AAS10-01] Impact of Eurasian Spring Snow Decrement on East Asian Summer Precipitation

*Ruonan Zhang[1], Renhe Zhang[1], Zhiyan Zuo[2] (1.Department of Atmospheric and Oceanic Sciences & Institute of Atmospheric Sciences, Fudan University, Shanghai, China, 2.State Key Laboratory of Severe Weather and Institute of Climate System, Chinese Academy of Meteorological Sciences, Beijing, China)

[AAS10-02] Warm-Season Convection Initiation in South China

*Lanqiang Bai[1], Guixing Chen[1], Ling Huang[2] (1.Sun Yat-sen University, 2.ITMM, CMA)

[AAS10-03] The observed properties of summer convective clouds and precipitation over the central Tibetan Plateau

*Yi Chang[1,2], Xueliang Guo[3], Jie Tang[2,4], Guangxian Lu[1,2], Peng Qi[2,5] (1.State Key Laboratory of Severe Weather (LASW), Chinese Academy of Meteorological Sciences, Beijing, China, 2.Key Laboratory for Cloud Physics, China Meteorological Administration, Beijing, China, 3.Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, 4.Collaborative Innovation Center for Meteorological Disasters Forecast, Early Warning and Assessment, Nanjing University of Information Science and Technology, Nanjing, China, 5.University of Chinese Academy of Sciences, Beijing)

[AAS10-04] **Impact of urban induced land-use change over eastern and southern Indian cities**

*JAGABANDHU PANDA [1], Sudhansu Sekhar Rath[1] (1.National Institute of Technology Rourkela)

[AAS10-05] **A new light on the long-term trends of extreme rainfall characteristics over Central India**

*Anu Gupta[1], Hiroshi G. Takahashi[1] (1.Tokyo Metropolitan University, Tokyo)

[AAS10-06] Future changes in East Asian summer monsoon precipitation and their uncertainty in 60km-mesh MRI-AGCM ensemble simulations

*Hirokazu Endo[1], Akio Kitoh[2,1], Ryo Mizuta[1], Tomoaki Ose[1] (1.Meteorological Research Institute, Japan Meteorological Agency, 2.Japan Meteorological Business Support Center)

Impact of Eurasian Spring Snow Decrement on East Asian Summer Precipitation

*Ruonan Zhang[1], Renhe Zhang[1], Zhiyan Zuo[2]

1. Department of Atmospheric and Oceanic Sciences & Institute of Atmospheric Sciences, Fudan University, Shanghai, China, 2. State Key Laboratory of Severe Weather and Institute of Climate System, Chinese Academy of Meteorological Sciences, Beijing, China

In this study, the relationship between Eurasian spring snow decrement (SSD) and East Asian summer precipitation and related mechanisms were investigated using observational data and the Community Atmospheric Model, version 3.1 (CAM3.1). The results show that a west–east dipole pattern in Eurasian SSD anomalies, with a negative center located in the region between eastern Europe and the West Siberia Plain (EEWSP) and a positive center located around Baikal Lake (BL), is significantly associated with East Asian summer precipitation via triggering an anomalous midlatitude Eurasian wave train. Reduced SSD over EEWSP corresponds to anomalously dry local soil conditions from spring to the following summer, thereby increasing surface heat flux and near-surface temperatures. Similarly, the increase in SSD over BL is accompanied by anomalously low near-surface temperatures. The near-surface thermal anomalies cause an anomalous meridional temperature gradient, which intensifies the lower-level baroclinicity and causes an acceleration of the subtropical westerly jet stream. The forced wave 2 and 4 further have constructive interference with the counterpart climatological waves, leading to an enhanced and maintained Eurasian wave train. Additionally, the atmospheric response to changed surface thermal conditions tends to simultaneously increase the local 1000–500-hPa thickness, which further enhances the Eurasian wave train. Consequently, significant wave activity flux anomalies spread from eastern Europe eastward to East Asia and significantly influence the summer precipitation over China, with more rainfall over northeastern China and the Yellow River valley and less rainfall over Inner Mongolia and southern China.

Keywords: Spring snow decrement, East Asian precipitation, Land-surface interaction, constructive interference

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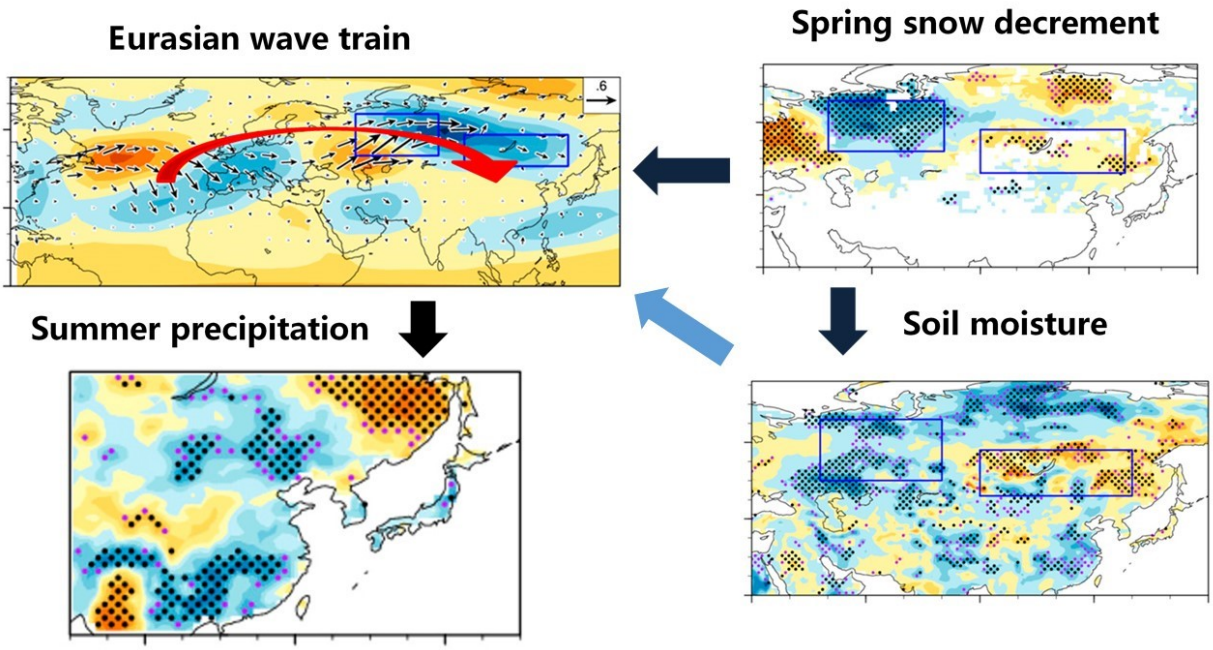

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Warm-Season Convection Initiation in South China

*Lanqiang Bai[1], Guixing Chen[1], Ling Huang[2]

1. Sun Yat-sen University, 2. ITMM, CMA

A large fraction of global rainfall occurs in the coastal areas of summer monsoon where are highly populated. Characterizing convective activity along monsoon coasts has been an important issue in regional/global climate and hydrological studies. In this study, we present a long-term radar climatology of convection initiation (CI) on the monsoon coasts of South China where has dense observational networks. Results show that CI becomes highly active after the summer monsoon onset. Most CI occurrences are concentrated within 100 km of the coastline, and the local maxima are strongly affected by topography and land–sea contrast. The triggering of coastal convention shows offshore propagation after midnight prior to rainfall, probably due to the convergence of land breezes or downslope winds with diurnally enhanced onshore monsoon flows. The findings provide key information to improve our understanding of how convective activity emerges in monsoon coastal areas.

Keywords: Convection initiation, Monsoon, Coast, South China

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The observed properties of summer convective clouds and precipitation over the central Tibetan Plateau

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1. State Key Laboratory of Severe Weather (LASW), Chinese Academy of Meteorological Sciences, Beijing, China, 2. Key Laboratory for Cloud Physics, China Meteorological Administration, Beijing, China, 3. Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, 4. Collaborative Innovation Center for Meteorological Disasters Forecast, Early Warning and Assessment, Nanjing University of Information Science and Technology, Nanjing, China, 5. University of Chinese Academy of Sciences, Beijing

Macro- and micro-physical properties of summer convective clouds and precipitation over the central Tibetan Plateau (TP) were investigated using the in-situ observations during the Third Tibetan Plateau Atmospheric Sciences Experiment (TIPEX-III) in 2014. The advanced aircraft and radar observational systems were employed during the experiment.

The results show that the convective activities mainly distributed in the central and southeast part of the TP. The average heights of cloud top and cloud base were 11.62 ±2.45 km and 6.89 ±1.58 km, respectively. The average rain rate was ≈1.2 mm/h, and most rain events lasted less than 1 hour. The raindrop size distribution spectra were wider than other of lower altitude, and compared to M-P distribution, the Γ distribution was more suitable in describing the raindrop size distribution of precipitation over the central TP. Due to the solar heating effect over the plateau, both convective clouds and precipitation processes had obvious daily variation. The convections began to develop in the afternoon, reached the maximum in the late afternoon, turned into stratiform-like at night, and decayed in the second half of the night, and vanished as the sun recurred.

The aircraft observations show that the summer clouds over the Tibetan Plateau were primarily characterized as mixed-phase cumulus clouds induced by strong solar radiation heating. The characteristic number concentration of cloud droplets (2~50 μm in diameter) in developing cumuli was around 10 cm^{-3}, which was about 1~2 orders of magnitudes lower than other continent and ocean regions, and that for large drops (>50 μm in diameter) was around 10–3 cm^{-3}, which was also lower than other regions. The droplet spectrum distributions (DSDs) of cloud drops were much wider than other regions, indicating that the cumulus clouds over the plateau could form precipitation easier than that in other regions. Ice microphysics was characterized as very active glaciation and riming processes with high supercooled water content, which caused the formation of high concentration of graupel particles in clouds.

Keywords: the Third Tibetan Plateau Atmospheric Sciences Experiment (TIPEX-III), convective clouds and precipitation, cloud microphysical characteristics, aircraft observations

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Impact of urban induced land-use change over eastern and southern Indian cities

*JAGABANDHU PANDA [1], Sudhansu Sekhar Rath[1]

1. National Institute of Technology Rourkela

This work considers both observational and numerical modeling techniques to quantify the urban sprawl and dynamics, analyse the long-term urban climatology and examines the role of urban induced land use (LU) change during extreme weather events like heatwaves (HW), thunderstorms (TS) and convectively driven rain events. Urban dynamics of cities using satellite data and ‘spatial metrics’ based indices are analyzed to quantify the LU change in different cities. Observational data is used to understand the effect of urban growth on long-term climatology. Multiple numerical simulation-based experiments were carried out considering the mentioned weather events over eastern and southern Indian cities. The urban induced LU change impact is examined using different types of LU data in the Weather Research and Forecasting (WRF) model with varying urban fractions. The cities, considered in this study, experienced a massive load of population inflow, industrialization, and economic development. The analysis suggests the growth of the cities expanding the boundary (e.g. Figures 1a-b) irrespective of their geographical location and type. Long-term climatological analysis suggests both an increase and a decrease of the diurnal temperature range over different cities. An overall increase in rainfall and lighting activity is seen for pre and post-monsoon days indicating the enhancement of convective processes over cities. LU change simulations during HW events revealed that the maximum temperature is hardly affected due to the LU change while the most prominent increment in minimum temperature is seen. Computed urban heat island shows higher values for updated LU considerations indicating the feedback from larger impervious areas (e.g. Figure 1d). Experiments during TS events predict most of the rainfall inside the city boundary or in its neighborhood in the downwind direction and high-density urban areas (e.g. Figure 1c) with significant improvements in the rainfall amount.

Keywords: WRF, Urbanization, Thunderstorms, Heat Wave, Land use

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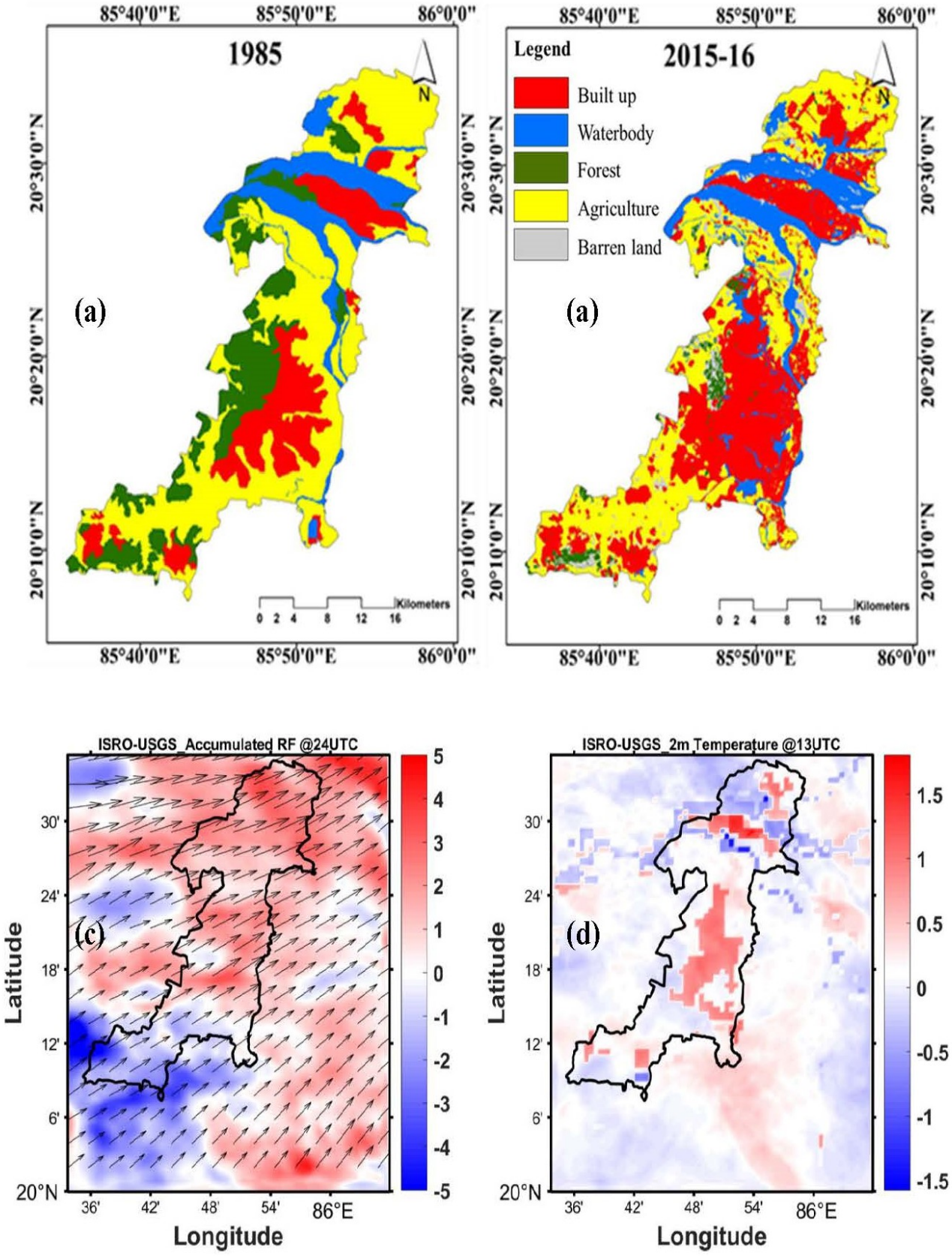

Figure 1: LU map for Bhubaneswar-Cuttack showing urban areas in red colour for (a) USGS and (b) ISRO. Difference between ISRO and USGS LU simulations for (c) accumulated rainfall and (d) near-surface temperature during the considered cases of convectively driven rain events.

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A new light on the long-term trends of extreme rainfall characteristics over Central India

*Anu Gupta[1], Hiroshi G. Takahashi[1]

1. Tokyo Metropolitan University, Tokyo

This study examines rainfall characteristics over central India, particularly, extreme rainfall events (EE). We focus on the spatial scale of the EE, which indicates spatial extent of different rainfall systems during summer monsoon season. A flood-fill algorithm is applied on Indian Meteorological Department gridded daily rainfall dataset, which finds the different connected EE rainfall patterns. Using this algorithm, different spatial scale rainfall patterns are categorized into three types sporadic, intermediate and massive systems based on their spatial extent. We found that sporadic EEs occur more frequently and contributes more than 80% to EE rainfall. Moreover, these sporadic EEs are different in size as well as in total rainfall amount and intensity as compared to Intermediate and massive systems. In the long term trend (1901-2018), only sporadic systems are increasing whereas Intermediate and massive have negative and no trend respectively. However, massive systems are increasing more rapidly in recent decades. Therefore, systems based analysis as well as decadal variation has been focused to provide a deep understanding on the variation of characteristics of EE in long term as well as in recent era based on their spatial scale. These different scale systems are linked with different mesoscale and synoptic level convective systems which might have got changed in recent few decades. This kind of understanding of EE is highly useful from the point of disaster identification and management.

Keywords: Extreme Rainfall Events, Flood-Fill Algorithm, Spatial scale, Sporadic Systems

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Future changes in East Asian summer monsoon precipitation and their uncertainty in 60km-mesh MRI-AGCM ensemble simulations

*Hirokazu Endo[1], Akio Kitoh[2,1], Ryo Mizuta[1], Tomoaki Ose[1]

1. Meteorological Research Institute, Japan Meteorological Agency, 2. Japan Meteorological Business Support Center

This study investigates future changes in summer monsoon precipitation over East Asia and their uncertainty, based on ensemble simulations with a 60-km mesh Meteorological Research Institute (MRI) atmospheric general circulation model (AGCM). The ensemble includes 28 members projections with a wide variety of sea surface temperature (SST) warming patterns that are obtained from coupled models of the Coupled Modeling Intercomparison Project phase 5 (CMIP5) as well as 12 members projections combining different types of convective parameterization schemes with different SST warming patterns. In the present-day climate realizations, which are forced by an observed SST, the MRI-AGCM shows high performance in simulating the Meiyu/Baiu rainband in terms of intensity and seasonal progress.

Future climate projections at the end of the 21 century under the RCP8.5 scenario show that both summer precipitation and summer monthly precipitation will generally increase over East Asia, accompanied by specific spatial patterns with some uncertainty. In June, the Meiyu/Baiu rainband is projected to enhance and slightly shift southward especially in the eastern part, with high agreement among the ensemble members. In July, there is large uncertainty in behavior of the Meiyu/Baiu rainband over Japan. In August, precipitation is projected to increase over the Eurasian continent and the surroundings.

Further analysis based on idealized experiments with the MRI-AGCM indicates that an SST warming has a dominant role in the general increase of precipitation in East Asia as well as the enhancement and southward shift of the Meiyu/Baiu rainband, while an CO_2-induced land warming exerts large influence on the increase of precipitation over the Eurasian continent, especially in late summer.

Keywords: monsoon precipitation, global warming, East Asia

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS11] Aerosol impacts on air quality, climate system, and our society

convener:Teppei J Yasunari(Arctic Research Center, Hokkaido University), Kyu-Myong Kim(NASA Goddard Space Flight Center), Hongbin Yu(NASA Goddard Space Flight Center), Toshihiko Takemura(Research Institute for Applied Mechanics, Kyushu University)

Aerosol particles degrade air quality, modulate the radiation budget, influence the formation and evolution of clouds and precipitation, affect the ecosystems and biogeochemical cycles. These impacts have important implications for global sustainability and societal benefits. This session invites papers reporting latest advances in understanding lifecycles of aerosol and assessing aerosol impacts on air quality, the climate system from regional to global scales using in situ observation, remote sensing, and numerical modeling techniques. We also welcome papers on how the important roles of aerosol in air quality and climate system have influenced our society such as economic and educational activities. The topics of interest include but are not limited to: (1) physical processes on aerosol emission, transport and deposition, (2) trends of regional aerosol and their controls by emissions and meteorology, (3) aerosol influences on radiation through scattering, absorption, as well as albedo changing, (4) aerosol impacts on monsoon hydrological cycle and extreme weather events such as drought, flood, wildfire, typhoon, as well as the influences of the extreme weather events on aerosol emissions and transport, (5) the role of aerosol in global biogeochemical cycles, (6) aerosol impact on our society and economy, (7) new analytical methods for assessment and prediction such as machine learning, and (8) aerosol related education and outreach.

[AAS11-03] **Observational study on the response of aerosol optical depth over Japan to springtime transboundary air pollution in 2011-2019**

*YING CAI[1] (1.chiba university)

[AAS11-04] Organic functional group composition of particulate matter from fresh and aged biomass burning and coal combustion emissions

*Amir Yazdani[1], Nikunj Dudani[1], Satoshi Takahama[1], Amelie Bertrand[2], André S. H. Prévôt[2], Imad El Haddad[2], Ann M. Dillner[3] (1.ENAC/IIE Swiss Federal Institute of Technology Lausanne (EPFL), Lausanne, Switzerland, 2.Laboratory of Atmospheric Chemistry, Paul Scherrer Institute, Villigen, Switzerland, 3.Air Quality Research Center, University of California Davis, Davis, California, USA)

[AAS11-05] **Fog Droplet Size Distribution** and the Interaction between **Fog Droplets** and **Fine Particles** During Dense Fog in *Tianjin, China*

*Qing Liu[1,2,4], Bingui Wu[2,3], Zhaoyu Wang [1,2] (1.Tianjin Weather Modification Office, China, 2. Tianjin Key Labarotory of Marine Meteorology, China, 3.Tianjin Meteorology Bureau, China, 4.Key Laboratory for Cloud Physics of China Meteorological Administration, Beijing, China)

Observational study on the response of aerosol optical depth over Japan to springtime transboundary air pollution in 2011-2019

*YING CAI[1]

1. chiba university

Observational study on the response of aerosol optical depth over Japan to springtime transboundary air pollution in 2011-2019

Ying Cai*, Hitoshi Irie, Kodai Yamaguchi (Chiba University)

Abstract:

The air pollution level in China is thought to have been improved drastically in recent years. Accordingly, it is expected that the air pollution level in Japan has also been improved. At the end of May 2019, however, the photochemical smog advisory was issued in Nagasaki and Fukue Island for the first time in eight years. Thus, the recent response of air quality over Japan to transboundary air pollution has not been fully understood yet. Here we analyzed recent changes in springtime Aerosol Optical Depth (AOD) data (500 nm) observed by ground-based skyradiometers at SKYNET sites of Chiba (35.6°N, 140.1°E, 60 m), Fukue (32.7°N,128.6°E, 50 m), Kasuga (33.5°N, 130.4°E, 55 m), and Saga (33.2°N, 130.2°E, 21 m) from 2011 through 2019. Besides, AOD data (550 nm) from MODIS (Medium Resolution Imaging Spectroradiometer) instruments onboard NASA's Earth observation satellites Terra/Aqua were also analyzed. Skyradiometer AOD values showed decreasing trends at all four sites at a rate of about -1% per year, although year-to-year variations were sometimes significant. MODIS data showed expected decreasing trends in AOD over mainland China and Japan. We also found from MODIS data that a high AOD belt due most likely to transboundary air pollution crossed over around Sendai. It was likely that around Japan, a faster reduction in AOD occurred in an area south of Sendai than in an area north of Sendai. This is likely because the high AOD belt could be shifted to the north in recent years, causing more reduction in an area south of Sendai.

Keywords: Transboundary air pollution; Aerosol optical depth; Skyradiometer; MODIS.

Keywords: Transboundary air pollution, Aerosol optical depth, Skyradiometer, MODIS

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Organic functional group composition of particulate matter from fresh and aged biomass burning and coal combustion emissions

*Amir Yazdani[1], Nikunj Dudani[1], Satoshi Takahama[1], Amelie Bertrand[2], André S. H. Prévôt[2], Imad El Haddad[2], Ann M. Dillner[3]

1. ENAC/IIE Swiss Federal Institute of Technology Lausanne (EPFL), Lausanne, Switzerland, 2. Laboratory of Atmospheric Chemistry, Paul Scherrer Institute, Villigen, Switzerland, 3. Air Quality Research Center, University of California Davis, Davis, California, USA

Particulate matter (PM) affects visibility and climate through light scattering, direct and indirect radiative forcing, and purturbing cloud formation. In addition, exposure to fine PM is known to cause adverse health effects and increase mortality. Organic matter (OM), can make up more than half of the total fine atmospheric PM, and yet its composition and formation mechanisms are not fully characterized due to its complex chemical composition. Biomass burning (e.g., residential wood burning, wildfires, and prescribed burning) and coal combustion (for heat and power generation) are two major OM sources, for which the impact of atmospheric aging - including secondary organic aerosol (SOA) formation - is not yet fully clear.

In this study, we investigated the effect of aging on composition and mass concentration of organic aerosols of wood burning (WB) and coal combustion (CC) emissions using mid-infrared spectroscopy and aerosol mass spectrometry (AMS). For this purpose, primary burning aerosols were injected into the Paul Scherrer Institute (PSI) environmental chamber and aged using hydroxyl and nitrate radicals to simulate day-time and night-time oxidation processes in the atmosphere. In these experiments, aerosols reached an oxidative age comparable to that of atmospheric aerosols. A time-of-flight AMS was used to measure the high-time-resolution composition of non-refractory fine PM, while we collected PM_1 aerosols on PTFE filters before and after four hours of aging for off-line Fourier transform-infrared spectroscopy (FT-IR) measurements.

AMS and FT-IR estimates of organic aerosol mass concentration were highly correlated ($r^2=0.92$), both indicating an approximately three-fold increase in organic aerosol concentration after aging. The OM/OC ratio, indicating the extent of oxidation, also agreed closely between the two instruments and increased, on average, from 1.6 (before aging) to 2 (after aging). Mid-infrared spectroscopy, which is able to differentiate among oxygenated species, shows distinct functional group compositions for aged WB aerosols (high abundance of carboxylic acids) and CC aerosols (high abundance of non-acid carbonyls) and detects considerable amounts polycyclic aromatic hydrocarbons (PAHs) for both sources.
Mid-infrared spectra of fresh WB and CC aerosols are reminiscent of their parent compounds with differences in specific functional groups, showing the dominant oxidation pathways for each emission source. Finally, the comparison of mid-infrared spectra of aged WB aerosols in the environmental chamber with that of ambient samples affected by residential wood burning and wildfires, reveals interesting similarities regarding the high abundance of alcohol COH and the visible signatures of lignin. This finding is useful for interpreting sources of atmospheric aerosols and better understanding their complex mid-infrared spectra.

Keywords: Mid-infrared spectroscopy, Biomass burning , Organic aerosol, AMS, Environmental chamber, FTIR

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Fog Droplet Size Distribution and the Interaction between **Fog Droplets** and **Fine Particles** During Dense Fog in *Tianjin, China*

*Qing Liu[1,2,4], Bingui Wu[2,3], Zhaoyu Wang [1,2]

1. Tianjin Weather Modification Office, China, 2. Tianjin Key Labarotory of Marine Meteorology, China, 3. Tianjin Meteorology Bureau, China, 4. Key Laboratory for Cloud Physics of China Meteorological Administration, Beijing, China

From November 2016 to January 2017, there were large-scale dense fog processes *in Tianjin area on the west coast of Bohai Bay, China*, even **strong dense fog with visibility less than 50 m occurred**. Based on the observation data of new fog monitor, visibility sensor, environmental particle monitor and high-density meteorological automatic station, the characteristics of **fog droplet size distribution** and the **interaction between the fog droplets and fine particles** during dense fog events were analyzed. The observed results show following characteristics: *(1)* The average concentration of fog droplets, the average liquid water content and the maximum liquid water content in the strong dense fog process were larger than those in the dense fog. Nucleation condensation was the main way of droplet growth in (strong) dense fog. **The average spectrum of fog droplet size distribution conformed to Junge distribution**, and they were all broad-spectrum fog with a spectrum width of about 45 μm. Due to its specific geographic location and background pollution, **the fog droplet size distribution in Tianjin was similar to that in heavily polluted inland cities and different from those of most coastal areas around the world**. *(2)* The average liquid water content (L_A) was 0.037g/m^3, **the heavy haze weather was the main reason why L_A in Tianjin was lower than that in some coastal areas of the world**. *(3)* **The maximum of fog droplet diameter during the formation stage had a good indication for the eruption of strong dense fog**. *(4)* Under the background of severe haze, **fog process can scavenge fine particles**, and the scavenging efficiency of $PM_{2.5}$ was remarkable. **The increase of the mass concentration of fine particles was conducive to the rapid growth of fog droplets and the sharp drop of visibility within a certain threshold (350 μg/m^3). However, when $C_{PM2.5}$ exceeded the critical value, the increase had a negative feedback effect on the development of the fog process.**

Keywords: Fog droplet size distribution, Strong dense fog, Atmospheric fine particles, Fog droplets

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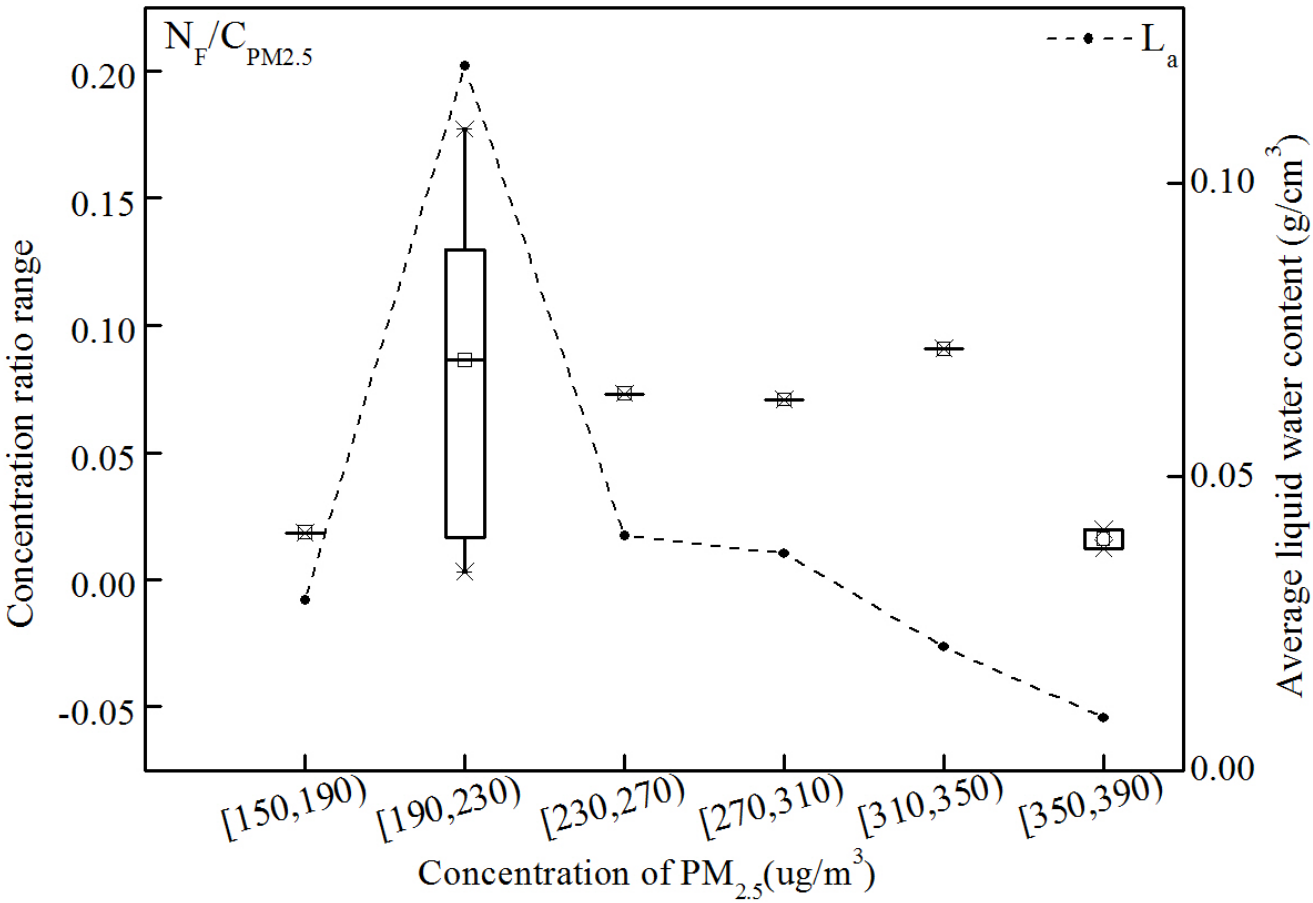

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS11] Aerosol impacts on air quality, climate system, and our society

convener:Teppei J Yasunari(Arctic Research Center, Hokkaido University), Kyu-Myong Kim(NASA Goddard Space Flight Center), Hongbin Yu(NASA Goddard Space Flight Center), Toshihiko Takemura(Research Institute for Applied Mechanics, Kyushu University)

Aerosol particles degrade air quality, modulate the radiation budget, influence the formation and evolution of clouds and precipitation, affect the ecosystems and biogeochemical cycles. These impacts have important implications for global sustainability and societal benefits. This session invites papers reporting latest advances in understanding lifecycles of aerosol and assessing aerosol impacts on air quality, the climate system from regional to global scales using in situ observation, remote sensing, and numerical modeling techniques. We also welcome papers on how the important roles of aerosol in air quality and climate system have influenced our society such as economic and educational activities. The topics of interest include but are not limited to: (1) physical processes on aerosol emission, transport and deposition, (2) trends of regional aerosol and their controls by emissions and meteorology, (3) aerosol influences on radiation through scattering, absorption, as well as albedo changing, (4) aerosol impacts on monsoon hydrological cycle and extreme weather events such as drought, flood, wildfire, typhoon, as well as the influences of the extreme weather events on aerosol emissions and transport, (5) the role of aerosol in global biogeochemical cycles, (6) aerosol impact on our society and economy, (7) new analytical methods for assessment and prediction such as machine learning, and (8) aerosol related education and outreach.

[AAS11-06] Challenges in constraining cloud and precipitation susceptibilities to aerosols: Satellite observations and global climate models

★Invited Papers

*Takuro Michibata[1], Kentaroh Suzuki[2], Toshihiko Takemura[1] (1.Research Institute for Applied Mechanics, Kyushu University, 2.Atmosphere and Ocean Research Institute, The University of Tokyo)

[AAS11-07] Effective Radiative Forcing Estimates of Anthropogenic Aerosols in MRI-ESM2

*Naga Oshima[1], Seiji Yukimoto[1], Makoto Deushi[1], Tsuyoshi Koshiro[1], Hideaki Kawai[1], Taichu Y Tanaka[1], Kohei Yoshida[1] (1.Meteorological Research Institute)

[AAS11-08] **Satellite and model perspectives of dust transport and deposition across tropical Atlantic Ocean and North Pacific Ocean in recent decades**

*Hongbin Yu[1], Qian Tan[2,3], Yingxi Shi[4,1], Huisheng Bian[1,4], Zhibo Zhang[4], Qianqian Song[4], Dongchul Kim[1,5], Mian Chin[1], Lorraine Remer[4] (1.NASA Goddard Space Flight Center, 2.Bay Area Environmental Research Center, 3.NASA Ames Research Center, 4.University of Maryland Baltimore County, 5.Universities Space Research Association)

[AAS11-09] Dependency of surface air temperature change by sulfate aerosols on CO_2 concentration

*Toshihiko Takemura[1] (1.Research Institute for Applied Mechanics, Kyushu University)

[AAS11-10] Quantifying the Impact of Missing Aerosol Sources on Long Range Transport and Extreme Events using Satellites and Models

*Jason Blake Cohen[1] (1.School of Atmospheric Sciences, Sun Yat-Sen University)

Challenges in constraining cloud and precipitation susceptibilities to aerosols: Satellite observations and global climate models

*Takuro Michibata[1], Kentaroh Suzuki[2], Toshihiko Takemura[1]

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Aerosol-cloud interactions (ACI) remain elusive and are one of the most uncertain processes in climate modeling due to their nonlinear complexity. There is still a large gap in the magnitude of ACI between model estimates and satellite retrievals. A key complexity arises from the hypothesized response of clouds to perturbed aerosols through two competing pathways, i.e. the traditional “cloud lifetime” effect and more recent “buffered system” effect. A systematic difference is found in the response of liquid water path (LWP) to aerosol perturbations between MIROC GCM simulations and A-Train satellite observations. The model results indicate a near-global uniform increase of LWP with increasing aerosol loading, while the sign of the response of the LWP from the A-Train varies from region to region. The satellite-observed response of the LWP is closely related to meteorological and/or macrophysical factors (e.g., cloud type), in addition to the microphysics. The model does not reproduce this variability of cloud susceptibility to aerosols because the parameterization of the autoconversion process assumes only suppression of rain formation in response to increased cloud droplet number, and does not consider macrophysical aspects explicitly that serve as a mechanism for the negative LWP responses. The autoconversion process can also be a source of uncertainty in warm rain initiation, which is generally “too light and too frequent” in GCMs. The satellite-based constraints on the warm rain process is found to cause unrealistic negative effective radiative forcing due to ACI (ERFaci), implying that compensating errors exist between the precipitation process and other key processes in the model, likely due to the lack of the buffered system. In order to improve the above issues, we introduced a comprehensive two-moment microphysics scheme into the global aerosol-climate model, MIROC6-SPRINTARS, which includes prognostic precipitation for both rain and snow and considers their radiative effects. We found that the prognostic precipitation significantly mitigates the LWP susceptibility to aerosols through collection processes among precipitating hydrometeors and cloud droplets. The precipitation-driven buffering effects would explain the model-observation discrepancy in ERFaci. The warm rain formation process is slowed down, which is in good agreement with satellite observations, implying that the new scheme reconciles the error compensation between precipitation process and required energy budget. These results strongly support the necessity of prognostic precipitation framework in GCMs for more reliable climate simulation with intrinsic buffered systems.

Keywords: aerosol-cloud interactions, climate, radiative forcing

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Effective Radiative Forcing Estimates of Anthropogenic Aerosols in MRI-ESM2

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The effective radiative forcing (ERF) of anthropogenic gases and aerosols in present-day conditions (year 2014) relative to preindustrial conditions (year 1850) is estimated using the Meteorological Research Institute Earth System Model version 2.0 (MRI-ESM2.0) as part of the Radiative Forcing Model Intercomparison Project (RFMIP) and the Aerosol and Chemistry Model Intercomparison Project (AerChemMIP), endorsed by the sixth phase of the Coupled Model Intercomparison Project (CMIP6). The global mean total anthropogenic net ERF estimate at the top of the atmosphere (TOA) is 1.96 W m^{-2}, and is composed mainly of positive forcings due to carbon dioxide (1.85 W m^{-2}), methane (0.71 W m^{-2}), and halocarbons (0.30 W m^{-2}) and of negative forcing due to total aerosols (-1.22 W m^{-2}). The total aerosol ERF consists of approximately 25% from aerosol-radiation interactions (-0.32 W m^{-2}), 80% from aerosol-cloud interactions (-0.98 W m^{-2}), and slightly from surface albedo changes caused by aerosols (0.08 W m^{-2}). The ERFs due to aerosol-radiation interactions consist of opposite contributions from light-absorbing black carbon aerosols (0.25 W m^{-2}) and from light-scattering sulfate (-0.48 W m^{-2}) and organic aerosols (-0.07 W m^{-2}) and is pronounced over the emission source regions. The ERFs due to aerosol-cloud interactions are prominent over the source and downwind regions, caused by increases in the number concentrations of cloud condensation nuclei and cloud droplets in low-level clouds. Concurrently, increases in the number concentration of ice crystals in high-level clouds caused by anthropogenic aerosols, particularly over the tropical convective regions, cause both substantial negative shortwave and positive longwave ERFs in MRI-ESM2.0. These distinct forcings can largely cancel each other out in terms of the radiation budget at the TOA; however, significant longwave radiative heating of the atmosphere caused by high-level clouds suggests the importance of further studies on the interactions of aerosols with ice clouds.

Keywords: Radiative forcing, Aerosols, Short lived climate forcer, Climate change, Earth system model, CMIP6

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Satellite and model perspectives of dust transport and deposition across tropical Atlantic Ocean and North Pacific Ocean in recent decades

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Large amounts of dust emitted from North Africa, Middle East, and Asia transport across the tropical Atlantic Ocean and North Pacific Ocean to reach the Americas, exerting far-reaching impacts on air quality, radiation balance, clouds and precipitation, and ecosystems. Significant fraction of dust is deposited into the ocean basins along the transport routes, which has important implications for ocean biogeochemical cycles and climate. Given their routine sampling over decadal time scales with extensive spatial coverage, satellites are a suitable platform to observe such large-scale phenomena and its variability at a range of time scales. Because of differences in dominant source regions, atmospheric circulations, as well as clouds and precipitation, the trans-Atlantic and trans-Pacific dust transport and deposition can differ in many aspects. In this study, we investigate similarities and differences between the trans-Atlantic and trans Pacific dust transport and deposition by analyzing the decade-long record of aerosol measurements from three distinctive satellite sensors, namely CALIOP, MODIS, and MISR. Specifically, we focus on the characteristics of dust optical depth (DOD) and its trend in recent decade, dust vertical profile, dust deposition rate, and dust loss frequency (LF), as well as how these dust characteristics are associated with atmospheric circulations, clouds and precipitation. Satellite remote sensing observations of aerosol optical depth (AOD) and particle size (e.g., the fine-mode fraction from MODIS) and shape (e.g., the depolarization ratio from CALIOP and the non-spherical fraction from MISR) properties are used to derive DOD. Although a daily snapshot of DOD from satellites does not provide information on dust deposition, an aggregation of these DOD snapshots over a timeframe of month or season yields a spatial distribution of DOD, in which the DOD gradient along the transport route indicates the amount of dust being deposited into surface ocean. The veering of dust plume by winds is accounted for in the estimate of dust deposition rate by calculating the divergence of zonal and meridional dust mass flux. The LF, defined as dust deposition rate normalized by the atmospheric dust loading, is derived to measures how efficient the dust is removed from the atmosphere. These observational characteristics of trans-Atlantic and trans-Pacific dust transport and deposition are also compared with model simulations to shed light on possible model deficiencies.

Keywords: Dust, Remote Sensing, Modeling, Deposition, Transport

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Dependency of surface air temperature change by sulfate aerosols on CO_2 concentration

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Sulfate aerosols are estimated to mitigate global warming through aerosol-radiation interactions by scattering solar radiation and through aerosol-cloud interactions enhancing it by cloud droplets. Under the present situation in which emissions of anthropogenic SO_2, a primary precursor of sulfate aerosol, are decreasing and, on the other hand, atmospheric CO_2 concentrations are increasing, it is anxious about accelerating global warming. In the previous study, a change in surface air temperature with perturbed SO_2 and black carbon emissions (factors of 0.0, 0.1, 0.3, 0.5, 0.8, 1.5, and 2.0 relative to present emissions) were analyzed using an atmosphere-ocean general circulation model coupled with an aerosol process model, MIROC-SPRINTARS (Takemura and Suzuki, 2019). In this study, extended experiments were performed with CO_2 concentrations both of present (369 ppm, recorded in 2000) and double (738 ppm, close to SSP3-7.0 scenario for 2080) for each SO_2 emission factor. The experimental results show that reducing SO_2 emission at high CO_2 concentration brings an enhanced increase in surface air temperature. The warming is especially strong over land at the mid- and high- latitudes in the Northern Hemisphere because of an larger increase in water vapor that is a greenhouse gas, a weaker increase in liquid water path, and stronger ice-albedo feedback under the higher CO_2 concentration.

Reference: Takemura, T., and K. Suzuki, Sci. Rep., 9, 2019, doi:10.1038/s41598-019-41181-6.

Keywords: aerosols, climate change, temperature, greenhouse gases, climate model, feedback

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Quantifying the Impact of Missing Aerosol Sources on Long Range Transport and Extreme Events using Satellites and Models

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Over the past two decades there have significant changes in the sources and magnitudes of aerosol emissions. One is from a rapid expansion of energy usage and urbanization in developing regions of Asia, Africa, and South America. The other is from increased deforestation world-wide. In addition to these changes we now have access to many measurements of aerosols on a global-scale from passive to active measurements from satellites and ground stations.

We have successfully proposed a new analytic method (i.e. Lin, Cohen, et al. 2020 [RSE]; Wang, Cohen et al. 2020 [ACP]; Lan, Cohen et al. 2020 [Under Review]) that combines the data from multiple remotely sensed platforms in space and on the ground into a single dataset. Subsequently a variance maximization scheme is applied to this data to analyze how the different sensed and measured variables related to aerosols change in relation to each other. This is then combined with a basic understanding of the physics and chemistry of these different sources and how they should evolve over time. Finally, these are merged together in connection with a traditional Kalman filters techniques to smooth out and scale the results, allowing for us to quantify the magnitudes of the aerosol emissions. Our results have a new a priori for global aerosol emissions from missing sources, or sources which have undergone rapid global change from 2000 to 2020.

However, such extreme changes in aerosol emissions as observed from our results and supported by the underlying measurements lead to significant impacts. First, in cases where a significant amount of the aerosols is lofted to height, there is a strong impact on vertical stability of the atmosphere and hence a feedback which allows for more intense long-range transport. This is demonstrated clearly when our method is used to run the new emissions in the global CESM model. We find that instead of sources from China dominating the plume over the Korean Peninsula and Japan out to the Pacific Ocean, that in fact, there is an even stronger signal from India and Southeast Asia, which itself is transported over Southern Greater China and in turn continues onwards over Japan and the Pacific Ocean. This signal is found to be a significant contribution nearly every year, and the dominant part of the contribution in the February to April system from a climatological perspective. The results of the underlying sources, physics, and dynamics will be presented. Comparisons with other measurements, such as CO from MOPITT will also be used to provide additional support to this assertion. One interesting thing to note is that similar long-range transport is found in other regions of the world as well, including from Indonesia and Central Africa over the Indian Ocean, and from South America over the Atlantic and sometimes even Indian Ocean.

On top of this, we will further analyze the impact that these new sources have on extreme events. While we observe clear decreases in sources from urban North America and urban Western Europe, increases in some parts of East Asia and decreases over other parts of East Asia, on average, in terms of extreme events the same is not true. We have found a significant impact on extreme events from the new sources from North America, Southeast Asia, Africa, and the Arctic. Often these events last from a few days to a few weeks and lead to conditions in areas which otherwise are generally very clean. Some of the feedbacks in terms of the transport and the conditions of the emissions themselves in terms of the vertical distribution

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will be discussed more fully.

Keywords: Aerosol Emissions, Long Range Transport, Extreme Events, In-Situ Processing

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS11] Aerosol impacts on air quality, climate system, and our society

convener:Teppei J Yasunari(Arctic Research Center, Hokkaido University), Kyu-Myong Kim(NASA Goddard Space Flight Center), Hongbin Yu(NASA Goddard Space Flight Center), Toshihiko Takemura(Research Institute for Applied Mechanics, Kyushu University)

Aerosol particles degrade air quality, modulate the radiation budget, influence the formation and evolution of clouds and precipitation, affect the ecosystems and biogeochemical cycles. These impacts have important implications for global sustainability and societal benefits. This session invites papers reporting latest advances in understanding lifecycles of aerosol and assessing aerosol impacts on air quality, the climate system from regional to global scales using in situ observation, remote sensing, and numerical modeling techniques. We also welcome papers on how the important roles of aerosol in air quality and climate system have influenced our society such as economic and educational activities. The topics of interest include but are not limited to: (1) physical processes on aerosol emission, transport and deposition, (2) trends of regional aerosol and their controls by emissions and meteorology, (3) aerosol influences on radiation through scattering, absorption, as well as albedo changing, (4) aerosol impacts on monsoon hydrological cycle and extreme weather events such as drought, flood, wildfire, typhoon, as well as the influences of the extreme weather events on aerosol emissions and transport, (5) the role of aerosol in global biogeochemical cycles, (6) aerosol impact on our society and economy, (7) new analytical methods for assessment and prediction such as machine learning, and (8) aerosol related education and outreach.

[AAS11-11] Impacts of increased Siberian wildfire on air quality, climate, and economy, assessed with MIROC/SPRINTARS sensitivity experiments

*Teppei J Yasunari[1,2,3], Shigeto Wakabayashi[4], Toshihiko Takemura[5], Daiju Narita[6] (1.Arctic Research Center, Hokkaido University, 2.Global Station for Arctic Research, GI-CoRE, Hokkaido University, 3.Center for Natural Hazards Research, Hokkaido University, 4.School of Engineering, Hokkaido University, 5.Research Institute for Applied Mechanics, Kyushu University, 6.Graduate School of Arts and Sciences, The University of Tokyo)

[AAS11-12] Linking Climate Modeling to Economic Assessment of Climate Change: Analysis of MIROC-SPRINTARS AOGCM Experiments on Siberian Wildfires

★Invited Papers

*Daiju Narita[1], Teppei J Yasunari[2], Toshihiko Takemura[3] (1.University of Tokyo, 2.Hokkaido University, 3.Kyushu University)

[AAS11-14] Towards a globally harmonized air quality forecasting: GAFIS, a new WMO-GAW initiative

*Taichu Y Tanaka[1], Johannes Flemming[2], Alexander Baklanov[3], Greg Carmichael[5], James H. Crawford[6], Vincent-Henri Peuch[2], Guy Brasseur[7], Ranjeet Sokji[8], Sean Khan[9], Slobodan Nickovic[10], Xiao-ye Zhang[11,10], Christopher Gan[12], Kobus Pienaar[13], Nathalie Laure Roebbel[4], Radenko Pavlovic[14], Markus Amann[15], Robert Pinder[16], Giulia Ruggeri[4], Sophie Pauline Gumy[4] (1.Meteorological Research Institute, Japan Meteorological Agency, 2.ECMWF, 3.WMO, 4.WHO, 5.Univ. Iowa, 6.NASA, 7.MPI-MET, 8.Univ. Hertfordshire, 9.UNEP, 10.SDS-WAS, 11.CMA, 12.NEA, 13.North-West Univ, 14.ECCC, 15.IIASA, 16.EPA)

Discussion

Impacts of increased Siberian wildfire on air quality, climate, and economy, assessed with MIROC/SPRINTARS sensitivity experiments

*Teppei J Yasunari[1,2,3], Shigeto Wakabayashi[4], Toshihiko Takemura[5], Daiju Narita[6]

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Wildfire is of large concern recently because it sometimes causes disasters in surrounding areas where people live, emits a large amount of air pollutions, and may also induce health issues. Siberian wildfire is a well-known wildfire in the world. To assess the impact of increased Siberian wildfires on air quality, climate, and economy, we implemented six AGCM (Atmospheric General Circulation Model; 15-year integration and analyses for the last 10 years) and AOGCM (Coupled Atmosphere-Ocean General Circulation Model; 100-year integration and analyses for the last 50 years) sensitivity experiments with MIROC/SPRINTARS model (version 5.9.0; [1-3]) for which we change the biomass burning (BB) emissions and climate conditions (i.e., different Representative Concentration Pathway, RCP, scenarios; RCP2.6 and RCP8.5 [4]): (1) the baseline experiment with the Global Fire Emissions Database (GFED) BB emissions [5] in 2004 (lower BB case) under the present climate condition in 2005 (PC05); (2) the increased BB case only replacing the BB emission over the defined Siberian domain (70˚-140˚E; 42.5˚-70˚N) to that in 2003 under PC05; (3) the doubling #2 BB emissions over the Siberian domain under PC05, expecting a more severe wildfire case in the future; (4) same as #2 but under the RCP2.6 condition in 2030; (5) same as #2 but under the RCP8.5 condition in 2030; (3) same as #3 but under the RCP8.5 condition. For the air quality assessment, here we use the outputs from the AGCM experiments to assess the air quality for which we further assess the premature mortality and its economic impacts due to the worse air quality in Japan (the method will be mentioned in detail at the presentation). For the climate impact, we used the outputs from AOGCM to here mainly assess the global aerosol and cloud radiative forcing, and surface air temperature. The relevant assessment of the climate impact on economy will be presented by Narita, D., et al. in the same session.

For example, the increased Siberian wildfire would likely induce the maximal premature mortality due to lung cancer and cardiovascular diseases and their economic impacts of approximately 7,000 persons/year and 1.56 trillion JPY in economic loss in Japan, respectively (Based on the difference between Experiments #3 and #1). Under the similar increase of air pollution case but under the RCP8.5 climate condition, the global aerosol shortwave and cloud longwave radiative forcing at the top of atmosphere and the surface showed the negative maxima. This would also increase the global 2-m temperature of 0.43 K. More details will be shown on the day of the presentation.

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Keywords: wildfire, air pollution, climate impact, health impact, economic impact, aerosol

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Linking Climate Modeling to Economic Assessment of Climate Change: Analysis of MIROC-SPRINTARS AOGCM Experiments on Siberian Wildfires

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1. University of Tokyo, 2. Hokkaido University, 3. Kyushu University

Climate change potentially affects the global macroeconomic performance through a number of pathways such as intensification of weather extremes and temperature-related yield losses of major crops. A wide range of economic research has been made for quantifying such impacts. The efforts have been synthesized by publications of the Social Cost of Carbon (e.g., [1]). Such estimations of economic impacts of climate change are often made in the use of Integrated Assessment Models (IAMs), which are models embodying modules for both macroeconomic and climatic simulations. However, there are some relatively neglected factors in the IAM literature so far, and among them are the climatic responses of aerosol emissions from wildfires.

This presentation will offer an overview of the IAM approach and propose a method of quantifying wildfires' impact on the macro-level economy through their climatic effects due to the changes of atmospheric aerosols. To this end, it discusses our analysis on Siberian wildfires as an attempt of such assessment. Specifically, we evaluate the potential scale of macroeconomic impacts of Siberian wildfires' climatic effects by drawing on results of sensitivity experiments on enhanced biomass burning (BB) emissions (i.e., aerosols: black carbon, organic carbon; precursor gas: SO2) over the defined Siberian domain using a global aerosol climate model, MIROC-SPRINTARS, in which the model was coupled with the ocean model (i.e., Atmosphere-Ocean coupled Global Climate Model: AOGCM). We use sets of simulation results differing in the conditions of BB emissions and climate, in which three different reference levels of BB emissions over the defined Siberian domain were used under the present (RCP scenario in 2005) or future climate (RCP2.6 and RCP8.5 in 2030) conditions. Differentials of annual average temperatures estimated by the simulations are used to compute monetary-equivalent economic impacts attributable to climatic effects of BB by applying the functions of the RICE-2010 model [3], which is a regionally disaggregated version of the most widely used IAM, the DICE model. The macroeconomic impacts are estimated for the most affected countries and regions, such as Russia, China and Europe.
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Keywords: Aerosols, Climate change, Economic impacts, Integrated assessment models

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Towards a globally harmonized air quality forecasting: GAFIS, a new WMO-GAW initiative

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Air pollution remains a severe health threat around the world. The extreme air pollution events such as dust storms or smokes immediately damage the life and properties. The World Health Organization (WHO) estimates that 9 out of 10 people breathe air containing high levels of pollutants, and seven million premature deaths are attributed to air pollution globally in a year (4.3 million indoor and 2.6 outdoor). Further, air pollution is detrimental to ecosystems and food production and impacts transport by degrading visibility. Air pollution enhances the vulnerability of climate change impacts. To take preventive mitigation measures from air pollution, air quality, and the induced atmospheric phenomena, forecasting systems with its observation and modeling components are a key element. Many meteorological and environmental centers are conducting air quality forecasting; however, air quality forecasting is missing in many parts of the world. To enable and provide science-based and operational-oriented air quality forecasting and information analysis services for various regions of the world in a globally coordinated and harmonized way tailored to the needs of society, and to mobilize various observations of GAW to carry out in-depth research combining observation and model development. World Meteorological Organization (WMO)'s Global Atmosphere Watch (GAW) program and several international organizations started a new initiative named "Global Air Quality Forecasting and Information Systems (GAFIS)." The aim of GAFIS includes to build a network for the development of good practices utilizing diverse approaches for air quality forecasting and monitoring, and enhance science and operational applications of atmospheric composition feedback in Numerical Weather Prediction. The critical elements for the success of the initiative are improving access to quality-assured air quality observations and user interaction/feedback. In this session, we introduce the state of the global air quality forecasting and prompt discussions with the research community.

Keywords: Air quality, Aerosol, forecasting

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS13] New particle formation and its impacts on atmospheric chemistry

convener:Jun Zheng(Nanjing University of Information Science and Technology), Lin Wang(Fudan University)

Despite of the fact that new particle formation (NPF) contributes about half of the aerosol population globally, the underlying mechanisms governing the NPF remain poorly understood. Current NPF models often lead to conflicting results with respect to real-time in-situ observations. Consequently, NPF process is seldomly incorporated into atmospheric models, causing great hindrance to accurately assess aerosol atmospheric impacts on air pollution formation and climate change on both regional and global scales. Although H2SO4, basic gases, and HOMs have been proposed to be responsible for NPF, searching for potential NPF precursors are still an active subject of research. Many recent studies strongly indicate that NPF mechanism may differ from place to place and the newly formed particles may also possess distinct properties (e.g., CCN activity). Nevertheless, there is a great demand to reconcile the conflicting results and to improve our understanding of the mechanisms for NPF. This session solicits contributions that describe research progresses on any aspects of NPF, including laboratory studies, theoretical calculation and modeling, and field measurements.

[AAS13-01] New particle formation in the polluted atmosphere of the North China Plain

★Invited Papers

*Hu Min[1], Dongjie Shang[1], Xin Fang[1], Song Guo[1], Zhijun Wu[1], Limin Zeng[1], Sihua Lu[1], Shiyi Chen[1], Keding Lu[1], Yuanhang Zhang[1] (1. State Key Joint Laboratory of Environmental Simulation and Pollution Control, College of Environmental Sciences and Engineering, Peking University)

[AAS13-02] **New particle formation and growth in the urban atmospheric environment**

★Invited Papers

*Jingkun Jiang[1] (1.Tsinghua University)

[AAS13-03] The role of NOx in the formation of highly oxygenated organic molecules and new particles

★Invited Papers

*Wei Nie[1], Chao Yan[2], Pontus Roldin[3], Mikael Ehn[2], Aijun Ding[1] (1.Joint International Research Laboratory of Atmospheric and Earth System Sciences, School of Atmospheric Sciences, Nanjing University, 2.Institute for Atmospheric and Earth System Research/Physics, Faculty of Science, University of Helsinki, 3.Division of Nuclear Physics, Department of Physics, Lund University)

[AAS13-05] How does NOx affect new particle formation from biogenic vapors

*Chao Yan[1] (1.University of Helsinki)

[AAS13-06] Theoretical investigation of heterogeneous oxidation of sulfuric dioxide on mineral dusts and its implication on atmospheric new particle formation

*Jun Zhao[1], Kunpeng Chen[1] (1.Sun Yat-Sen University)

New particle formation in the polluted atmosphere of the North China Plain

*Hu Min[1], Dongjie Shang[1], Xin Fang[1], Song Guo[1], Zhijun Wu[1], Limin Zeng[1], Sihua Lu[1], Shiyi Chen[1], Keding Lu[1], Yuanhang Zhang[1]

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New particle formation (NPF) are the major source of atmospheric particles and may contribute up to 50% of particle number concentrations and cloud condensation nuclei (CCN), both of which affect cloud–climate interactions. Thus, the NPF has important impacts on climate and air quality at both regional and global scale. A lack of quantitative understanding of NPF processes is responsible for the largest uncertainty in global climate models, of which NPF processes under polluted conditions are the least understood.

Under the complex air pollution conditions in China it was found the new particle formation and subsequent growth resulted in haze pollution, especially in the North China Plain (NCP) areas, where nucleation rates (J) ware 1–2 orders of magnitude higher than in relatively clean regions.

A near-complete closure between NPF observations over the North China Plain and a corresponding cluster-aerosol dynamics modelling was conducted to understand NPF mechanism. The model combines mechanisms for explicit representation of H_2SO_4-NH_3 cluster dynamics and condensational growth by highly oxygenated organic molecules from aromatic hydrocarbons and terpenes. Under NH_3 and H_2SO_4 rich conditions (>10 ppb NH_3; >10^7 cm^{-3} H_2SO_4), the simulated and measured nucleation rates are within the same order of magnitude. The particle (1-10 nm in diameter) volume growth can partially explained by the condensation of H_2SO_4 (23%), oxidation products of aromatics (9%), monoterpenes (19%), and isoprene (9%), the remaining products (40%) need to be further resolved. The study reveals the increasing importance of NH_3 and volatile organic compounds for NPF under current air quality policies in relatively polluted regions.

Keywords: New particle formation, Nucleation, Ammonia, HOMs, Particle growth, Sulfuric acid

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New particle formation and growth in the urban atmospheric environment

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The transformation from low-volatility vapors to new particles (new particle formation, NPF) is a frequent phenomenon in various atmospheric environments and it impacts aerosol number concentration, cloud formation, and hence climate. In comparison to numerous NPF studies in clean atmospheric environments, however, NPF mechanism in polluted atmospheric environments remains elusive. For instance, the new particle formation rate of 1.5 nm particles in urban Beijing was found to be magnitudes higher than those reported in relatively clean atmospheric environments. Polluted environments often have high concentrations of precursors and high aerosol loadings. Therefore, the scavenging of newly formed particles due to coagulation contribute significantly to the formation and the growth of new particles. The clustering of H_2SO_4 and amines is a possible mechanism driving the fast nucleation and initial growth of new particles against the scavenging by the high aerosol concentration in the polluted urban environment. However, the molecular-level mechanism and governing factors for H_2SO_4-amine nucleation have not been quantitatively investigated in the real atmosphere. Based on long-term atmospheric measurements in urban Beijing, the critical step of acid-base nucleation in the urban atmosphere will be discussed. The influences of precursor concentrations, aerosol loading, and temperature on particle formation rate are quantitatively addressed. Atmospheric species contributing to particle growth are revealed.

Keywords: new particle formation, urban atmospheric environment, acid base nucleation

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The role of NOx in the formation of highly oxygenated organic molecules and new particles

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NOx is abundantly distributed in the present-day atmosphere and has been demonstrated to participate in the troposphere chemistry prevalently, including the formation of highly oxygenated organic molecules (HOMs), who have been demonstrated to be key precursors in new particle formation and growth (NPF). Here, with CERN CLOUD chamber facility, we investigated the complicated roles of NO_x in the formation of HOMs from the oxidation of monoterpenes, and in turn the new particle formation and growth. We find that NOx influences the HOM formation deeply and nonlinearly via forming a large amount of organonitrate and suppressing the HOM dimer formation. In addition, we showed that NO_x suppresses particle growth in general, but the suppression is rather non-uniform and size-dependent, which can be quantitatively explained by the shifted HOM volatility after adding NO_x. By illustrating how NO_x affects the early growth of new particles - a critical step of CCN formation, our results help to provide a refined assessment of the potential climatic effects caused by the diverse changes of NO_x level in forest regions around the globe.

Keywords: highly oxygenated organic molecules, new particle formation and growth, NOx

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How does NOx affect new particle formation from biogenic vapors

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New particle formation (NPF) is a major source of ultrafine particles in the atmosphere. In continental boundary layer, sulfuric acid is believed to play a major role in NPF, and NOx does not have any direct influence on this process, as it does not affect the formation of sulfuric acid. However, it has been discovered that highly oxygenated organic molecules (HOMs) are also a key participator in NPF. As NOx is actively involved in the formation of HOMs, it subsequent influence can be expected. We will present detailed analysis on how NOx can alter the chemical composition of HOMs and in turn, its role on different stages of the NPF process.

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Theoretical investigation of heterogeneous oxidation of sulfuric dioxide on mineral dusts and its implication on atmospheric new particle formation

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1. Sun Yat-Sen University

Heterogeneous oxidation of sulfur dioxide on mineral dusts is an important source of atmospheric sulfate which affects solar radiation and air quality, but mechanistic understanding at molecular level is largely lacking. We employed in this work a novel computational approach to investigate this process on hematite, a chosen model mineral dust. This approach performs molecular dynamic simulations by incorporating the our own n-layered integrated molecular orbital and molecular mechanics (ONIOM) method and other advanced quantum and kinetic methods. Our results clearly showed that under low relative humidity sulfur dioxide can react with surface hydroxyl groups to produce interfacial sulfate, while in medium relative humidity it reacts with interfacial water to form HSO3 radicals which then escape the surface and are further oxidized to gas-phase sulfuric acid. In addition, hydrophilic organic species can serve as water aggregator to alter heterogeneous reaction mechanisms. Our study demonstrated that reaction channels and subsequent impacts can be substantially different under various interfacial environments, which are closely correlated to relative humidity, and hence kinetic parameterization of each channel and corresponding impact should be respectively evaluated for further models of atmospheric chemistry. Atmospheric implication, in particular, contribution to new particle formation will be discussed.

Keywords: new particle formation, heterogeneous oxidation, sulfuric dioxide, mineral dusts, hematite, atmospheric radicals

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS14] Extreme Events: Observations and Modeling

convener:Sridhara Nayak(Disaster Prevention Research Institute, Kyoto University), JAGABANDHU PANDA(National Institute of Technology Rourkela)

[AAS14-01] Changes in “hotter and wetter” events across China

*Hanqing Deng[1] (1.Anhui climate center)

[AAS14-02] Modulations of European and North American weather variability and extremes by interdecadal variability of the atmospheric circulation over the North Atlantic

★Invited Papers

*Hisashi Nakamura[1], Patrick Martineau[1], Yu Kosaka[1], Bunmei Taguchi[2], Masato Mori[1] (1.Research Center for Advanced Science and Technology, University of Tokyo, 2.Faculty of Sustainable Design, University of Toyama, Toyama)

[AAS14-04] Role of midlatitude SSTs on Extreme Precipitation Events

★Invited Papers

*Satoshi Iizuka[1], ATSUYOSHI MANDA[2] (1.National Research Institute for Earth Science and Disaster Resilience, 2.Mie University Graduate School and Faculty of Biosciences)

[AAS14-05] An overall investigation of changing nature of tropical storms in the North West Pacific basin

*Ravi Shankar Pandey[1], Yuei-An Liou[1] (1.National Central University)

[AAS14-06] Variability of Monsoon Onset in India and Different Modes of Climate Variation (1951-2017)

*Atul Saini[1], Netrananda Sahu[1,2] (1.Department of Geography, University of Delhi, 2.Disaster Prevention Research Instituite, Kyoto University)

Changes in “hotter and wetter” events across China

*Hanqing Deng[1]

1. Anhui climate center

As global warming intensifies, efforts to understand changes in extreme climate events have increased in recent years. However, some extreme events that are unprecedented remain a persistent challenge. Using daily temperature and precipitation dataset from 531 meteorological stations in China from 1961 to 2015, we define the hotter and wetter (HW) events (The HW event in this study is defined as an extreme event with high-temperature days and torrential rain days exceeding long-term averages (1961-2015a) simultaneously), and we further analyze the changes in HW events to evaluate the impacts in China during the period from 1961 to 2015. It is reasonable to define several different climatological regions. Following China’s national assessment report on climate change, 8 subregions in China are defined. More details on the 8 subregions can be found in Table 1.

A HW event is designed to be used when there is a JJA period in which high-temperature days and torrential rain days exceed the long-term average. We examined changes in the HW events in order to evaluate the impacts in China during 1961-2015. The results revealed that the distributions of the mean high-temperature and torrential rain days vary regionally. The CC, EC, and SC subregions experience the most frequent extreme heat and precipitation events, which occur concurrently. Increasing high-temperature days are found in NWC, SWC2, SWC1, and SC after the mid- to late 1990s. However, torrential rain days show an increasing trend in EC and decreasing trends in NWC and SC after the mid to late 1990s. This result not only indicates the important role of variability in both extreme events across NWC, SC, and EC but also considerably impacts societies and ecosystems.

The HW events in each subregions show different changes in both frequency and intensity. The frequency of the HW events is much higher in central and eastern China (SC, EC, and CC) than in other areas, especially SC. In SC and EC, there are significant increasing trends of 2.7 and 1.9 events per decade, respectively. In China, the HW events mostly occurred in the most recent 20 years of the study period, indicating that China has entered a period of high-frequency HW events. Therefore, it is implied that more simultaneous high-temperature and extreme precipitation events in JJA may lead to severe impacts that are unanticipated and have a major effect. Indeed, the torrential rain anomalies are greater than the high-temperature anomalies in NWC, CC, and EC after the mid- to late 1990s. However, the opposite trend is observed in NEC, SWC1, SWC2, and SC. Finally, the relationship between the HW events and warming is estimated. The results imply that the changes in HW events are associated with warming. Thus, an increase in the number of HW events with warming could be quite common in the future.

Understanding the changes in the HW events has an important role in climate adaptation and mitigation efforts. Further, although the historical changes in the HW events also have been recognized in this paper, we intend to use this definition to project future changes under different RCP scenarios.

Keywords: Extreme events, Hotter and wetter, Projection

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Name	Latitude	Longitude
NWC: Northwest China	36°N—46°N	75°E—111°E
SWC2:Southwest China-region 2	22°N—27°N	98°E—106°E
SWC1: Southwest China-region 1	27°N—36°N	77°E—106°E
SC: South China	20°N—27°N	106°E—120°E
CC: Central China	27°N—36°N	106°E—116°E
EC: East China	27°N—36°N	116°E—122°E
NC: North China	36°N—46°N	111°E—119°E
NEC: Northeast China	39°N—54°N	119°N—134°N

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Modulations of European and North American weather variability and extremes by interdecadal variability of the atmospheric circulation over the North Atlantic

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1. Research Center for Advanced Science and Technology, University of Tokyo, 2. Faculty of Sustainable Design, University of Toyama, Toyama

The dominant mode of wintertime covariability between sub-seasonal surface air temperature (SAT) variability and (multi-) decadal mid-tropospheric circulation anomalies over the North Atlantic sector is identified through singular value decomposition analysis applied to century-long reanalysis data. This mode highlights a tendency for sub-seasonal SAT variability over Europe and eastern North America to be enhanced during the negative phase of the North Atlantic Oscillation (NAO). This (multi-) decadal NAO is characterized by a stationary Rossby wave train that originates from the subtropical Atlantic, propagates northward into the subpolar Atlantic, and finally refracts towards Europe and the Middle East. An increase in precipitation in the subtropics under the enhanced supply of heat and moisture from the Gulf Stream and its surroundings appears to act as a source for this wave train. The influence of interdecadal NAO variability on sub-seasonal SAT variability is explained primarily by the modulated efficiency of baroclinic conversion of available potential energy from the background atmospheric flow to sub-seasonal eddies. The combination of enhanced sub-seasonal variability and below-normal winter-mean temperature associated with the negative phase of the NAO increases the frequency of cold extremes affecting Europe and the eastern U.S.

Keywords: North Atlantic Oscillation (NAO), decadal modulations, surface air temperature, Rossby waves

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Role of midlatitude SSTs on Extreme Precipitation Events

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1. National Research Institute for Earth Science and Disaster Resilience, 2. Mie University Graduate School and Faculty of Biosciences

Satellite-derived sea surface temperature (SST) products are widely used as the lower boundary condition for numerical weather predictions and atmospheric simulations. However, cloud contamination is problematic in producing high-resolution infrared-based SST data. Temporal and spatial optimal interpolation is often used for constructing high-resolution gap-free SST products. This interpolation, however, can in effect smooth out temporal high-frequency SST variations or fine SST structures such as oceanic fronts and mesoscale eddies, which can potentially influence atmospheric simulations.

Torrential rains organized lines of deep convective cells often occur in the western Kyushu during the early-summer season. The prevailing low-level southwesterly transports the conditionally unstable air from the subtropics toward the coasts where the convection can develop often triggered by a flow interaction with orography. Yet, some observed and numerical studies demonstrate that the early-summer warming of SSTs over the East China Sea acts in maintaining the conditionally unstable air. Conversely, the relative cooler SSTs over the East China Sea suppress the convective activity. The similar air mass transformation can occur over the other midlatitude oceans.

Here we will discuss the impact of SST uncertainty on heavy precipitation events simulated in a regional atmospheric model. The sensitivity experiments to SST uncertainty for Akita-Iwate Heavy rainfall event on August 9, 2013 suggest that SST bias may alter both the area-averaged precipitation and the geographical locations of intense precipitation, which can potentially impact flash flood and landslide warnings. We will also demonstrate the results of other rainfall events to understand the role of midlatitude SSTs on extreme events.

Keywords: extreme event, Precipitation, SST

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An overall investigation of changing nature of tropical storms in the North West Pacific basin

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1. National Central University

An increasing strength of tropical storms (TS) in the North West Pacific (NWP) basin in recent years is a crucial matter of concern for the meteorological scientists as the basin already possesses the highest number of storms in the world. This study is broadly divided into two portions. First, the observational analysis on the nature of tracks of all (959) TS originated over four decades in the NWP basin is conducted by adopting a track sinuosity-based approach. The spatiotemporal variations in the nature of TS tracks in the four decades are investigated. The relationship of track sinuosity with TS parameters and with warm/cold phases of El Niño/Southern Oscillation (ENSO) is also examined. Strong enhancement of storm track sinuosity is observed from early to late typhoon season months (July to October). Significant longitudinal shift (from 110^0–140^0 E to 130^0– 160^0 E) in the positions of genesis points of majority of TS is observed with increasing track sinuosity. Mostly intense TS are originated during warm phase of El-Nino in the eastern part of NWP basin with their high track sinuosity values. Second, the favorable seasonal meteorological factors for the recent (2013-2017) all (30) most intense storms, generally called Super-Typhoons (STY), are also studied. It is found that a dominant and crucial role of southwest air flow and northwest cold air mass intensify STYs in summer and winter seasons, respectively. The majority of winter STYs are also partially assisted by southwest air flows and, thus, exhibit higher intensities than summer STYs in general. The findings of the study are crucial for mitigating the risk related to TS in the NWP region by improving understanding of their changing nature in recent years.

Keywords: North West Pacific, Track Sinuosity, Super-Typhoon, Southwest Air Flow, Cold Air Mass, El Niño/Southern Oscillation

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Variability of Monsoon Onset in India and Different Modes of Climate Variation (1951-2017)

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Monsoon in India plays a major role to play in the survival of the agricultural ecosystem and therefore variability in the amount of rainfall received is a matter of joy or sorrow to different sub-regions in the country. ***In the present study, we analyzed the Monsoon onset dates at the sub-regional level in India by identifying the onset date of Monsoon using the objective methodology.*** The objective method used to identify the Monsoon onset used NCAR reanalyzed data **(2.5˚ ×2.5˚)** for zonal wind, meridional wind, geopotential height precipitable water and total cloud cover is used and high-resolution rainfall data **(0.25˚ ×0.25˚)** obtained from India Meteorological Department. Monsoon onset phenomena are very dynamic and synoptic events play a very important role in changing the general nature of Monsoon onset date in the sub-regions of India, therefore the role of interannual climate variations in certain years is also discussed in detail to justify the connection between climate variation mode and Monsoon onset in India. Monsoon onset behavior in different climate modes is found varying for different regions in India but the majority of the region are found in harmony with the general trend of the Monsoon onset pattern of India. During the considered time period **(1951-2017)** for study, the region in and around SR15 (Rajasthan province) is found highly susceptible to the Monsoon onset. Results show that the SR17 (Bihar and Jharkhand region) in India is highly prone to early onset during the flood years. We found the late-onset pattern is almost homogenously spread at a pan-India level during El Niño, Drought and Negative IOD and early onset pattern during La Niña and Flood event years. Provinces in North India, which are part of SR19 are found in the influence of El Niño events and therefore in more than 70% of cases, the late onset of more than 5 days is observed in these regions. The intensity of the anomaly of Monsoon onset dates has also been discussed sub-region wise and the probability of the Monsoon onset date for different sub-regions is India is explained in detail, which will definitely be a help for the agronomists, policymakers and planners.

Keywords: Monsoon Onset, El Niño, La Niña, ±IOD, Flood and Drought, Sub-regions

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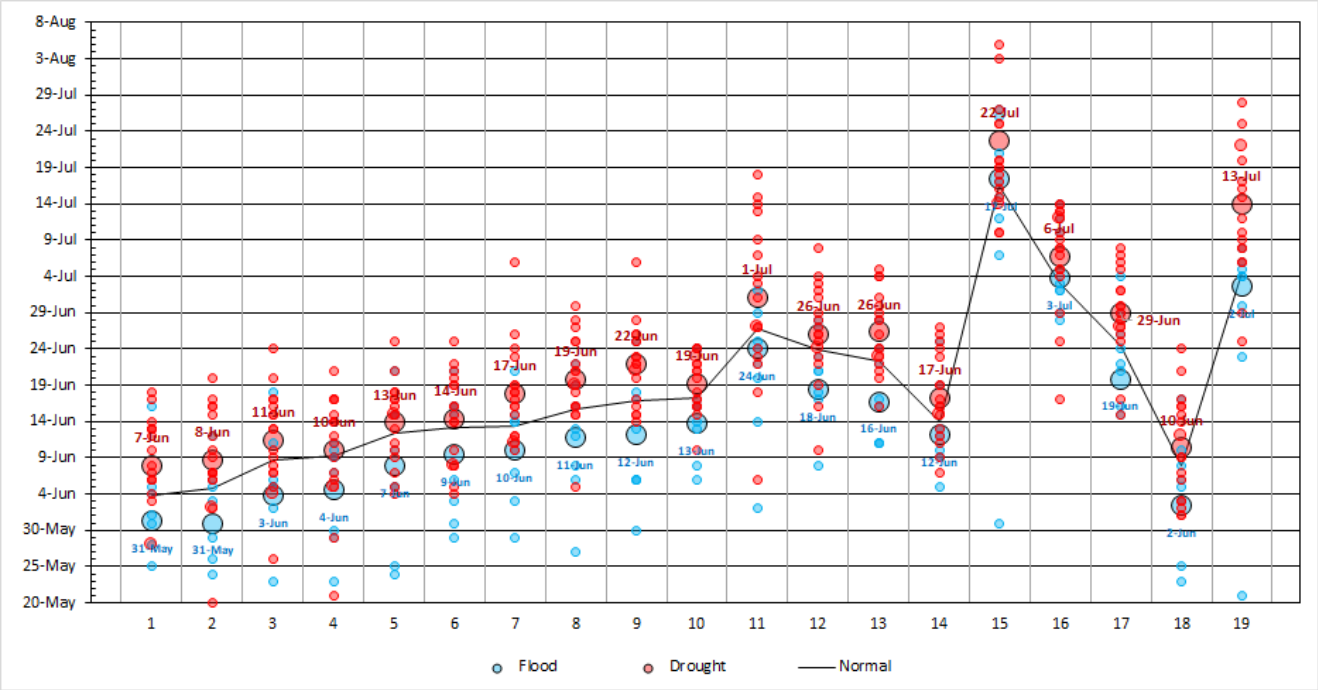

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-AS Atmospheric Sciences, Meteorology & Atmospheric Environment

[A-AS14] Extreme Events: Observations and Modeling

convener:Sridhara Nayak(Disaster Prevention Research Institute, Kyoto University), JAGABANDHU PANDA(National Institute of Technology Rourkela)

The frequencies and intensities of extreme events such as heavy rainfall, flash floods, droughts, heat waves, tropical cyclones etc. have increased in many regions across the globe and are of serious concern due to their socio-economic and climate change connections. Thus, understanding of the patterns of such events and particularly their characteristics have been the focus of many recent studies. This session invites abstracts on observational and numerical modeling studies to enhance the understanding of the spatial and temporal characteristics and predictability of the extreme events. In particular, abstracts are encouraged on regional analysis of the extreme events in past years and in near or far future (30-100 years), which would assist the policy makers to build potentially more resilient societies to face the extreme event related disasters. This session also welcomes the submissions on model simulations and evaluations to advance the understanding of the physics and dynamics associated with the extreme events.

[AAS14-07] **Contribution of global warming and atmospheric circulation to the hottest spring in Eastern China in 2018**

*Chunhui Lu[1], Ying Sun[1], Nikolaos CHRISTIDIS[2], Peter STOTT[2] (1.Beijing Climate Center, China Meteorological Administration, 2.Met Office Hadley Centre, Met Office, UK)

[AAS14-08] **The Synoptically-Influenced Extreme Precipitation Systems over Asian-Australian Monsoon Region from TRMM PR Measurements**

*Wei-Ting Chen[1], Hong-Wen Jian[1], Peng-Ren Chen[1], Chien-Ming Wu[1], Kristen L. Rasmussen[2] (1.National Taiwan University, 2.Colorado State University)

[AAS14-09] Atmospheric Rivers in a Changing Climate: An Overview from the second phase of the Atmospheric River Tracking Method Intercomparison Project (ARTMIP)

*Ashley Elizabeth Payne[1], Christine Shields[2], Jonathan Rutz[3], L. Ruby Leung[4], Travis O'Brien[5], F. Martin Ralph[6], Michael Wehner[7] (1.Department of Climate and Space Sciences and Engineering, University of Michigan, Ann Arbor, MI, USA, 2.Climate and Global Dynamics Division, National Center for Atmospheric Research, Boulder, CO, USA, 3.Science and Technology Infusion Division, National Weather Service Western Region Headquarters, National Oceanic and Atmospheric Administration, Salt Lake City, UT, USA, 4.Earth Systems Analysis and Modeling, Pacific Northwest National Laboratory, Richland, WA, USA, 5.Earth and Atmospheric Sciences, Indiana University, Bloomington, Indiana, USA, 6.Center for Western Weather and Water Extremes, Scripps Institution of Oceanography at the University of California, San Diego, CA, USA, 7.Computational Research Division, Lawrence Berkeley National Laboratory, Berkeley, CA, USA)

[AAS14-10] An Understanding of the Physical Mechanism for the back-to-back Drought over India in last one Century

*RAJU PATHAK[1], Sandeep Sahany, Saroj Kanta Mishra (1.Centre for Atmospheric Science, Indian Institute of Technology Delhi)

[AAS14-11] Detection and Possible Interpretation of Tropospheric Dispersive Phase Associated with Heavy Rain Events

*Naufal Setiawan[1], Masato Furuya[1] (1.Space Geodesy Research Section, Department of Earth and Planetary Sciences, Hokkaido University, Japan)

[AAS14-12] **Numerical Simulations of Smoke Haze Transport over Southeast Asia by using WRF-Chem**

★Invited Papers

*Srikanth Madala[1], Tan Li[1], Santo V. Salinas [1], Jun Wang[2,3] (1.Centre for Remote Imaging Sensing and Processing, National University of Singapore, Singapore, 2.Center for Global and Regional Environmental Research, University of Iowa, Iowa City, Iowa, USA , 3.Department of Chemical and Biochemical Engineering, University of Iowa, Iowa City, Iowa, USA)

Contribution of global warming and atmospheric circulation to the hottest spring in Eastern China in 2018

*Chunhui Lu[1], Ying Sun[1], Nikolaos CHRISTIDIS[2], Peter STOTT[2]

1. Beijing Climate Center, China Meteorological Administration, 2. Met Office Hadley Centre, Met Office, UK

The spring of 2018 was the hottest on record since 1951 over eastern China based on station observations, with 2.5 ˚C higher than the 1961-1990 mean and more than 980 stations reaching the record spring mean temperature. The number of warm spring days in eastern China also ranked the highest in the observational record. This event exerted serious impacts on agriculture, plant phenology, electricity transmission systems and human health in the region. Contributions of human-induced climate change and an anomalous anticyclone to this event is investigated using the newly homogenized observations and updated Met Office Hadley Centre system for attribution of extreme events, as well as the Canadian Earth System Model simulations. Results indicate that both anthropogenic influences and anomalous anticyclone play significant roles in increasing the probability of the 2018 hottest spring. Quantitative estimates of the probability ratio show that anthropogenic forcing may have increased the chance of this event by 10-fold, while the anomalous circulation approximately increased by 2-fold. The persistent anomalous anticyclone located in the north side of China blocks the air with lower temperature from high latitudes into the eastern China. Without anthropogenic forcing or without the anomalous anticyclone in northern China, the occurrence probability of the extreme warm spring will be significantly reduced.

Keywords: extreme warm spring, extreme event attribution, anthropogenic influence, circulation effect

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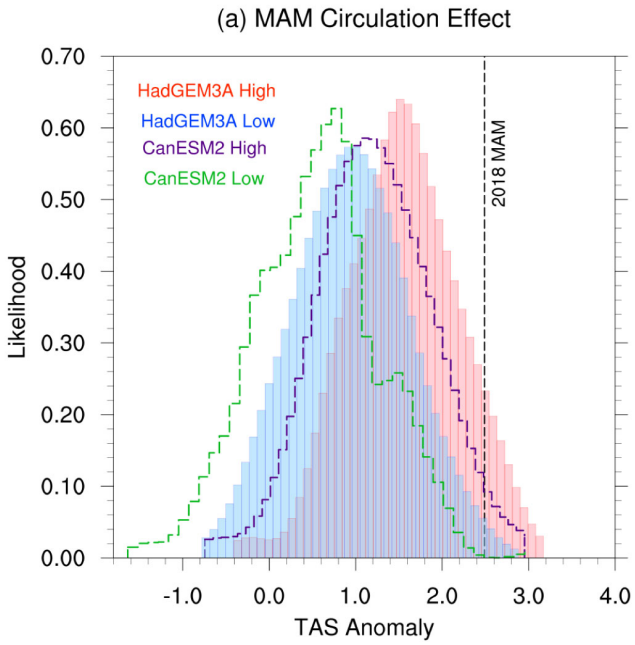

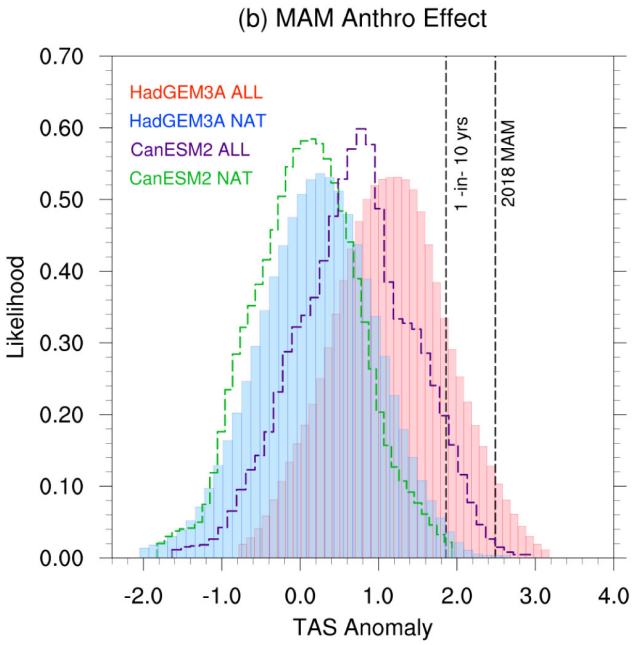

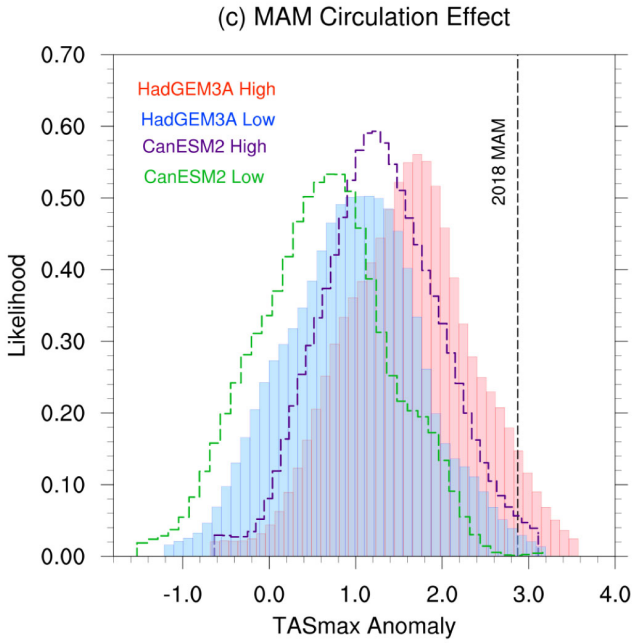

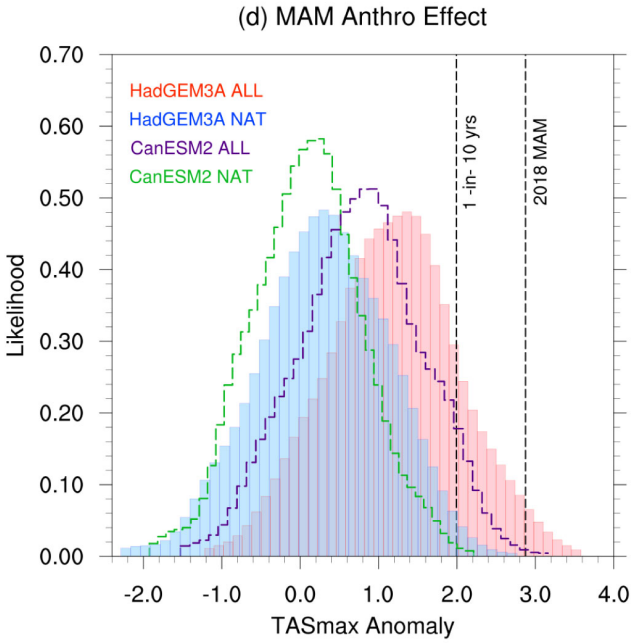

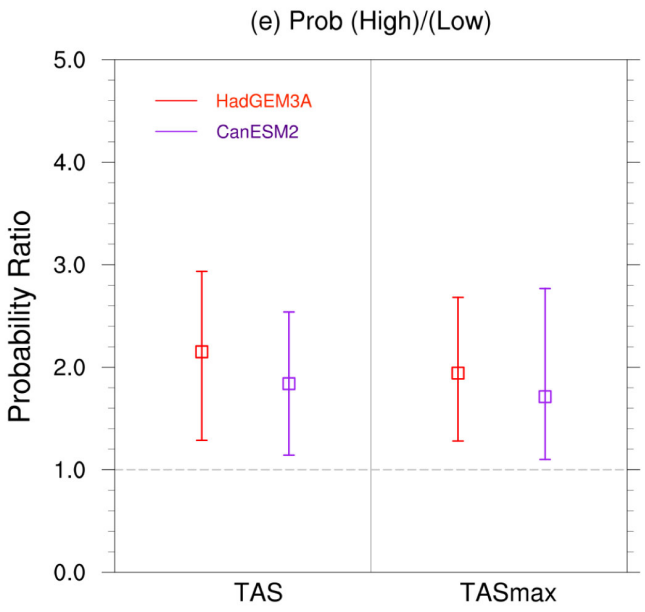

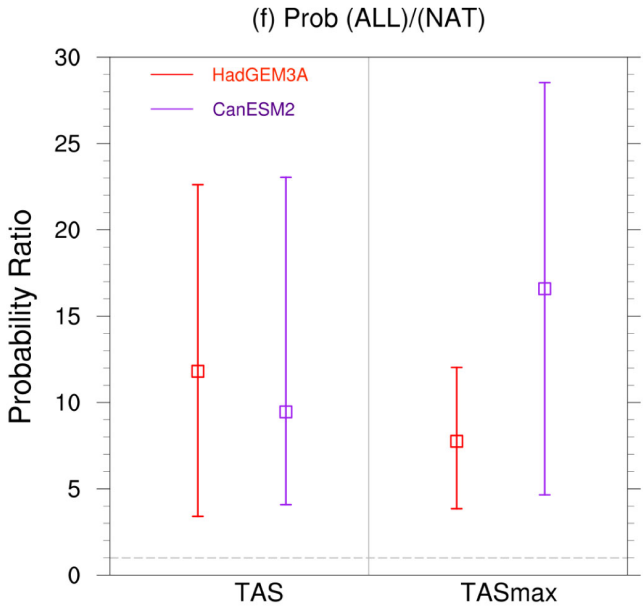

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The Synoptically-Influenced Extreme Precipitation Systems over Asian-Australian Monsoon Region from TRMM PR Measurements

*Wei-Ting Chen[1], Hong-Wen Jian[1], Peng-Ren Chen[1], Chien-Ming Wu[1], Kristen L. Rasmussen[2]

1. National Taiwan University, 2. Colorado State University

This study investigates the synoptic-scale flows associated with the extreme rainfall systems over the Asian-Australian monsoon region. Based on statistics of the 17-year Precipitation Radar observations from Tropical Rainfall Measurement Mission, a total of 916 extreme systems with both the horizontal size scale and maximum rainfall intensity exceeding the 99.9^{th} percentiles of the tropical rainfall systems were identified over this region. The annual number of occurrences of these systems showed an increasing trend of + 0.76 $year^{-1}$. The synoptic wind pattern and rainfall coverage distribution surrounding each system are classified into four major types: Vortex, Coastal, Coastal with Vortex, and None of the above, and each account for 44%, 29%, 7%, and 20%, respectively. Despite the different types of synoptic environment, these extremes show a similar internal structure, with broad stratiform and wide convective core rain. The occurrence of coastal-related types shows significant seasonal variations with high frequency at the Bay of Bengal in boreal summer and at the west side of Borneo and Sumatra in boreal winter. Besides, coastal-related types occur more frequently during late night to early morning (01-09 LT), and more likely with lightning flashes. High-frequency regions of both high total column water vapor and low-level vertical wind shear is consistent with the distribution of coastal-related extreme in the warm season. Our results highlight the critical role of the strength and direction of synoptic flows to the generation of extreme rainfall systems near the coastal areas. With the enhancement of the low-level vertical wind shear and moisture by the synoptic flow, the coastal convections triggered diurnally can have a higher chance to organize into meso-scale convective systems and hence higher probability to produce extreme rainfall.

Keywords: Extreme rainfall systems, Synoptic-scale flow, TRMM

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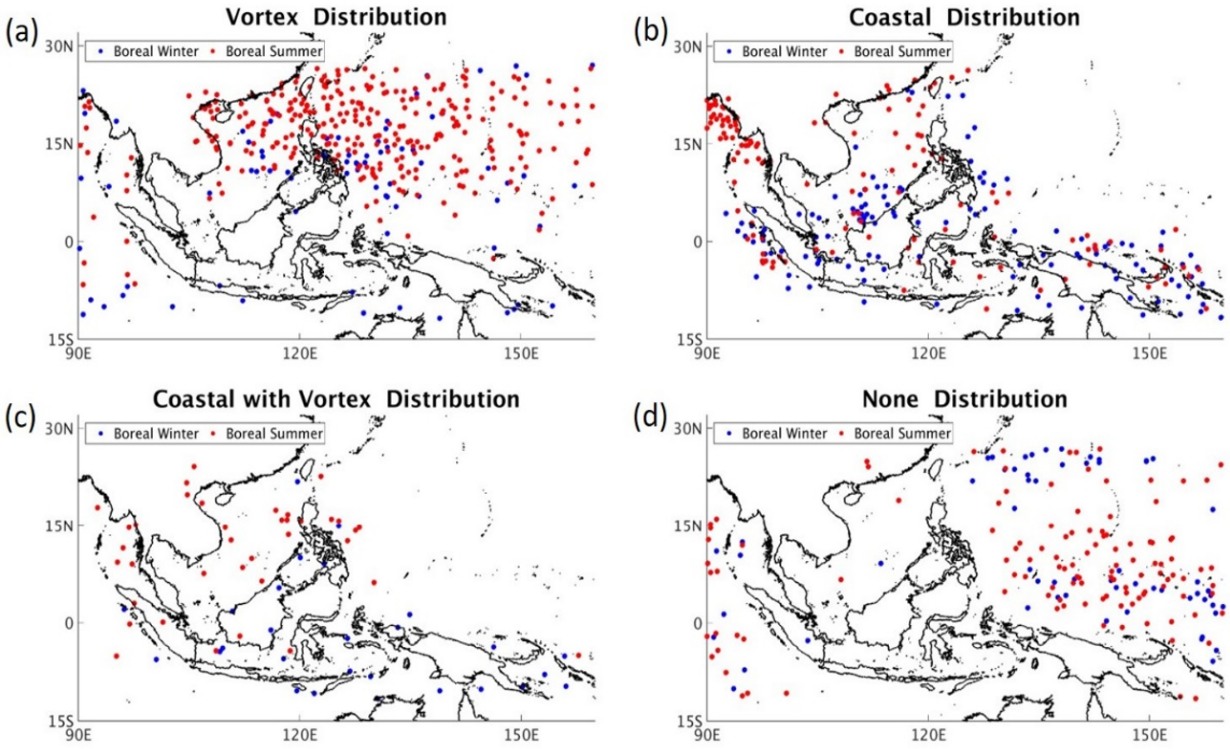

Figure 1. Spatial distribution for extreme rainy systems in boreal summer (red dots) and boreal winter (blue dots) for V type (a), C type (b), VC type (c) and N-type (d). The dot marks the geometric center of each system.

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Atmospheric Rivers in a Changing Climate: An Overview from the second phase of the Atmospheric River Tracking Method Intercomparison Project (ARTMIP)

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The Atmospheric River Tracking Method Intercomparison Project (ARTMIP) is an international collaborative effort to understand and quantify the uncertainties in atmospheric river (AR) science based on the use of different methods for identifying and tracking ARs. Many AR detection techniques are currently employed for a number of purposes, and the literature reports a wide range of conclusions based on these techniques. The goals of the recently completed first phase of ARTMIP, Tier 1, were to quantify differences in AR metrics, such as frequency and seasonality, intensity, duration, and precipitation attributable to ARs through the application of all algorithms to MERRA-2 reanalysis. The second phase of the project, Tier 2, will focus on addressing specific science questions, such as sensitivity to reanalysis product and climate change topics, that may benefit from the application of an ensemble approach.

We present results from the first of a series of Tier 2 projects. In this study, we use an ensemble of AR labels from a large number of detection algorithms applied to high resolution (0.25-degree, 3-hrly) climate change simulations from the International CLIVAR C20C+ Detection and Attribution Project. Changes in the character and variability of ARs are explored in two climates: (1) the historical period (1979 - 2005) and (2) end-of-the-century RCP 8.5 (2079 - 2099); specifically addressing the role of changes in the large-scale circulation in shifting the patterns of landfall and implications for precipitation extremes. We will also discuss the development of metrics to quantify changes in the characteristics of ARs across various methodologies in future climate scenarios. In particular, we explore the role of algorithm restrictiveness and significance for AR-related responses to warming.

Keywords: atmospheric rivers, climate change, extremes

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An Understanding of the Physical Mechanism for the back-to-back Drought over India in last one Century

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This work usage the observational and reanalysis data to investigate the primary physical mechanism behind the back-to-back Indian summer monsoon droughts over India. There have been only four back-to-back droughts (e.g., 1904-1905, 1965-1966, 1986-1987, and 2014-2015) over India in the past 120 years. Our analysis have revealed that each of four back-to-back droughts have faced at least one strong El-Nino associated with them, the stronger among the back-to-back drought pair is always associated with the mature phase of EL-Nino. The low-level-jet (LLJ) and the cross-equatorial flow have been reported to be weaker in all back-to-back drought years, except in one drought during 2014. In the majority of back-to-back droughts, the monsoon dynamic features such as the LLJ, cross-equatorial flow, Hadley circulation, and sub-tropical westerly jet are unfavorable for the good monsoon. Overall, the persistent nature of El-Nino condition are found responsible for the two of the back-to-back droughts (1904-1905 and 2014-2015), and partially responsible for the other two back-to-back droughts (1965-1966 and 1986-1987).

Keywords: Indian Summer Monsoon, Drought, EL-Nino, LLJ

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Detection and Possible Interpretation of Tropospheric Dispersive Phase Associated with Heavy Rain Events

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Hanssen et al., 1999 demonstrated the ability of Interferometric Synthetic Aperture Radar (InSAR) in the detection of water vapor associated with rain, using during the European Remote Sensing (ERS) satellite tandem mission. Furthermore, taking the advantage of the Advanced Land Observing Satellite (ALOS) satellite emergency observation, a localized signal related to water vapor during Seino heavy rain event was identified (Kinoshita et al., 2013). There were no surface deformation events during these former studies.

Utilizing the dispersive nature of the ionospheric layer, the range split spectrum method (SSM) separates InSAR phase into non-dispersive and dispersive phase, and thus ionospheric delay could be mitigated (Brcic et al., 2010; Rosen et al., 2010; Gomba et al., 2016). Additionally, higher-order ionospheric effects, such as geomagnetic and geometric ray-bending could be revealed using different frequency dependence of InSAR phase (Furuya et al., 2017). In contrast, tropospheric/ neutral atmospheric delay has a non-dispersive nature. Thus, if during heavy rain case, no surface deformation occurred and ionospheric contribution were negligible, water vapor can be detected in the non-dispersive phase accompanied by a virtually no dispersive phase.

In this presentation, we will show our detection results on ; (i) InSAR phase anomaly related to the water vapor during heavy rain episodes during ALOS-2 normal observation mode, (ii) unknown dispersive phase in SSM, and (iii) possible interpretation of the unknown dispersive phase during heavy rain cases.

Keywords: Heavy rain event, InSAR, Split-spectrum method

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Numerical Simulations of Smoke Haze Transport over Southeast Asia by using WRF-Chem

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Accurate representation of hazardous smoke haze forecast and assessment is critical for environmental management and planning purposes. Singapore is affected by severe smoke haze due to forest fires and open biomass burning to clear land for agricultural uses in the region. In the present study, an attempt has been made to simulate the South-East Asia (SEA) hazardous smoke case (September 2019), which affected several countries in SEA. We conducted simulations using the Weather Research and Forecasting model coupled with Chemistry (WRF-Chem) at a spatial resolution of 9 km ×9 km to simulate the formation and transport of biomass-burning hazardous smoke case in SEA. High-resolution simulations are conducted using 1x1 degree, 6 hourly Final Analysis (FNL) data and 0.5x0.5 degree, 3 hourly Global Forecasting System (GFS) data for meteorological fields for initial and boundary conditions for event. The Naval Research Laboratory’ s Fire Locating and Modeling of Burning Emissions (FLAMBE) emission inventory with 800 m injection height is used for model simulations. There are many uncertainties in the mesoscale modeling of smoke transport over the study region because of persistent cloud cover, high relative humidity, urban topography and the complexity of the tropical meteorology. Results show that WRF-Chem is able to capture the hazardous smoke haze reasonably well for both FNL and GFS. A slight under prediction of the PM2.5 mass concentration for FNL_30days simulations and overprediction with FNL_4days and GFS_4days simulations compare to five available observation stations over Singapore region is observed. Qualitative and quantitative comparisons between the model results reveal that the FNL_30days best simulated the hazardous smoke haze event over the study region, followed by FNL_4days and GFS_4days.

Keywords: South-East Asia (SEA), WRF-Chem, FLAMBE, FNL, GFS

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS17] Climate variability and predictability on subseasonal to decadal timescales

convener:Takashi Mochizuki(Department of Earth and Planetary Sciences, Kyushu University), V Ramaswamy(NOAA GFDL), Yushi Morioka(Japan Agency for Marine-Earth Science and Technology)

Many efforts have been made to understand and predict climate on subseasonal to decadal timescales (e.g. MJO, IOD, ENSO, PDV, AMV), while our knowledge still remains at an insufficient level to fully resolve socioeconomic challenges arising from climate variations and change. Model simulations and predictions usually present large uncertainties, particularly due to lack of understanding of weather and climate interactions across different spatial and temporal timescales (e.g. tropical cyclones and ENSO), as well as due to multiple physical processes underlying climate variations (e.g. troposphere-stratosphere coupling, air-sea-ice interactions; atmosphere-ocean-land interactions). Recently, datasets from Coupled Model Intercomparison Project Phase 6 (CMIP6) have been opened to the public, and understanding and predicting the changing climate together with its impacts on frequency and intensity of abnormal weather (e.g. cold/heat waves, tropical storms, and floods/droughts) should also be a timely topic in the areas of earth science and socioeconomics. This session aims to share current knowledge of subseasonal to decadal climate variability and predictability in order to identify the unresolved issues and aim at a better understanding and accurate prediction. This session invites all abstracts related to the observational, theoretical, process-level and modelling research on subseasonal to decadal variability and predictability of climate.

[AOS17-01] The Role of AMOC in Atlantic Decadal Predictability

★Invited Papers

*Rong Zhang[1] (1.NOAA Geophysical Fluid Dynamics Laboratory)

[AOS17-02] Underestimated Decadal Predictability and the Existence of the Signal-to-noise Paradox in CMIP5 Models

*Wei Zhang[1], Ben Kirtman[1] (1.University of Miami)

[AOS17-03] An overview of seasonal to Decadal Predictions with MIROC6

*Takahito Kataoka[1], Hiroaki Tatebe[1], Hiroshi Koyama[1], Takashi Mochizuki[1,2], Koji Ogochi[1], Hiroaki Naoe[3], Yukiko Imada[3], Hideo Shiogama[4,5], Masahide Kimoto[5], Masahiro Watanabe[5] (1.JAMSTEC Japan Agency for Marine-Earth Science and Technology, 2.Kyusyu University, 3.Meteorological Research Institute, 4.National Institute for Environmental Studies, 5.The University of Tokyo)

[AOS17-04] Detected Climatic Change in Global Distribution of Tropical Cyclones

*Hiroyuki Murakami[1] (1.Geophysical Fluid Dynamics Laboratory/University Corporation for Atmospheric Research)

[AOS17-05] Thermodynamic coupled modes in the tropical atmosphere-ocean

*Faming Wang[1] (1.Chinese Academy of Sciences, Institute of Oceanology)

[AOS17-06] Could Gulf Stream and Kuroshio be synchronized?

★Invited Papers

*Tsubasa Kohyama[1], Yoko Yamagami[2], Hiroaki Miura[3], Shoichiro Kido[3], Hiroaki Tatebe[4], Masahiro Watanabe[2] (1.Department of Information Sciences, Ochanomizu University, 2.Atmosphere and Ocean Research Institute, The University of Tokyo, 3.Graduate School of Science, The University of Tokyo, 4.Japan Agency for Marine-Earth Science and Technology)

The Role of AMOC in Atlantic Decadal Predictability

*Rong Zhang[1]

1. NOAA Geophysical Fluid Dynamics Laboratory

Atlantic Decadal predictability has a wide range of societal and economic applications. Understanding its underlying physical mechanisms is crucial for successful future predictions. This presentation will discuss recent findings on the role of Atlantic meridional overturning circulation (AMOC) in Atlantic decadal predictability. One key mechanism for enhanced decadal predictability of the subpolar North Atlantic upper ocean heat content is the slow southward propagation of AMOC anomalies from northern high latitudes to the subtropics and associated anomalous Atlantic meridional heat transport convergence. Atlantic decadal predictability is much higher in fully coupled models with relatively stronger multidecadal AMOC variability than in fully coupled models with relatively weaker multidecadal AMOC variability, and almost disappears in models coupled with a slab ocean (i.e. slab ocean models) with no AMOC variability. The observed decadal persistence of the subpolar North Atlantic sea surface temperature (SST) anomalies associated with Atlantic Multidecadal Variability (AMV) will lead to much higher Atlantic decadal predictability than that obtained from the slab ocean models or the red noise process. Multidecadal AMOC variability is a major source of enhanced low-frequency variability and thus decadal persistence in the subpolar North Atlantic SST anomalies associated with the AMV. Multidecadal AMOC variability also has predictive impacts on Atlantic major hurricane frequency and Arctic sea ice extent. It is crucial to improve the amplitude of multidecadal AMOC variability in fully coupled models to achieve much higher Atlantic decadal predictability.

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Underestimated Decadal Predictability and the Existence of the Signal-to-noise Paradox in CMIP5 Models

*Wei Zhang[1], Ben Kirtman[1]

1. University of Miami

Recent studies suggest increasing evidence for the existence of the signal-to-noise paradox in climate models, where in the ensemble-based climate prediction, model ensemble mean forecast generally shows higher correlations with observations than with individual ensemble members. This seems to lead to a paradox referred to as the signal-to-noise paradox that the model makes better predictions for reality than predicting itself. The signal-to-noise paradox highlights a potentially serious problem with climate model predictions as previous seasonal-to-decadal model predictions may be underestimated due to the existence of the paradox. The main purpose of the study is to determine if decadal climate predictability is underestimated in CMIP5 models, and if so, is the underestimated decadal predictability associated with the existence of the signal-to-noise paradox? Decadal potential predictability of SST in CMIP5 models is first examined and compared with observations. The result suggests that most CMIP5 models underestimate SST decadal predictability especially in part of the North Atlantic, the Indo-western Pacific, and the Southern Ocean. A simple Markov model framework is used to represent the ensemble forecasts and reproduce the signal-to-noise paradox. We argue that the existence of the signal-to-noise paradox is dependent on the relative amplitude of the persistence and noise variance in models and observations. Based on the Markov model framework, we find the widespread existence of the signal-to-noise paradox in CMIP5 models, and the regions with the signal-to-noise paradox are very likely to underestimate SST decadal predictability.

Keywords: Decadal Predictability , Signal-to-noise Paradox, CMIP5 Models

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An overview of seasonal to Decadal Predictions with MIROC6

*Takahito Kataoka[1], Hiroaki Tatebe[1], Hiroshi Koyama[1], Takashi Mochizuki[1,2], Koji Ogochi[1], Hiroaki Naoe[3], Yukiko Imada[3], Hideo Shiogama[4,5], Masahide Kimoto[5], Masahiro Watanabe[5]

1. JAMSTEC Japan Agency for Marine-Earth Science and Technology, 2. Kyusyu University, 3. Meteorological Research Institute, 4. National Institute for Environmental Studies, 5. The University of Tokyo

The study presents results of seasonal-to-decadal climate predictions based on a coupled climate model called the Model for Interdisciplinary Research on Climate version 6 (MIROC6) contributing to the Coupled Model Intercomparison Project Phase 6 (CMIP6). MIROC6 is initialized every year for 1960-2018 by assimilating observed ocean temperature and salinity anomalies and full-fields of sea-ice concentration, and by prescribing atmospheric initial states from reanalysis data. The impacts of updating system on prediction skill are then evaluated by comparing hindcast experiments between the MIROC6 prediction system and a previous system based on MIROC version 5 (MIROC5).
Skill of seasonal prediction is overall improved in association with representation of El Niño/Southern Oscillation (ENSO), the Quasi-Biennial Oscillation (QBO), and the Barents-Kara sea-ice concentration in MIROC6. In particular, the QBO is skillfully predicted up to 3 years ahead with a maximum anomaly correlation exceeding r=0.8. The prediction skill for the North Atlantic Oscillation in winter is also enhanced, but the prediction still suffers from model’ s inherent errors. On decadal timescales, MIROC6 has a predictive skill in the annual-mean sea surface temperature (SST) in the North Atlantic and the tropical Pacific. In particular, SST variability in the eastern tropical Pacific is predicted up to 7-10 years with a significantly larger skill score than the uninitialized experiment. MIROC6 hindcasts predict the Pacific regime shifts in the late-1970s and late-1990s better than MIROC5 hindcasts likely because of the improved skill of predicting interannual ENSO variability.

Keywords: decadal prediction, seasonal prediction, climate variation

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Detected Climatic Change in Global Distribution of Tropical Cyclones

*Hiroyuki Murakami[1]

1. Geophysical Fluid Dynamics Laboratory/University Corporation for Atmospheric Research

Although previous studies have reported that global mean temperature has been rising since the mid 20th century and is attributable to increases in emissions of greenhouse gasses, the annual number ofglobal tropical cyclones has been unchanged at around 86 since 1980. Owing to the limited length of observed tropical cyclonedata and the effect of multi-decadal internal variability, it has been a challenging issue to detect the trends in tropical cycloneactivity at a global scale. However, there is a distinct spatial pattern of the trends in tropical cyclonefrequency of occurrence at the global scale since 1980, such as significant decreases in frequency of occurrence in the South Indian Ocean, western North Pacific, and increases in the North Atlantic and Central Pacific. Here, using a suite of high-resolution dynamical model experiments, we show for the first time that the observed spatial pattern of trends cannot be explained only by the underlying multi-decadal internal variability; rather, external forcing such as greenhouse gasses, aerosols, and volcanic eruptions likely played an important role. This study demonstrates that a climatic change in terms of global spatial distribution of tropical cyclones has already emerged in observations, and may in part be attributable to the increase in greenhouse gas emissions.

Keywords: Tropical Cyclone, Detection and Attribution, Trend in Spatial Pattern

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Thermodynamic coupled modes in the tropical atmosphere-ocean

*Faming Wang[1]

1. Chinese Academy of Sciences, Institute of Oceanology

A set of thermodynamic coupled modes is derived from a simple linear atmosphere model coupled to a slab ocean model through the wind-evaporation-SST (WES) feedback. For pure easterly mean winds, the zeroth mode is a series of meridional SST dipoles in the tropics, antisymmetric about the equator and moving westward; the first mode is a series of zonal SST dipoles in the subtropics, symmetric about the equator and moving eastward. The meridional component of the mean winds will break such an equatorial symmetry and enable the coupled modes to intensify in the Southern Hemisphere for southerlies and the Northern Hemisphere for northerlies. Despite the existence of positive WES feedbacks, these thermodynamic coupled modes are largely damped oscillation with periods in years. These findings are further tested with an aqua-planet model and assessed with the reanalysis data.

Keywords: Subtropical Dipole Mode, Tropical Meridional Mode, Ocean-Atmosphere Coupling

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Could Gulf Stream and Kuroshio be synchronized?

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1. Department of Information Sciences, Ochanomizu University, 2. Atmosphere and Ocean Research Institute, The University of Tokyo, 3. Graduate School of Science, The University of Tokyo, 4. Japan Agency for Marine-Earth Science and Technology

The Gulf Stream and the Kuroshio Current transport heat from the tropics to the extratropics, so their temperature variations affect densely-populated areas in the northern hemisphere through extreme weather and fisheries production. The two ocean currents are separated by the North American continent, and thus, they cannot exchange heat by oceanic processes within a few years.

Based on data analyses of satellite observations and global climate models (GCMs), we show that sea surface temperatures of the Gulf Stream and the Kuroshio are synchronized for the decadal time scale. This synchronization, which we refer to as the Boundary Current Synchronization (BCS), is associated with meridional migrations of the atmospheric jet stream.

Output from four global climate models are analyzed: GFDL-CM4C192, MIROC6subhires, and their counterparts with lower resolutions. Cross-spectral analysis reveals that GCMs with higher resolutions exhibit higher low-frequency coherence than those with lower resolutions. Lag-correlation analysis shows that the temperature variations are almost simultaneous between the two currents. The BCS variability is also detected by performing the Singular Value Decomposition analysis between the two western boundary current regions, and this analysis supports a notion that the temperature variability emanates from meanderings of the two ocean currents. Atmospheric GCM experiments show that SST variability of the MIROC6subhires model actively modulates the position of the westerly jet stream. On the contrary, as suggested by the conventional view, SST variability of the low-resolution version of MIROC6 has less influence on the midlatitude atmosphere.

Keywords: Western Boundary Currents, Atmospheric Jet Stream

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS17] Climate variability and predictability on subseasonal to decadal timescales

convener:Takashi Mochizuki(Department of Earth and Planetary Sciences, Kyushu University), V Ramaswamy(NOAA GFDL), Yushi Morioka(Japan Agency for Marine-Earth Science and Technology)

Many efforts have been made to understand and predict climate on subseasonal to decadal timescales (e.g. MJO, IOD, ENSO, PDV, AMV), while our knowledge still remains at an insufficient level to fully resolve socioeconomic challenges arising from climate variations and change. Model simulations and predictions usually present large uncertainties, particularly due to lack of understanding of weather and climate interactions across different spatial and temporal timescales (e.g. tropical cyclones and ENSO), as well as due to multiple physical processes underlying climate variations (e.g. troposphere-stratosphere coupling, air-sea-ice interactions; atmosphere-ocean-land interactions). Recently, datasets from Coupled Model Intercomparison Project Phase 6 (CMIP6) have been opened to the public, and understanding and predicting the changing climate together with its impacts on frequency and intensity of abnormal weather (e.g. cold/heat waves, tropical storms, and floods/droughts) should also be a timely topic in the areas of earth science and socioeconomics. This session aims to share current knowledge of subseasonal to decadal climate variability and predictability in order to identify the unresolved issues and aim at a better understanding and accurate prediction. This session invites all abstracts related to the observational, theoretical, process-level and modelling research on subseasonal to decadal variability and predictability of climate.

[AOS17-07] Subseasonal Predictions at GFDL

★Invited Papers

*Baoqiang Xiang[1,2] (1.GFDL, 2.UCAR)

[AOS17-08] Does the tidal mixing affect the MJO in the Maritime Continent?

John D. Steffen[1], *Hyodae Seo[1] (1.Woods Hole Oceanographic Institution)

[AOS17-09] **The Role of Pacific Subtropical High Belts in the ENSO Cycle**

*Yafei Wang[1] (1.Chinese academy of meteorological sciences)

[AOS17-10] Seasonal-to-multiyear prediction of ENSO using machine deep learning technique

*Jing-Jia Luo[1], Fenghua Ling[1], Yoo-Geun Ham[2], Jeong-Hwan Kim[2] (1.ICAR Institute for Climate and Application Research, NUIST, 2.Chonnam National University,South Korea)

[AOS17-11] **Predictability of the super IOD event in 2019 and its link with El Niño Modoki**

*Takeshi Doi[1], Swadhin Behera[1], Toshio Yamagata[1,2] (1.JAMSTEC APL, 2.NUIST ICAR)

[AOS17-12] Impact of the boreal summer intraseasonal oscillation on typhoon tracks in the western North Pacific

★Invited Papers

*Masuo Nakano[1], Frederic Vitart[2], Kazuyoshi Kikuchi[3] (1.JAMSTEC Japan Agency for Marine-Earth Science and Technology, 2.ECMWF, 3.IPRC / University of Hawaii)

Subseasonal Predictions at GFDL

*Baoqiang Xiang[1,2]

1. GFDL, 2. UCAR

At the frontier of climate forecasting, subseasonal prediction (usually referring to the timescales between two weeks and one season) has become an increasingly active research topic in recent years followed the rapidly growing societal demands for forecast products at these timescales. In this talk, I will give a brief overview of the research activities on subseasonal predictions at GFDL. The focus will be placed on predictions of tropical cyclone geneses, wintertime temperature and cold extremes. Understanding the potential sources of predictability is another important topic, and I will explore the potential contribution from MJO, NAO, PNA, stratospheric polar vortex, snow-atmosphere feedback on subseasonal predictions. Our ongoing and future work using our current generation of model (SPEAR/SHiELD) will be also presented together with some preliminary results. Finally, I will talk about the great challenges as well as opportunities for subseasonal predictions.

Keywords: Subseasonal prediction, sources of predictability, SPEAR , SHiELD

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Does the tidal mixing affect the MJO in the Maritime Continent?

John D. Steffen[1], *Hyodae Seo[1]

1. Woods Hole Oceanographic Institution

The intraseasonal convective precipitation over the Maritime Continent (MC) is primarily controlled by the propagating Madden-Julian Oscillation (MJO) from the Indian Ocean. But recent evidence suggests that MJO energetically interacts with a range of ocean-atmosphere-land processes local to MC. In particular, the MC region is known to have a robust tidal mixing signature that is reflected in cooler SSTs. However, the detailed mechanism by which the tidal effect affects the MJO in the MC is not well documented, and this is the focus of this study.

Two sets of ensemble simulations have been conducted using a high-resolution regional coupled ocean-atmosphere model with explicit convection, in which the ocean component of the coupled model is forced with and without tides. Prescribing tidal forcing in a coupled model creates a cascade of coupled ocean-atmosphere responses, resulting in a significant SST cooling of comparable magnitude to the intraseasonal SST response to MJO, and the significantly reduced MJO-related rainfall. In particular, the size of tide-induced SST cooling is strongly dependent on MJO phases; that is, the cooling is far more enhanced during the active phase than the suppressed. Considering that the tidal effect is of oceanic origin unrelated to MJO, the demonstrated tidal effect on the MJO could be another reason for the ostensibly random nature of MJO variability in the MC. Since the most substantial tidal effect on SST is fortnightly, co-occurring with the dominant time-scale of the MJO, it is also conceivable that the tidal effect would contribute to sub-seasonal to seasonal predictability of the MJO.

Keywords: MJO, Maritime Continent, Air-Sea Interaction

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The Role of Pacific Subtropical High Belts in the ENSO Cycle

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1. Chinese academy of meteorological sciences

This article conducted statistical analyses on the formation of El Niño and Southern Oscillation (ENSO) from several angles by using conventional data. We found that both El Niño and La Niña are closely associated with the preliminary activity of the Pacific Subtropical High (PSH) belts on both sides of equator if bringing an assumption of the influence of annual cycle on ENSO cycle into our calculations. The PSH belts, especially in their eastern sides, tended to have been continuous weakening for months before El Niño maturing. Oppositely, the continuous enhancing of the PSH belts might be regarded as a prelude of a La Niña. This signal the PSH belts send to omen ENSO’ s coming appeared about two months earlier than the one from the elements in tropical regions. We found that the strengthening or weakening of the PSH belts could act as a more original force for driving the ENSO cycle than the elements in tropics through controlling the variation of trade winds. Since the southern PSH belt appeared more powerful than the northern one in the situation, the phase lock of the ENSO cycle might be explained by this clue. Because the southern PSH belt that approaches the nearest area of the equator every June-August in a calendar year can exert a more powerful impact on equatorial elements, SST in Eastern Equatorial Pacific will be significantly affected 3-4 months later, i.e. the general ENSO mature phase happening around the end of a calendar year. We proposed a plausible mechanism for the ENSO formation based on the results and conducted a targeted discussion on this new mechanism that could explain the problems the current conceptual ENSO models left.

Keywords: ENSO theory, Subtropical high belts, Extratropical forcing, ENSO phase-lock, Combination of Walker Circulation and Hadley Cell

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Seasonal-to-multiyear prediction of ENSO using machine deep learning technique

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1. ICAR Institute for Climate and Application Research, NUIST, 2. Chonnam National University,South Korea

Variations in the El Niño/Southern Oscillation (ENSO) are associated with a wide array of regional climate extremes and ecosystem impacts. Robust, long-lead forecasts would therefore be valuable for managing policy responses. But despite decades of effort, forecasting ENSO events at lead times of more than one year remains problematic. Here we show that a statistical forecast model employing a deep-learning approach produces skilful ENSO forecasts for lead times of up to one and a half years. To circumvent the limited amount of observation data, we use transfer learning to train a convolutional neural network (CNN) first on historical simulations and subsequently on reanalysis from 1871 to 1973. During the validation period from 1984 to 2017, the all-season correlation skill of the Nino3.4 index of the CNN model is much higher than those of current state-of-the-art dynamical forecast systems. The CNN model is also better at predicting the detailed zonal distribution of sea surface temperatures, overcoming a weakness of dynamical forecast models. A heat map analysis indicates that the CNN model predicts ENSO events using physically reasonable precursors. The CNN model is thus a powerful tool for both the prediction of ENSO events and for the analysis of their associated complex mechanisms.

Keywords: ENSO, machine learning, seasonal to multi-year climate prediction

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Predictability of the super IOD event in 2019 and its link with El Niño Modoki

*Takeshi Doi[1], Swadhin Behera[1], Toshio Yamagata[1,2]

1. JAMSTEC APL, 2. NUIST ICAR

A positive Indian Ocean Dipole in 2019 reached the level of the strongest events occurred in 1994 and 1997 and caused disasters in countries around the Indian Ocean. Using a quasi-real-time ensemble seasonal prediction system based on the SINTEX-F climate model, its occurrence was predicted a few seasons ahead and the possible impacts were warned by overcoming the so-called winter predictability barrier. The successful prediction of such a super event at long lead-time may contribute to reducing the risks of socio-economic losses by introducing suitable measures for adaptation. Here, we have investigated possible sources of the successful prediction by analyzing co-variability of inter-member anomalies defined as deviations from the mean in the ensemble reforecasts. Interestingly, it is found that the potential predictability of the 2019 super positive event is linked with the preexisting El Niño Modoki in the tropical Pacific.

Keywords: Seasonal Prediction, Indian Ocean Dipole , El Nino Modoki

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Impact of the boreal summer intraseasonal oscillation on typhoon tracks in the western North Pacific

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It is widely accepted that the intraseasonal oscillation (ISO) has a strong influence on tropical cyclone (TC) genesis. For example, more TCs form in convective enhanced phases of the boreal summer ISO (BSISO) in the western North Pacific (WNP). However, little is known about its impact on TC tracks. Here, we examined how TC tracks in the WNP are modified by the BSISO for each month of the TC season (June-October) using IBTrACS (v03r09) and how it is reproduced in the ECMWF S2S reforecast data. TCs in the reforecast are tracked by the method developed by Vitart et al. (1997). In this study, TCs formed south of 25N with lifetime of longer than 2 days and the maximum surface wind speed of higher than 25 kt are regarded to tropical storms in nature. We compared track density of TCs that formed in convectively enhanced (5-8) and suppressed (1-4) phases of the BSISO in the WNP (based on the index developed by Kikuchi et al., 2012).

It is found that TC tracks are significantly influenced by the state of the BSISO and the way the BSISO affects TC tracks shows regional and seasonal variations. For instance, normalized TC track density (i.e., normalized by TC number) in the enhanced phases in the adjacent seas of the northern Philippines tends to be significantly higher over the course of the season. In contrast, the track density around Japan displays a pronounced seasonal dependence: it is significantly lower in September, while it is higher in October. Biases in TC track density simulated in the model is likely influenced by biases both in TC genesis location and steering flow.

To examine which biases (e.g., TC genesis location/steering flow) are more influence on biases in normalized TC track density, sensitivity experiments using beta advection model are performed. The model reasonably reproduced observed and simulated changes in TC track density except for October. The experiments with observed TC genesis location and simulated steering flow showed better performance than the experiments with simulated TC genesis location and observed steering flow. These results suggest that improvement in TC genesis location leads to more accurate representation of impact of the BSISO on TC track density.

Keywords: intraseasonal oscillation, tropical cyclone, typhoon, S2S

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS19] Marine ecosystems and biogeochemical cycles: theory, observation and modeling

convener:Takafumi Hirata(Arctic Research Center, Hokkaido University), Shin-ichi Ito(Atmosphere and Ocean Research Institute, The University of Tokyo), Enrique N Curchitser(Rutgers University New Brunswick), Eileen E Hofmann(Old Dominion University)

The ocean accounts for about 50% of global net primary production. This production is significant for carbon cycling and ecosystem functioning, and is related directly or indirectly to a variety of climatic and ecological phenomena. The responses to natural and anthropogenic environmental stressors that influence marine production and diversity can cause perturbations to marine ecosystems that alter trophic dependencies and interactions among organisms at a range of space and time scales. Quantification of the principal mechanisms driving spatio-temporal variability of marine ecosystem remains to be done, especially in terms of evaluation of uncertainty in responses. As a result, evaluating vulnerability of marine ecosystems to environmental change requires systematic and holistic approaches that integrate physics to ecology and are based in observations and modelling. In addition, expectations to deliver these science to public society is raising. This session aims to provide a venue for not only discussing recent advances in understanding marine biogeochemical cycles, ecosystems and their interactions, but also networking with a variety of people to seed new ideas in marine ecological research. Observational, modeling and conceptual studies, including technological development and operational applications, that consider linkages among biogeochemical and ecosystem processes, biodiversity, and the effects of multiple stressors from molecular to planetary scales are encouraged.

[AOS19-01] On three important ecological properties linking ocean changes to marine biodiversity and ecosystems impacts under a changing climate

★Invited Papers

*William Wai Lung Cheung[1], Tayler Clarke[1], Tyler D. Eddy[2], Gabriel Reygondeau[3] (1.Changing Ocean Research Unit, Institute for the Oceans and Fisheries, The University of British Columbia, 2.Fisheries and Marine Institute of Memorial University of Newfoundland, 3.Department of Ecology and Evolution Biology, Yale University)

[AOS19-02] Understanding the effects of dynamic interactions between changing ocean conditions and fishing effort on living marine resources

★Invited Papers

*Wing Yee Lam[1], Andrés Cisneros Montemayor[1], Colette C. C. Wabnitz[1], William Wai Lung Cheung[1] (1.Fisheries Economics Research Unit and Changing Ocean Research Unit, Institute for the Oceans and Fisheries, The University of British Columbia)

[AOS19-03] High resolution observations of a pelagic tunicate bloom in a warm water filament using a video plankton recorder: development, fate, and effect on biogeochemical cycles and planktonic food webs

★Invited Papers

*Kazutaka Takahashi[1] (1.The University of Tokyo)

[AOS19-04] Large-scale study on patchy distribution of salps and doliolids in North Pacific Ocean: Patterns, Drivers and Impacts.

*Nurul Huda Ahmad Ishak[1,2], Kentaro Motoki[1], Hiroomi Miyamoto[3], Kazutaka Takahashi[1] (1.University of Tokyo, 2.Universiti Malaysia Terengganu, 3.Tohoku National Fisheries Research Institute)

[AOS19-05] Conspecific comparison on the swimming and metabolic performance of Pacific chub mackerel (*Scomber japonicus*) distributed in different area

*Chenying Guo[1], Shin-ichi Ito[1], Megumi Enomoto[1], Tomoya Aono[1] (1.Atmosphere and Ocean Research Institute, the University of Tokyo)

On three important ecological properties linking ocean changes to marine biodiversity and ecosystems impacts under a changing climate

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Anthropogenic emissions of carbon dioxide are driving changes in the physical and biogeochemical properties of the ocean. Impacts of these oceanographic changes on marine ecosystems, from phytoplankton to fishes and seabirds, with consequences for human societies have been observed in many cases. Marine ecosystem impact models have also projected increasing climate-risk on marine biodiversity and ecosystem services with large regional variations. Understanding the mechanisms linking the changing ocean conditions to ecosystem impacts is necessary for improving the robustness of detection, attribution and projection of climate impacts and risks on biodiversity and dependent human communities.

Here, I highlight the state of knowledge and scope for further understanding of three ecological properties, namely thermal tolerance, trophic transfer efficiency and body size, that have largely shaped our understanding of the effects of ocean warming, deoxygenation and changing nutrient supplies on marine ecosystem structure and functions. Recent analyses using large marine biodiversity databases have demonstrated the important role of species' thermal tolerances in determining global ocean biogeography and their responses to warming. Empirical analyses of fisheries and survey data suggest that trophic transfer efficiency (the efficiency of passing energy from primary production up the food chain) of marine ecosystems vary systematically by temperature and food web structure. Body size imposes a first-order geometric constraint on physiology of marine organisms and their ecological interactions with others. Body size is now widely used for predicting a variety of climate impacts on marine ecosystems, from fishes' sensitivity to deoxygenation to alteration of trophodynamics and fisheries production. Integrating these three ecological properties can help assess past trends and project future changes of global and regional marine biodiversity and ecosystem functions under changing multiple ocean physical and biogeochemical drivers. We illustrate the potential for such integrations using models and their outputs from the Fisheries and Marine Ecosystems Model Intercomparison Project (FishMIP). The synthesis of knowledge on these three ecological properties could inform new hypotheses of climate impacts in the ocean, and future development of ecosystem and fisheries impact models.

Keywords: Climate change, Trophies transfer efficiency, Body size, Thermal tolerance, Biodiversity, Ecosystem functions

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Understanding the effects of dynamic interactions between changing ocean conditions and fishing effort on living marine resources

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Global climate change affects the physical and biogeochemical characteristics of the ocean including ocean temperature, stratification, oxygen content, salinity and net primary productivity. These changes in turn impacts on marine ecosystems and associated organisms, affecting their distribution and ecology, as well as dependent marine fisheries and communities. Socio-economic outcomes linked to climate-related shifts in the distribution and productivity of marine species can increase the vulnerability and risk of many coastal communities and countries. Indeed, previous studies suggest that changes in marine ecosystems are amplified through trophic webs, from primary production to upper trophic levels, both without fishing or under idealized fishing scenarios. However, much less is known about the degree to which accounting for dynamic human actions including targeted fisheries management measures and the economics of fishing effort and behavior might affect the sensitivity of marine ecosystems responses to climate perturbations in global models.

Here, we develop and apply a holistic approach for projecting impacts of climate change on global fish stocks and fisheries by linking a fishing effort dynamic model with a biological simulation model, the Dynamic Bioclimate Envelope Model (DBEM). Spatial and temporal changes in fishing effort are projected based on changes in catch and profitability of exploited species, while the DBEM projects changes in species distribution and abundance under given climate change and prior fishing effort. In the effort dynamic model, fishers are assumed to seek to maximize their profit under the constraints of management measures (e.g., harvest control rules), and a set of given economic factors such as seafood price, operating costs of fishing, and capital and depreciation costs for purchasing a new vessel and the depreciation cost of fishing vessels. We show that the effort dynamic model can broadly reproduce historical changes in fishing effort, and that projections of future catches can be substantially different if economic effort dynamics are considered, compared with previous studies with simple fishing effort assumptions. Using these model outputs, we examine whether, and to what degree, fishing may affect the vulnerability of fish stocks to changing ocean conditions. This study highlights the critical importance of including realistic fishing scenarios when attempting to understand and project climate change impacts on fisheries. Thus, research focusing on using scenarios and models to inform policy on marine ecosystems and fisheries needs to include fishing effort dynamics and it is suggested as a way to support the development and application of economic-based tools when seeking ocean-based climate solutions.

Keywords: Ocean-based climate solutions, Fishing Effort, Scenarios, Socio-economic, fisheries, vulnerability

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High resolution observations of a pelagic tunicate bloom in a warm water filament using a video plankton recorder: development, fate, and effect on biogeochemical cycles and planktonic food webs

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1. The University of Tokyo

An important goal of marine ecology studies is to understand the distribution patterns of marine organisms and the structure and functioning of pelagic ecosystems, as doing so can be used to predict how environmental changes and human activities will impact the distribution patterns of marine fauna and the biology of the ocean. Within this context, the ephemeral, patchy, and sporadic nature of pelagic tunicate blooms makes these events very difficult to investigate in any detail. This is largely because of the conventional plankton-net sampling which only covers < 1 m^2 water column at several ten-km scale do not match with the spatiotemporal scale of oceanographic event to control the pelagic tunicate bloom. To tackle the problem, we investigated distribution patterns of a doliolid (*Dolioletta gegenbauri*) bloom in relation to the physical environment using a video plankton recorder in the Oyashio–Kuroshio mixed water region. Using 12 km transects, doliolid blooms were encountered at a horizontal scale of about 2–3 km, which corresponds to submesoscale physical events. Doliolids were also consistently encountered in the subsurface layer above the pycnocline in warmer (> 14ºC) and higher-salinity (> 34) water masses, and seawater density was the most critical factor affecting distribution depth. Compared to previous studies, the density and biomass of the blooms observed in this study (77 mgC m^{-3} and 4600 inds m^{-3}) were highest in the open ocean. Bloom formation consisted of two phases; first, the seeding population of a nurse stage increased rapidly to 2000 inds m_{-3} by asexual reproduction, followed by asexual production of phorozooids. Estimated population clearance rates revealed that these dense patches could potentially sweep the surrounding water within 2–3 d. The incidence of exhausted and shrunken zooids was significantly correlated with patch density, suggesting that mortality was due to overgrazing. Shrunken doliolids appeared to sink below the pycnocline, corresponding to 8–17% of the particulate organic carbon flux at 150 m. Hydromedusae, pelagic polycheates, and sapphirinid copepods preyed on the doliolids. These results indicate that doliolids, which were seeded by populations originating from the Kuroshio, formed dense blooms in response to submesoscale physical events and would alter the sinking particle properties (i.e., biological pump) and the epipelagic food web structure through their grazing and mortality.

Keywords: Plankton, Sub-mesoscale, biological pump

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Large-scale study on patchy distribution of salps and doliolids in North Pacific Ocean: Patterns, Drivers and Impacts.

*Nurul Huda Ahmad Ishak[1,2], Kentaro Motoki[1], Hiroomi Miyamoto[3], Kazutaka Takahashi[1]

1. University of Tokyo, 2. Universiti Malaysia Terengganu, 3. Tohoku National Fisheries Research Institute

Zooplankton are central link in the marine pelagic food web. They bridge the gap between primary producers and higher order consumers. Their sensitivity to environmental variability enables them to indicate the ecological condition in the ecosystem. However, highly diverse groups of zooplankton in the pelagic environment respond differently to the environmental variables. We investigated a large-scale surface distribution, biomass and species composition of salps and doliolids during four consecutive summers (2016-2019) along several transects on 36ºN and 46.38ºN extended from 141.9ºE to 164.9ºW along North Pacific Current (NPC). NPC is a dynamic region that is formed by southern part of the North Pacific Subpolar Gyre and the northern part of the North Pacific Subtropical Gyre. Collections of ten groups of zooplankton were made at total of 267 stations and six environmental parameters were recorded (temperature, salinity, NO_3, PO_4, SiO_2 and Chlorophyll a). Spatial distribution patterns of gelatinous and non-gelatinous zooplankton were distinct and were closely associated with nutrients and hydrographic conditions. Salp, *Thalia democratica* showed a preference for lower temperatures (mean SST 11.1-13.4 ˚C) than *Salpa fusiformis* (mean SST 14.5˚C) but with similar range of salinity (mean SSS 34.16-34.40 and 34.3 respectively).The doliolid *Dolioletta gegenbauri* preferred lower temperatures (mean SST 15.0-17.8˚C) and lower salinity (mean SSS 32.76-32.99) than *Doliolum denticulatum* (mean SST 21.3 ˚C; mean SSS 33.67). Relationship between spatial distribution of salps and doliolids and environmental factors was assessed by the BIOENV analysis which highlighted the patchy distribution patterns in NPC were erratic in time or space due to the variability in environmental parameters.

Keywords: pelagic tunicate, salp, doliolid, North Pacific Ocean

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Conspecific comparison on the swimming and metabolic performance of Pacific chub mackerel (*Scomber japonicus*) distributed in different area

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1. Atmosphere and Ocean Research Institute, the University of Tokyo

Pacific chub mackerel (*Scomber japonicus*) is a small pelagic fish species widely distributed throughout the coastal areas of Pacific, and this study focused on the Northwest stock (distributed in the Pacific side of Japan) and Northeast stock (distributed along the coastline from Washinton to Baja California). Both of these two stocks showed large biomass fluctuation but not in a completely same pattern. Biomass was usually related to growth, which was decide by the difference of prey consumption to dissipation in a general bioenergetics budget. Since the swimming ability could be an indicator of availability to consumption (wider migration area for searching food and higher speed for preying), while metabolism was the main energy dissipation term. Comparing swimming performance and metabolism of each stock could be helpful for understanding differences on the bioenergetics budget and then the potential mechanism on biomass fluctuation and life strategy.

To explore the abiotic (e.g., temperature, current speed) and biotic (fish size) effects on swimming performance and metabolism, the wild-caught juvenile as well as aquaculture-reared young juvenile and immature of Northwest stock were measured under various temperatures (14˚C, 18˚C and 24˚C) using a variable-speed swim-tunnel respirometer. Then these data compared with the previous findings from the wild-caught Northeast Pacific stock measured under same temperatures to determine differences in their traits among these stocks.

On the temperature of 18˚C, the maximum sustainable swimming speeds (U_{max}) increased with fish size showed no significant difference among stocks, suggesting these stocks have similar swimming ability. Meanwhile, the mass-specific oxygen consumption rate (M_{O2}) of wild-caught Northwest stock increased exponentially with swimming speed (U, in cm s^{-1}) with same increase rate of aquaculture-reared Northwest stock and wild-caught Northeast stock. These results were further parameterized that M_{O2} increased with temperature at a given speed and fish mass, and this relationship was consistent with previous studies of Northeast stocks. At the same temperature, Northwest stock took more M_{O2} than Northeast stock, but temperature dependency of M_{O2} was lower . This indicated that the metabolism of Northwest stock was less sensitive to temperature fluctuation, which may related to wider migration area, higher habitat temperature and more variated environment in Kuroshio transition compare to the California current.

Keywords: Pacific chub mackerel, Scomber japonicus, bioenergetics, swimming speed, metabolism

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS19] Marine ecosystems and biogeochemical cycles: theory, observation and modeling

convener:Takafumi Hirata(Arctic Research Center, Hokkaido University), Shin-ichi Ito(Atmosphere and Ocean Research Institute, The University of Tokyo), Enrique N Curchitser(Rutgers University New Brunswick), Eileen E Hofmann(Old Dominion University)

The ocean accounts for about 50% of global net primary production. This production is significant for carbon cycling and ecosystem functioning, and is related directly or indirectly to a variety of climatic and ecological phenomena. The responses to natural and anthropogenic environmental stressors that influence marine production and diversity can cause perturbations to marine ecosystems that alter trophic dependencies and interactions among organisms at a range of space and time scales. Quantification of the principal mechanisms driving spatio-temporal variability of marine ecosystem remains to be done, especially in terms of evaluation of uncertainty in responses. As a result, evaluating vulnerability of marine ecosystems to environmental change requires systematic and holistic approaches that integrate physics to ecology and are based in observations and modelling. In addition, expectations to deliver these science to public society is raising. This session aims to provide a venue for not only discussing recent advances in understanding marine biogeochemical cycles, ecosystems and their interactions, but also networking with a variety of people to seed new ideas in marine ecological research. Observational, modeling and conceptual studies, including technological development and operational applications, that consider linkages among biogeochemical and ecosystem processes, biodiversity, and the effects of multiple stressors from molecular to planetary scales are encouraged.

[AOS19-06] Basin-scale Relations between Marine Ecosystem Indices and Physical Environment in North Pacific

*Emi Yati[1,6], Shoshiro Minobe[1,2], Nathan Mantua[3], Shin-ichi Ito[4], Emanuele Di Lorenzo[5] (1.Department of Natural History Sciences, Graduate School of Science, Hokkaido University., 2.Department of Earth and Planetary Sciences, Faculty of Science, Hokkaido University. E-mail: minobe@sci.hokudai.ac.jp, 3.Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanographic and Atmospheric Administration, California 95060, USA., 4.Atmosphere and Ocean Research Institute, University of Tokyo., 5.School of Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta, Georgia, USA., 6.Remote Sensing Application Center, Indonesian National Institute of Aeronautics and Space.)

[AOS19-07] Development of the Potential Vulnerability Index for the Arctic Marine Ecosystems

*Takafumi Hirata[1], Yoshio Masuda[2], Jorge García Molinos[1], Keiko Sato[1], Irene Alabia[1], Toru Hirawake[3], EIJI WATANABE[4], Maki Noguchi Aita[5], Sei-Ichi Saitoh[1] (1.Arctic Research Center, Hokkaido University, 2.Faculty of Environmental Earth Science, Hokkaido University, 3.Graduate School of Fisheries Sciences, Hokkaido University, 4.Institute of Arctic Climate and Environment Research, Japan Agency for Marine-Earth Science and Technology, 5.Earth Surface System Research Center, Japan Agency for Marine-Earth Science and Technology)

[AOS19-08] Environmental drivers of recent biodiversity patterns in the Eastern Bering Sea

*Irene Alabia[1], Jorge Garcia Molinos[1], Sei-Ichi Saitoh[1], Takafumi Hirata[1], Toru Hirawake[3], Franz Mueter[2] (1.Arctic Research Center, Hokkaido University, 2.University of Alaska Fairbanks, 3.Faculty of Fisheries Sciences, Hokkaido University)

[AOS19-09] Modeling studies on pan-Arctic ice-algal productivity: Present status and future projection

*EIJI WATANABE[1] (1.Japan Agency for Marine-Earth Science and Technology (JAMSTEC))

[AOS19-11] Potential differences between *in-situ* and remote oceanic primary productivity

*Ko-Mei LIN[1], Chung-Yu Chiang[1], Yung-Yen Shih[1] (1.R.O.C NAVAL ACADEMY Dept. of Applied Science)

Basin-scale Relations between Marine Ecosystem Indices and Physical Environment in North Pacific

*Emi Yati[1,6], Shoshiro Minobe[1,2], Nathan Mantua[3], Shin-ichi Ito[4], Emanuele Di Lorenzo[5]

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To understand how marine ecosystem varies and how that variability is related to physical climate conditions, it is useful to conduct a multivariate analysis using large number (several tens) of marine ecosystem indices (e.g., Hare and Mantua 2000) and this type of analysis is referred to as large multivariate analysis (LMA). In this study we conduct an LMA for the marine ecosystem for whole North Pacific, for the first time to the author's knowledge, using the marine ecosystem indicators both in the eastern and western side of the basin. The main analysis method is Empirical Orthogonal Function (EOF) of marine ecosystem indicators and the relation of the marine ecosystem EOFs and physical climate condition is examined. The EOFs are calculated for marine ecosystem indicators in the western and eastern basin separatory or combined. The results indicate that the first EOF mode is characterized by a long-term trend, irrespective of the EOF domain. The second mode varies on multi-decadal timescale in the eastern North Pacific, and on somewhat shorter timescale in the western North Pacific. It appears that the first mode is related to the overall warming over the North Pacific, but the second modes are closely related to decadal climate modes, i.e., the Pacific (inter-)Decadal Oscillation and North Pacific Gyre Circulation modes. The implications of the present results for marine ecosystem predictability will be discussed.

Keywords: Marine ecosystem indices, Decadal variability, Physical environment , Climate changes, Basin-scale fisheries, North Pacific

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Development of the Potential Vulnerability Index for the Arctic Marine Ecosystems

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While recent changes in the Arctic marine environment, as represented by the drastic decrease of sea ice, may increase socio-economic opportunities, such as natural resource exploitation and utilization of the northern-route for intercontinental shipping, they may also cause a degradation of the present marine ecosystems and their ecological services; directly or indirectly. Therefore, assessment of the potential impacts of these environmental changes on marine ecosystem is desired for both deliberate socio-economic development and conservation of the Arctic oceans. Using Planetary Boundaries as thresholds for proposed processes regulating the stability and resilience of the Earth system, and assuming that larger environmental change increase the potential impacts on the marine ecosystems, we developed the Potential Vulnerability Index (PVI) of the Arctic marine ecosystems. The PVI is based on statistical analysis that identifies geographical regions where (1) the large variance of the selected Planetary Boundaries components is found (larger exposure to environmental forcing), (2) a response of marine ecosystems to the environmental forcing is larger (larger sensitivity), and (3) an adaptive capacity of the ecosystems is smaller (smaller resiliency). Our results highlight regions in the Arctic oceans where the potential vulnerability is large and may require further attention. Our work is expected to contribute to ecosystem management.

Keywords: Arctic, Marine Ecosystems, Vulnerability

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Environmental drivers of recent biodiversity patterns in the Eastern Bering Sea

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The Eastern Bering Sea (EBS) is a highly productive shelf region that accounts for 40% of the total US fish landings. This area is also exposed to drastic climatic changes marked by extreme fluctuations in temperature, sea ice concentration, and timing. Here, we examined the spatial structures of species richness (SR) and phylogenetic diversity (PD) using occurrence and abundance data from NOAA bottom trawl surveys in the EBS from 1990-2018. Our biodiversity analyses focused on 159 marine vertebrate and invertebrate taxa consistently identified for at least 20 years within the study duration. The study period was defined by stanzas of low (1990-1999) and high (2000-2019) magnitudes of climatic variability. SR and PD during the latter period were generally higher than the former. Moreover, under the period of a high degree of climatic variability, diversity averaged over cold winters was higher than in warm winters. Modeling the effects of abiotic factors to SR and PD further revealed that sea ice minimum from mid-winter to summer, winter sea ice concentration and summer surface and bottom temperatures were the most influential factors to biodiversity in the EBS. In particular, higher sea ice minimum corresponds to an increase in SR, however, lower winter sea ice concentration results in an increase in PD. Warmer summer (June-September) temperatures, however, tend to support higher marine diversity. These findings showed that the interplay of abiotic factors elicited complex diversity responses in the EBS community. The ongoing and abrupt variations in sea ice and thermal conditions in the region impact and will continue to drive substantial changes in the biodiversity dynamics, underpinning ramifications on the prevailing ecosystem structure and function.

Keywords: Marine biodiversity, Eastern Bering Sea, Climate changes

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Modeling studies on pan-Arctic ice-algal productivity: Present status and future projection

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Seasonal, interannual, and decadal variations in the Arctic ice algal productivity (icePP) for 1980–2009 were investigated using daily outputs from five sea ice–ocean ecosystem models participating in the Forum for Arctic Modeling and Observational Synthesis (FAMOS) project.

The models show a shelf–basin contrast in the spatial distribution of icePP. The simulated icePP substantially varies among the four subregions (Chukchi Sea, Canada Basin, Eurasian Basin, and Barents Sea) and among the five models, respectively. The simulated annual total icePP has no common decadal trend at least for 1980–2009 among the five models in any of the four subregions, although snow depth and sea ice thickness in spring are mostly declining. The model intercomparison indicates that an appropriate balance of stable ice algal habitat (i.e., sea ice cover) and enough light availability is necessary to retain icePP. The selected value for the maximum growth rate (V_{max}) of the ice algal photosynthesis term is a key source for the inter-model spreads. Understanding the simulated uncertainties on the pan-Arctic and decadal scales is expected to improve coupled sea ice–ocean ecosystem models. This step will be a baseline for further modeling/field studies and future projections.

Now, we are preparing a new model intercomparison project “Ice Algae Model Intercomparison Project phase 2 (IAMIP2)”. The experiment period will be extended to 150 years spanning from the mid-twentieth century to the end of the twenty-first century, using the same atmospheric forcing dataset based on outputs from the Coupled Model Intercomparison Project phase 6 (CMIP6).

Keywords: Arctic Ocean, ice algae, sea ice-ocean model

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Potential differences between *in-situ* and remote oceanic primary productivity

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1. R.O.C NAVAL ACADEMY Dept. of Applied Science

Oceanic primary productivity (OPP) is a source to keep marine ecosystem cycling;

it also plays an significant role in supplying the energy for marine lives; hence, it is essential to estimate OPP accurately so as to understand the ocean carbon cycle. There are two ways to measure OPP, including satellite remote sensing and *in-situ* observation. However, numerous previous studies indicate that there are differences between remote and *in-situ* OPP in diverse time and space scales. Therefore, this research intends to investigate the factors that cause the differences through remote and *in-situ* data on OPP at the northern South China Sea (NSCS). We draw on six cruise data, collected from November 2018 to November 2019, which contain spatiotemporal factors in different seasons and natural phenomena. The results show that the average value from satellite remote sensing is 266 mg-C m^{-2} d^{-1} and average mean from *in-situ* observation is 211 mg-C $m^{-2}d^{-1}$.The former is 26% higher than the latter. One of the main cause of the difference may result from Chlorophyll-*a* (chl *a*). The surface chl *a* measured by satellites cannot truly reflect the integrated chl *a* effected by various spatiotemporal conditions and natural factors, it may result in inevitable differences when estimating of OPP by the VGPM (Vertically Generalized Production Model). In addition, the data in our preliminary study shows that OPP obtained by satellite remote sensing needs to be calibrated in the application at the NSCS.

Keywords: oceanic primary productivity, northern South China Sea

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS19] Marine ecosystems and biogeochemical cycles: theory, observation and modeling

convener:Takafumi Hirata(Arctic Research Center, Hokkaido University), Shin-ichi Ito(Atmosphere and Ocean Research Institute, The University of Tokyo), Enrique N Curchitser(Rutgers University New Brunswick), Eileen E Hofmann(Old Dominion University)

The ocean accounts for about 50% of global net primary production. This production is significant for carbon cycling and ecosystem functioning, and is related directly or indirectly to a variety of climatic and ecological phenomena. The responses to natural and anthropogenic environmental stressors that influence marine production and diversity can cause perturbations to marine ecosystems that alter trophic dependencies and interactions among organisms at a range of space and time scales. Quantification of the principal mechanisms driving spatio-temporal variability of marine ecosystem remains to be done, especially in terms of evaluation of uncertainty in responses. As a result, evaluating vulnerability of marine ecosystems to environmental change requires systematic and holistic approaches that integrate physics to ecology and are based in observations and modelling. In addition, expectations to deliver these science to public society is raising. This session aims to provide a venue for not only discussing recent advances in understanding marine biogeochemical cycles, ecosystems and their interactions, but also networking with a variety of people to seed new ideas in marine ecological research. Observational, modeling and conceptual studies, including technological development and operational applications, that consider linkages among biogeochemical and ecosystem processes, biodiversity, and the effects of multiple stressors from molecular to planetary scales are encouraged.

[AOS19-12] Impact of the deviation of phytoplankton stoichiometry from Redfield ratio on global oceanic net primary production

*Yoshio Masuda[1], Yasuhiro Yamanaka[1], Takafumi Hirata[2], Hideyuki Nakano[3] (1.Graduate School of Environmental Earth Science, Hokkaido University, 2.Arctic Research Center, Hokkaido University, 3.Meteorological Research Institute)

[AOS19-13] Vertical migration by bulk phytoplankton sustains biodiversity and nutrient input to the surface ocean

*S. Lan Smith[1], Kai W. Wirtz[2] (1.Marine Ecosystem Dynamics Research Group, Research Institute for Global Change, Japan Agency for Marine-Earth Science and Technology, 2.HZG, Geesthacht, Germany)

[AOS19-14] Breakup of marine aggregates under laminar shear flow

*Yasuhito Hayashi[1], Shigeki Wada[1], Yasuhisa Adachi[1] (1.University of Tsukuba)

[AOS19-15] **Summertime oxygen depletion and acidification in Bohai Sea, China**

*Guisheng Song[1], Liang Zhao[2], Huixiang Xie[3], Hao Wei[1] (1.Tianjin University, 2.Tianjin Univ. Sci Technol., 3.ISMER-UQAR)

[AOS19-16] **Seasonal oceanic variability and associated biogeochemical responses around a ridge area along the Kuroshio off Japan**

*Xu Zhang[1], Yusuke Uchiyama[1,2], Yota Suzue[3], Eiji Masunaga[4] (1.Kobe University, 2.Port and Airport Research Institute, 3.Construction Technique Institute Engineering Co., Ltd., 4.Ibaraki University)

[AOS19-17] Drivers and dynamics of change in Altamaha, Doboy, and Sapelo Sounds along the Georgia coast

*Kimberly K Takagi[1], Kimberley S Hunter[2], James B Deemy[1], Wei-Jun Cai[3], Samantha B Joye[2] (1.College of Coastal Georgia, 2.University of Georgia, 3.University of Delaware)

Impact of the deviation of phytoplankton stoichiometry from Redfield ratio on global oceanic net primary production

*Yoshio Masuda[1], Yasuhiro Yamanaka[1], Takafumi Hirata[2], Hideyuki Nakano[3]

1. Graduate School of Environmental Earth Science, Hokkaido University, 2. Arctic Research Center, Hokkaido University, 3. Meteorological Research Institute

The deviation of the carbon to nitrogen ratio (C:N) of oceanic phytoplankton from Redfield ratio is well known in field observations; however almost all marine ecosystem models are based on Redfield ratio. Incubation experiments show that C:N increases with an increase in the chlorophyll a to carbon ratio (chl:C) of phytoplankton. Recently developed FlexPFT (Flexible phytoplankton Functional Type) model proposed in Smith et al. (2016) can naturally represent the observed relation between chl:C and C:N. We introduced the FlexPFT model into a 3D ecosystem model combined with an OGCM (Oceanic General Circulation Model). We found that the global oceanic net primary production in a variable C:N case is 1.5 times larger than that in the fixed Redfield C:N case. Higher C:N in equatorial regions mainly contributes to the increase in global primary production.

Keywords: global net primary production, CN ratio, OGCM

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Vertical migration by bulk phytoplankton sustains biodiversity and nutrient input to the surface ocean

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Phytoplankton subsumes the great variety of unicellular photoautotrophs that perform roughly half of Earth’ s primary production. They achieve this despite their challenging oceanic habitat, with opposing vertical gradients of nutrients (which often limit their growth near the surface) and light (which becomes limiting with increasing depth). Most phytoplankton species are commonly assumed to be incapable of moving actively between the zones of light and nutrient availability, which are separated vertically by from 30-120 m. Here we propose that a considerable fraction of phytoplankton vertically traverse these gradients over time scales from hours to weeks, employing variations of a common migration strategy to acquire multiple resources. We present a mechanistic Lagrangian model resolving phytoplankton growth linked to optimal migration behaviour and demonstrate unprecedented agreement of its calculated vertical CHL-a distributions with 773 profiles observed at five prominent marine time-series stations. Our simulations reveal that vertically cycling phytoplankton can pump up enough nutrients to sustain as much as half of oceanic Net Primary Production (NPP). Active locomotion is therefore a plausible mechanism enabling relatively high NPP in the oligotrophic surface ocean. Our simulations also predict similar fitness for a variety of very different migration strategies, which helps to explain the puzzling diversity of phytoplankton observed in the ocean.

Keywords: trade-offs, ecosystem modeling, biogeochemistry

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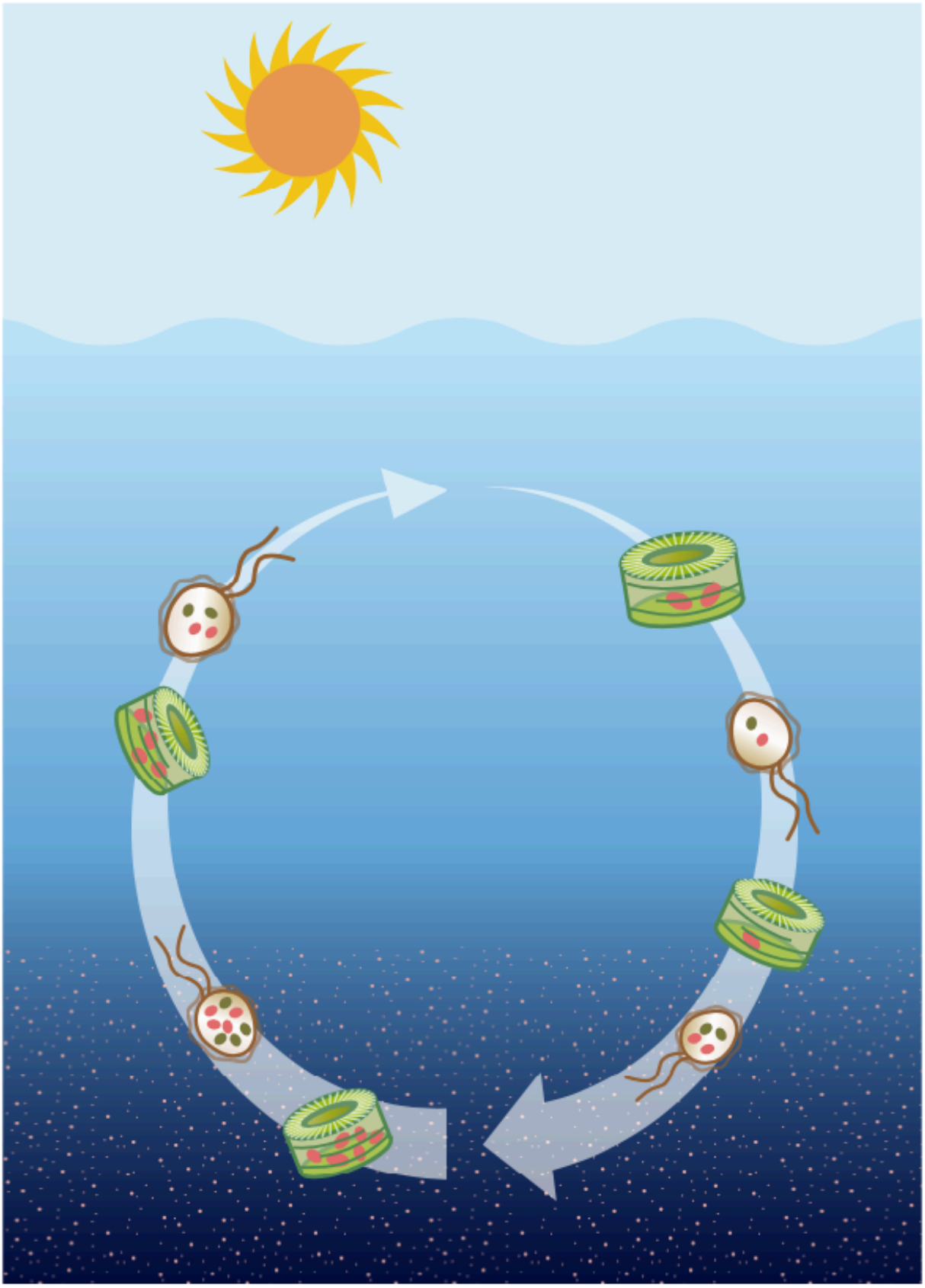

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Breakup of marine aggregates under laminar shear flow

*Yasuhito Hayashi[1], Shigeki Wada[1], Yasuhisa Adachi[1]

1. University of Tsukuba

Marine sinking particles are the major carrier of organic carbon originating from phytoplankton from surface to the ocean interior. This process regulates both oceanic and atmospheric CO_2 concentration. The efficiency of this process is determined by the settling velocity, carbon content, and the remineralization rate of particles. Since settling velocity is considerably controlled by the particle size, the coagulation of small particles into large aggregates in the flow field is important in the transport process of the organic carbon. On the other hand, fluid shear resulting from variations in fluid velocity around the aggregates could induce breakup due to erosion or fragmentation. While field observation in the previous study conducted in ocean surface and coastal benthic boundary layer suggested that turbulence causes aggregate breakup, experimental assessment for breakup of aggregates had been carried out by only Alldredge (1990), in which breakup of marine aggregates rarely occur even under the storm condition (energy dissipation rates > 10^{-4} W kg^{-1}). Their method of collecting aggregates from the ocean could overestimate the strength of the aggregates.

In our study, a Couette device which consists of two concentric cylinders with different diameters (inner cylinder is fixed, and outer one rotates) was used to examine the breakup of aggregates derived from natural phytoplankton communities, which were cultured in seawater collected from a eutrophic coastal sea (Tokyo bay, Japan). A stable laminar shear flow was generated in the gap between two cylinders. Shear rates were from 3.2 to 22 s^{-1} adjusted by the rotational speed of the outer cylinder. Durations of the experiments were one to two hours because the sizes of particles were mostly stable within these periods. The size of the aggregates were 309, 182, 129, 128 μm at a shear rate of 3.2, 6.9, 10.1, 22 s^{-1}, respectively. Size and shear rate were described by the following theoretical scaling relation,

$$D \approx G^{-\gamma} \quad (1)$$

where D, G and γ denote aggregate's size, shear rate, and aggregate strength constant respectively. The value of γ is theoretically 0.50 when the cohesive strength of aggregate is constant irrespective of the size. In this study, the calculated γ value of 0.48 was similar to the theoretical value. The relationship between the shear rate and the commonly measured energy dissipation rate (ε) is,

$$G = (\varepsilon / \nu)^{1/2} . \quad (2)$$

The values of ε were 9.7 $\times 10^{-6}$ to 4.4 $\times 10^{-4}$ W kg^{-1} which is within the range of the turbulence generated by the wind and zooplankton community. Therefore, the breakup of marine aggregates by the fluid shear would occur under natural environment.

Keywords: Marine snow, Turbulence, Breakup, Shear flow

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Summertime oxygen depletion and acidification in Bohai Sea, China

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1. Tianjin University, 2. Tianjin Univ. Sci Technol., 3. ISMER-UQAR

Increasing attention has recently been drawn to oxygen depletion and ocean acidification in coastal seas and their impacts on the marine ecosystem. Intensive organic matter degradation combined with weak water exchange is considered to be mainly responsible for bottom water oxygen depletion and acidification. Hypoxia and acidification in the bottom water of Bohai Sea have been frequently observed in August over the past decade. In this study, monthly investigations were conducted along an inshore-offshore transect in the north Bohai Sea from May to August in 2017 and 2018. The physical structure of the water column in the study area was characterized by a well-mixed surface layer and an essentially homogeneous deep layer that were separated by a strong pycnocline over the period from mid-Jun to late August in both years. Dissolved oxygen (DO), pH and dissolved inorganic carbon (DIC) in the water column were also split into two layers by the pycnocline and varied little in each layer. No significant interannual variations were observed for the temporal progressions of DO, pH and DIC in the bottom water. Average DO concentration and pH in the bottom water linearly decreased with time from May to August while DIC presented an opposite trend. DO became increasingly unsaturated from mid-June to late August when DO decreased to 96 mmol L^{-1} and pH to 7.74. The molar ratio of net oxygen consumption to DIC production was 1.42, similar to the Redfield ratio (1.30). The degradation of sedimentary organic matter was estimated to contribute ~30% of the oxygen depletion and acidification observed. Pelagic oxygen consumption due to degradation of fresh organic matter thus dominated the oxygen depletion. The duration and intensity of oxygen depletion and acidification in the study area were strongly affected by stormy weather events such as typhoons.

Keywords: oxygen depletion, acidification, dissolved inorganic carbon, organic matter degradation, typhoon, Bohai Sea

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Seasonal oceanic variability and associated biogeochemical responses around a ridge area along the Kuroshio off Japan

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1. Kobe University, 2. Port and Airport Research Institute, 3. Construction Technique Institute Engineering Co., Ltd., 4. Ibaraki University

Biological processes have strong effects on the global carbon cycle on all time scales. In general, the nutrient fluxes from the nutrient-rich subsurface to the nutrient-depleted surface are substantial for maintaining primary production. The Kuroshio is one of the most energetic western boundary currents, significantly affecting biogeochemical productivity in the Pacific marginal seas off Japan. In addition, the Kuroshio flows through an oceanic ridge that is located at the south coast of Japan. This unique topography has remarkable influences on the Kuroshio currents, further affecting the associate biogeochemical responses. In the present study, a climatological regional oceanic modeling was conducted based on ROMS coupled with an NPZD biogeochemical model, encompassing the Kuroshio region and the Izu-Ogasawara ridge with a horizontal grid spacing of 3 km. The model was run for ten years and the tenth year output was used for the analysis. The nutrient concentration is significantly higher on the western side of the ridge rather than its eastern side. The primary production also occurs more actively in the western region, which is generally consistent with the subsurface nutrient distribution. Upward eddy-driven nutrient transport occurs in the western area near the ridge, while a downward flux appears in the eastern area. However, in colder seasons, the baroclinic instability due to the surface cooling and mixed layer deepening promotes a weak eddy-driven downward nutrient transport in Enshu-nada Sea, which is situated further west of the ridge, suppressing the biological production. By contrast, the shear instability occurs with considerable spatial variability and insignificant seasonal difference. The positive barotropic conversion rate shed by ridge topographically promotes much greater eddy-induced vertical flux in the eastern part of the ridge.

Keywords: Biogeochemistry, Kuroshio, eddy-induced nitrate flux, baroclinic instability

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Drivers and dynamics of change in Altamaha, Doboy, and Sapelo Sounds along the Georgia coast

*Kimberly K Takagi[1], Kimberley S Hunter[2], James B Deemy[1], Wei-Jun Cai[3], Samantha B Joye[2]

1. College of Coastal Georgia, 2. University of Georgia, 3. University of Delaware

Changes in climate, weather, and population alter the biogeochemical dynamics of coastal environments. The Altamaha River Estuarine System provides a unique opportunity to assess how these dynamics are altered across three sounds (Altamaha, Doboy, and Sapelo) with unique freshwater inputs, hydrologic circulation, and physics. The dominant freshwater source to the system is the Altamaha River. The Altamaha watershed is the largest in Georgia and is comprised of five sub-watersheds covering roughly 35,500 km^2. Nutrient loads to the system were dominated by organic forms of nitrogen and phosphorous. Nutrient loading was strongly impacted by population, land and water use, and livestock, whereas retention within the system was affected by changes in climate and weather. The aim of this study was to elucidate the factors that impact biogeochemical dynamics in the Altamaha River Estuarine System. This was accomplished through integration of long-term chemical, climatological, and hydrological data collected through the Georgia Coastal Ecosystems –Long Term Ecological Research project (2000-2019), US Geological Survey discharge database, and the South Eastern Regional Climate Center. We project that the biogeochemical dynamics of the Altamaha River Estuarine System mirror the changes seen in the Altamaha River Watershed over this time period. These changes are likely exacerbated by changes in climate patterns.

Keywords: Estuarine, Biogeochemistry, Nutrients

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS20] Coastal physical processes associated with mixing, eddies, and internal waves

convener:Taira Nagai(Graduate School of Science, The University of Tokyo), Eisuke Tsutsumi(Atmosphere and Ocean Research Institute, The University of Tokyo), Eiji Masunaga(Ibaraki University)

Recently developed observational and numerical approaches have revealed details of physical processes in coastal regions, which can affect large-scale oceanic/atmospheric circulations and ecosystems. This session aims to provide a platform to discuss mixing, eddies, and internal waves in coastal/marginal oceans including estuaries and lakes. This session also covers topics that consider linkages between coastal phenomena and large scale processes in the open ocean (e.g., the Kuroshio Current).

[AOS20-01] Tidally-driven submesoscale coherent eddies at Naruto Strait in the Seto Inland Sea, Japan

*Yusuke Uchiyama[1], Shota Yanase[1], Xu Zhang[1] (1.Graduate School of Engineering, Kobe University)

[AOS20-02] Seasonal variation of water masses and turbulence structure off the Sanriku Coast

*ikeda masashi[1], Eiji Masunaga[1], Toshi Nagata[2], Sachihiko Itoh[2] (1.ibaraki university , 2.Atmosphere and Ocean Research Institude, The University of Tokyo)

[AOS20-03] Material transport processes around Sagami Bay and Suruga Bay using a particle tracking model

*Takayoshi Inoue[1], Eiji Masunaga[1], Yusuke Uchiyama[2] (1.Ibaraki University, 2.Kobe University)

[AOS20-04] Three-dimensional transport of microplastics in the South China Sea using a Lagrangian particle tracking model

*Kosei Matsushita[1], Yusuke Uchiyama[1], Naru Takaura[1] (1.Kobe Univ.)

[AOS20-05] Volume transport due to internal wave generation along the continental shelf in the South China Sea

*Qiang Li[1], Xiaohua Zhang[1], Xiuyu Zheng[1], Jintao Gu[1], Xiaoting Zhu[1] (1.Tsinghua University)

Discussion

Discussion

Discussion

Tidally-driven submesoscale coherent eddies at Naruto Strait in the Seto Inland Sea, Japan

*Yusuke Uchiyama[1], Shota Yanase[1], Xu Zhang[1]

1. Graduate School of Engineering, Kobe University

“Whirlpools” at Naruto Strait in the Seto Inland Sea (SIS), Japan, are widely recognized as an extraordinary dynamic and beautiful natural phenomenon. The strait lies between Awaji Island and Shikoku Island in the SIS, and has a quite narrow opening of 1.4 km. Rapid currents are often generated due to tidal level differences on two sides of the strait, *i.e.*, Harima-nada Sea to the north and the Kii Channel to the south, most prominently during every spring tide. The narrow strait induces intensive tidal currents accompanied by vigorous submesoscale eddies, resulting in one of the most energetic “whirlpools” in the world. However, because little has been investigated scientifically on the Naruto whirlpools from a geophysical standpoint, we conduct a very high-resolution, quadruple-nested downscaling ocean modeling based on the JCOPE-ROMS system to provide a solid scientific view of the Naruto whirlpools. The outermost boundary conditions for the ROMS models are imposed from the assimilative JCOPE2 reanalysis at the perimeter of the L1 model. The lateral grid spacing is then successively refined from 1/12˚ (~10 km, JCOPE2), 2 km (ROMS-L1), 600 m (L2), 100 m (L3), and finally down to 20 m (L4). Barotropic tides are imposed on the L2 model, which spontaneously propagate into the inner L3 and L4 models through the open boundaries. Approximately a 16 km x 16 km region with the 1.4 km-narrow strait topography is analyzed with the inner-most L4 model, which enables us to realistically reproduce the complex flow field with submesoscale eddies comprising whirlpools around Naruto Strait as precisely as possible. A synoptic computation for three spring-neap tidal cycles for the late summer condition in 2015 is carried out to achieve the statistical significance of temporally varying tidal fluctuations.

It is quantitatively identified that tidal sea-surface elevation in the Harima-nada Sea lags about three hours behind that in the Kii Channel, because of the counter-clockwise propagation of M_2 tidal waves around Awaji Island. This pahse delay results in a pronounced meridional pressure gradient force that drives energetic tidal currents at the strait. Mean residual transport occurred at the strait is determined as southward dominant, from the Harima-nada Sea to the Kii Channel. Depth-dependency is apparent in the residual transport at the cross-section of the strait, which is characterized by the northward transport near the surface and the center of the strait, while by the southward transport along the bed. A kinetic energy budget analysis indicates that the work done by lateral mean velocity shear and horizontal Reynolds stress is enhanced by squashing tidal currents to increase the mean to eddy kinetic energy conversion, which is almost solely attributed to generation of vigorous eddies around the tidal currents. Therefore, lateral shear instability plays a major role in the eddy generation mechanism. On the other hand, as the density fields are rather homogeneous on the two sides of the strait, buoyancy-driven baroclinic instability barely takes place over there.

Keywords: tidal current, narrow strait, submesoscale eddy

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Seasonal variation of water masses and turbulence structure off the Sanriku Coast

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1. ibaraki university , 2. Atmosphere and Ocean Research Institude, The University of Tokyo

Marine environments off the Sanriku Coast are important for oceanic ecosystems and influence fishing grounds in the north pacific. However, details of physical processes associated with marine environment have not been understood well. This study shows observational results off the Sanriku Coast obtained from continuous towing observations using BioUCTD (RINKO-profiler) and a microstructure profiler, VMP-250 (Turbo VMP). The observations were carried out in two seasons, May 5-7 (spring season) and October 8-11 (summer season), 2019. The horizontal resolution of BioUCTD was approximately 1.3 km and roughly 10 times higher than conventional CTD surveys. Details of internal wave and water mass structures were obtained by the BioUCTD towing observations. In observations in spring season, Oyashio Kuroshio mixed water distributed from the surface layer to the bottom layer approximately 0–20 km from the coast and the Oyashio water located below the surface layer in the offshore. The southern limit latitude of Oyashio was the southernmost in the year, the Oyashio dominated in the observation area (62% of the all observed water). The turbulence kinetic energy dissipation rate was high between Oyashio-Kuroshio mixed water and Oyashio water, ε reaching 2.6×10^{-7}W kg^{-1}. In observations in summer season, the Oyashio water accounted only 24% of the total observed water, and six water masses appeared in the observation area (Kuroshio water, Oyashio water, Tsugaru warm current water, cold lower layer water, surface layer water, Oyashio-Kuroshio mixed water). Large amplitude Internal waves were observed between Oyashio-Kuroshio mixed water and Oyashio. Sediment resuspension occurred where strong turbulent mixing were observed (5.7×10^{-8}W kg^{-1}). This study suggests that high-resolution surveys are desired to fully grasp mixing processes associated with water masses and internal waves.

Keywords: Sanriku, mixing, water mass

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Material transport processes around Sagami Bay and Suruga Bay using a particle tracking model

*Takayoshi Inoue[1], Eiji Masunaga[1], Yusuke Uchiyama[2]

1. Ibaraki University, 2. Kobe University

In this study, material transport and diffusion processes in Sagami Bay and Suruga Bay were evaluated using the ROMS model with a 3-D Lagrangian particle tracking model. The model was run for summer and winter seasons performed with long term averaged climatological reanalyzed data. A half of the total particles was outflowed from the bay within two (three) weeks in summer (winter) for both bays. The tidal forcing suppressed the outflow from the bays with a time scale of approximately two days. The particle outflow rate from the Sagami Bay mouth was higher than that for Suruga Bay. The Kuroshio Current inflowed into the inner part of Sagami Bay with a horizontal velocity of 1.5 m s^{-1} when the Kuroshio Current passed near the coast. On the other hand, for Suruga Bay, the Kuroshio Current influenced only around the bay mouth. Model results for the both seasons showed that particles that flowed out from Sagami Bay were mainly transported to the east (70%) caused by the Kuroshio Current. For Suruga Bay, particles were mainly outflowed on the west side of the bay mouth (75%). The westward particle transport in Suruga Bay were induced by a cyclonic eddy located off the bay (Enshu-nada). Both for Sagami Bay and Suruga Bay, horizontal particle transport were stronger in summer than winter, since the Kuroshio Current passes near to the coast in summer. Material transport in vertically were stronger in winter than summer probably due to intensified winter convections or eddy motions.

Keywords: ROMS, Sagami Bay, Suruga Bay

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Three-dimensional transport of microplastics in the South China Sea using a Lagrangian particle tracking model

*Kosei Matsushita[1], Yusuke Uchiyama[1], Naru Takaura[1]

1. Kobe Univ.

Oceanic plastic waste has been gaining attention over the past decade. Because of exposure to ultraviolet radiation and mechanical erosion, plastics are gradually degraded into small plastic fragments (microplastics). Marine organisms accidentally ingest microplastics that may absorb pollutant, resulting in deleterious effects as harm to marine ecosystem. Recent studies have reported the presence of microplastics in the worldwide ocean including polar waters. A global model of plastic inputs from rivers into oceans showed that the top 20 polluting rivers, mostly located in Asia, account for 67% of the global total. In particulalr, 12 of the top 20 rivers are located around the South China Sea (SCS). In the present study, a 3D tracking of neutrally buoyant Lagrangian particles that mimic microplastics is conducted using the 3D current velocity field pre-computed by the HYCOM-ROMS downscaling model for the SCS. A total of more than 5×10^4 particles are released continuously for one year period of 2012 from the mouths of the ten rivers around the SCS. It is found that the microplastics derived from the rivers discharged into the SCS remain in the SCS at about 80% even after one year since each release. In contrast, the microplastics derived from the outside of the SCS are barely transported back into the SCS. Furthermore, the transport and dispersal of microplastics are found to have prominent seasonality due to seasonally varying SCS circulations strongly affected by the monsoons. However, such seasonal transport does not bring most of particles out of the SCS but retains them mostly within the SCS regardless of the seasons.

Keywords: Microplastics, South China Sea, Three-dimensional, Monsoons

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Volume transport due to internal wave generation along the continental shelf in the South China Sea

*Qiang Li[1], Xiaohua Zhang[1], Xiuyu Zheng[1], Jintao Gu[1], Xiaoting Zhu[1]

1. Tsinghua University

Abrupt topography in Luzon Strait and the continent shelf in the South China Sea spawns one of the most energetic internal wave generation sites in the global ocean. Besides of tremendous momentum and energy flux, recent mooring observations reveal measurable volume or mass transport which is possibly related to internal waves. Local dissipation of internal waves mixes seawater. Inhomogeneous distribution of mixing may generate density or pressure gradient, thus inducing mean flow under the geostrophic balance. On the other hand, divergence of internal wave momentum flux acts as a stress on seawater, which may also force a mean flow. In the South China Sea, internal waves are generated by different topographic features, such as ridges, canyons and shelf break, resulting in different mean flows. High-resolution numerical models are implemented for the topography of ridges, canyons and shelf break in the South China Sea, to evaluate the mean flow caused by internal waves. The effects of nonlinearity, viscosity and bottom drag, as well as the characteristics of bottom topography, are also investigated through sensitivity experiments. Through this study, we expect to further reveal the role of internal waves in the exchange between shelf sea and open ocean.

Keywords: Internal waves, Volume transport, Numerical models

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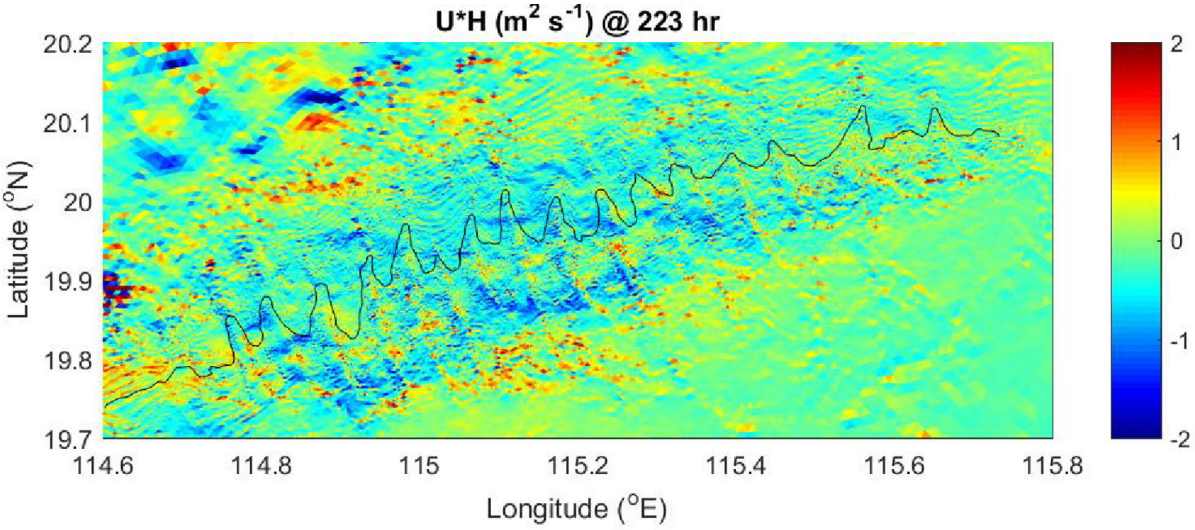

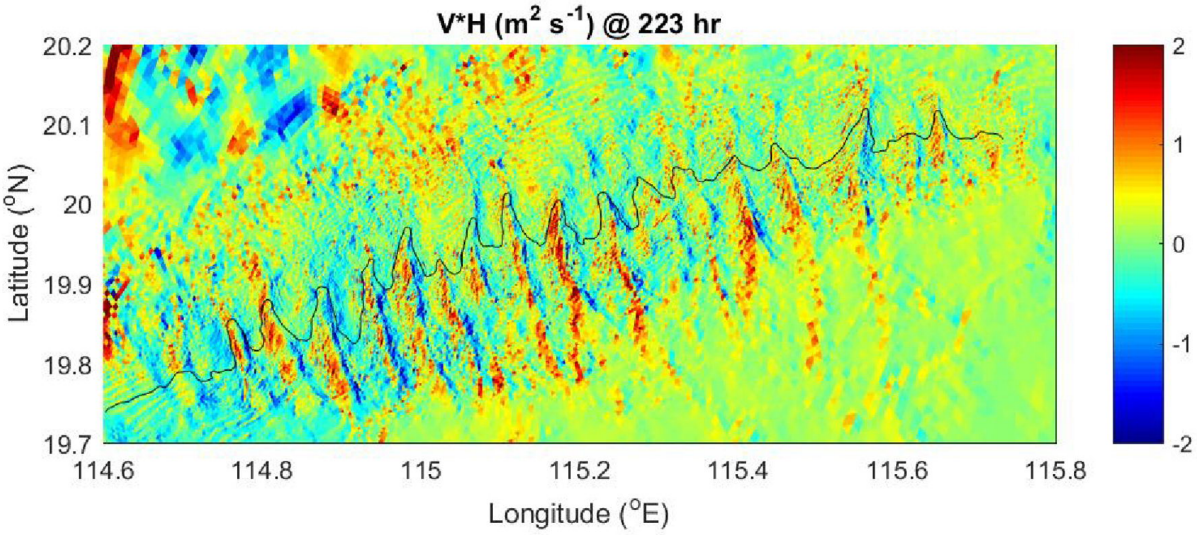

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS20] Coastal physical processes associated with mixing, eddies, and internal waves

convener:Taira Nagai(Graduate School of Science, The University of Tokyo), Eisuke Tsutsumi(Atmosphere and Ocean Research Institute, The University of Tokyo), Eiji Masunaga(Ibaraki University)

Recently developed observational and numerical approaches have revealed details of physical processes in coastal regions, which can affect large-scale oceanic/atmospheric circulations and ecosystems. This session aims to provide a platform to discuss mixing, eddies, and internal waves in coastal/marginal oceans including estuaries and lakes. This session also covers topics that consider linkages between coastal phenomena and large scale processes in the open ocean (e.g., the Kuroshio Current).

[AOS20-06] Observations of vertical mixing and sediment heat flux in a shallow lake

*Eiji Masunaga[1], Shunsuke Komuro[2], Tatsumi Kitamura[2] (1.Ibaraki University, 2.Ibaraki Kasumigaura Environmental Science Center)

[AOS20-07] Effects of the wind forcing on a shallow lake associated with the lake size and stratification

*Daiki Asaoka[1], Eiji Masunaga[1], shunsuke komuro[2], Tatsumi Kitamura[2] (1.Ibaraki University, 2.Ibaraki Kasumigaura Environmental Science Center)

[AOS20-08] Estimating internal tidal current in a tidally-energetic shallow estuary, Ariake Sea, Japan

*Eisuke Tsutsumi[1], Chitake Matsufuji[2], Takeshi Matsuno[3], Tomoharu Senjyu[3], Takahiro Endoh[3] (1.Atmosphere and Ocean Research Institute, The University of Tokyo, 2.Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, 3.Research Institute for Applied Mechanics, Kyushu University)

[AOS20-09] The decreasing trend of M_2 tidal amplitude observed along northwestern Kyushu

*Hiromi Matsuura[1], Katsuto Uehara[2], Shinichiro Kida[2], Toshiyuki Hibiya[3] (1.Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, 2.Research Institute for Applied Mechanics, Kyushu University, 3.Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo)

[AOS20-10] **Multimodal fusion for sea level anomaly forecasting**

*Guosong Wang[1,2], Xidong Wang[1], Xinrong Wu[2], Kexiu Liu[2], Chunjian Sun[2], Hongli Fu[2] (1.College of Oceanography Hohai University, 2.National Marine Data and Information Service)

Discussion

Discussion

Discussion

Observations of vertical mixing and sediment heat flux in a shallow lake

*Eiji Masunaga[1], Shunsuke Komuro[2], Tatsumi Kitamura[2]

1. Ibaraki University, 2. Ibaraki Kasumigaura Environmental Science Center

This study presents observational results of vertical mixing and heat budget in a shallow lake, Lake Kasumigaura, Japan, during summer season. Coastal seas and lakes are known as important areas for material, heat and buoyancy exchanges between lands and oceans. A recent study of Masunaga and Komuro (2019, Limnology) reported that the sediment heat flux is not negligible and it influences vertical mixing in a shallow lake. However, mixing observations in shallow areas are limited due to difficulty in microstructure surveys. We carried out observations to estimate the vertical eddy diffusivity with a newly developed method using the Ellison scale from high frequency temperature mooring arrays (Ivey et al., 2018, JGR: Oceans). The estimated eddy diffusivity well matches to the gradient Richardson number (*Ri*), thus, the vertical mixing can be simply inferred from *Ri* in the study area. In addition, the daily averaged *Ri* is highly correlated with the Monin-Obukhov length scale and the internal Froude number. The sediment temperature at 0.2 m below the sediment-water interface was approximately 1.5 degrees lower than the water temperature at the lake bottom (0.2 m above the interface), which implies the heat flux toward sediments. The sensible sediment heat flux *(H_{sed})* was estimated using the bulk method with consideration of *Ri* (viz, the Stanton number decreases with increasing in *Ri* (Louis, 1979)). H_{sed} is consistent with the surface residual heat flux (H_R) (H_R is the residual heat flux component computed by a difference between water temperature from observations and from the surface heat flux parameterization). The correlation between the daily averaged H_{sed} and H_R is 0.84. Therefore, stability/mixing and the sediment heat flux have to be considered to estimate the heat budget in the lake water. We suggest that the sediment heat flux controlled by mixing largely affects physical processes in shallow coastal lakes and ocean.

Keywords: mixing, Heat flux, Coastal areas

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Effects of the wind forcing on a shallow lake associated with the lake size and stratification

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This study shows effects of the wind forcing on a shallow lake associated with the lake size and stratification. Mixing in lakes and reservoirs are frequently evaluated by using nondimensional parameters, for example the Wedderbrun number (W_e). W_e can be estimated for a steady state wind condition or computed by using time averaged wind data, however, winds largely vary within several hours or less. Time scales associated with mixing in a shallow lake were investigated using a two dimensional (x-z) numerical simulator, SUNTANS. Several conditions of the horizontal scale of the modeled lake, stratification and wind speed were used in simulations with W_e ranging 0.1–10. This study employees two time scales: (1) time scale required for a steady state temperature distribution estimated from the tilt of the thermocline, T_s, and (2) time scale required for complete vertical mixing, T_{mix}. T_{mix} is computed from change in the potential energy. Numerical results showed that T_s linearly decreases with decreasing in the stratification or increasing in the horizontal distance under a same W_e condition. T_{mix} also increased when the stratification decreased or the horizontal distance increased under a same W_e condition. A quarter of the internal seiche period (T_i) was calculated using a stratification and a horizontal distance. Numerical results showed a linear relationship between T_i and T_s. Moreover, a quarter of T_i was fundamentally shorter than T_{mix} under a same stratification and horizontal distance. This implies that the lower limit of the mixing time scale is determined by a quarter of T_i.

Keywords: Wind forcing, Stratification, Mixing

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Estimating internal tidal current in a tidally-energetic shallow estuary, Ariake Sea, Japan

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Coastal ocean mixing affects transfer of materials, heat and freshwater not within a local sea but also among ocean, land and atmosphere. It results largely from tides. Surface tides, which are propagating towards coastal sea from open-ocean, are mostly dissipated by local frictional processes at coastal boundaries while internal waves, especially ones at tidal frequencies, redistribute a certain fraction of the surface-tide energy for the coastal ocean mixing. Estimating such an internal-tide energy in the coastal ocean is therefore important to understand the coastal marine processes, although it is sometimes challenging in shallow areas because significant bottom boundary layer (BBL) makes it difficult to make a common assumption when we estimate internal-tide current velocity: surface (barotropic) tidal current is depth-independent and internal (baroclinic) tidal one is anomaly from it. In this study, we develop a method estimating internal tidal current in regions where surface tidal current forms a bottom boundary layer at significant part of the water column. We observed tidal currents using bottom-mounted acoustic Doppler current profilers for a fortnight cycle in highly stratified season in the Ariake Sea, a shallow estuary (mean depth is ~20 m) located on southwest of Japan. Surface tide in the sea is dominated by semidiurnal constituents and the semi-diurnal current speed reached ~0.8 m s^{-1} in spring tide, exhibiting a well-developed bottom boundary layer structure. Based on the bottom Ekman balance, we estimated vertical profile of tidally-averaged vertical eddy viscosity from the harmonic coefficients of the observed velocity. The estimated viscosity was fairly consistent with the estimate from simultaneous measurements of microstructure turbulence. We calculated semi-diurnal surface-tide current profile including the BBL component based on the bottom Ekman balance and the estimated eddy viscosity, and then obtained semi-diurnal internal tidal current by extracting the surface-tide velocity from net semi-diurnal velocity. The estimated internal-tide velocity was in-phase with vertical elevation of pycnocline, suggesting a propagating nature of semi-diurnal internal tide during the observational period.

Keywords: internal tide, shallow seas, vertical eddy viscosity, bottom boundary layer, Ariake Sea

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The decreasing trend of M_2 tidal amplitude observed along northwestern Kyushu

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Observations show that M_2 tidal amplitude is decreasing along the northwestern coast of Kyushu. Using JODC and JMA datasets, we found that this decrease in M_2 tidal amplitude from 1980 to 2018 is 4% on average and that the trend is stronger towards the northwest than the southwest. When we further investigated the M_2 tidal amplitude along the coast of the Japan Sea and the Pacific Ocean, we found the decreasing trend to continue along the coast of Japan Sea but not along the Pacific Ocean. The mechanism responsible for this decreasing trend is still unknown. In this presentation, we plan to show the observed spatial distribution in M_2 tidal amplitude trend and the possible mechanisms using a numerical model.

Keywords: M2 tide, tide, Northwestern Kyushu Coast

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Multimodal fusion for sea level anomaly forecasting

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The accumulated remote sensing data of altimeters and scatterometers have provided a new opportunity to predict the ocean states and improve the knowledge in ocean/atmosphere exchanges. Few previous studies have focused on sea level anomaly (SLA) forecasting by deep learning for different modalities. For this paper, a novel multimodal fusion approach named MMFnet is used for SLA forecasting in the South China Sea (SCS). First, a grid forecasting network is trained by an improved Convolutional Long Short-Term Memory (ConvLSTM) network on daily multiple remote sensing data from 1993 to 2016. Then, an in-situ forecasting network is trained by an improved LSTM network, which is decomposed by the ensemble empirical mode decomposition (EEMD-LSTM), on real-time, in-situ and remote sensing data. Finally, the two single-modal networks are fused by an ocean data assimilation scheme. During the validation period from 2017 to 2019, the average RMSE of the MMFnet (single-modal ConvLSTM) is 4.03 cm (4.51 cm), the 15th day anomaly correlation coefficient is 0.78 (0.67), the performance of MMFnet is much higher than those of current state-of-the-art dynamical (HYCOM) and statistical (ConvLSTM, Persistence and Climatology) forecasting systems. Sensitivity experiments analysis indicates that, compared with a set of based single models, the MMFnet, which added CCMP SCAT products and OISST for SLA forecasting, has improve the period of validity over a week and can effectively produces 15-day SLA forecasting with reasonable accuracies. Take wind stress curl and SST anomaly as input data, the MMFnet has better forecasting ability for large-radius eddies in the open sea, and is able to produces accurately SLA forecasting with weak kinetic energy in shallow coastal regions, overcoming a weakness of single forecasting models. In an extension of the validation over the western Pacific Ocean, MMFnet can calculate the forecasting results in a few minutes, and we find good agreement in amplitude and distribution of SLA variability between MMFnet and other classical operational model products.

Keywords: multiple remote sensing, South China Sea, deep learning, convolutional LSTM, multimodal fusion

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS21] Dynamics of oceanic and atmospheric waves, vortices, and circulations

convener:Yuki Tanaka(Fukui Prefectural University), Ryo Furue(APL/JAMSTEC), Yukiharu Hisaki(University of the Ryukyus), Norihiko Sugimoto(Keio University, Department of Physics)

Oceanic and atmospheric dynamics aims at abstracting general principles from observed phenomena and constructing a system of mathematical models, thereby leading to the understanding, prediction, and parameterization of those phenomena. It provides perspectives for the advancement of sciences in various areas such as wind waves, swells, internal waves, Rossby waves, equatorial waves, tides, eddies, meandering of jets and fronts, general circulation, boundary layers, and ocean-atmosphere coupled modes. It has also been and will continue to be benefited by new uses of ideas and methods from such theories as resonance, nonlinear interaction, spectral analysis, probability, statistics, and dynamical systems. In this session, we solicit presentations on observational, experimental, numerical, and theoretical studies of oceanic and atmospheric dynamics and on exploratory use of new ideas and methods. We also welcome presentations on interdisciplinary studies in fields such as ecosystems, climate, and environment.

[AOS21-02] Structure and evolution of the tropical synoptic-scale waves in the Indian Ocean-Maritime Continent region

*Fukutomi Yoshiki[1], Hidenori AIKI[1] (1.Institute for Space-Earth Environmental Reasearch, Nagoya University)

[AOS21-03] Toward practical use of EFSO for weekly weather forecasts: Dynamics of propagation of observation impacts

*Akira Yamazaki[1], Takemasa Miyoshi[2,1], Takeshi Enomoto[3,1], Nobumasa Komori[1], Jun Inoue[4,1] (1.Application Laboratory, Japan Agency for Marine-Earth Science and Technology, 2.RIKEN Center for Computational Science, 3.Disaster Prevention Research Institute, Kyoto University, 4.National Institute of Polar Research)

[AOS21-04] Numerical and Theoretical Study on the relationship between the amplitudes of tsunamis and the associiated atmospheric Lamb waves

*Kensuke Nakajima[1] (1.Department of Earth and Planetary Sciences,Flculty of Sciences,Kyushu University)

[AOS21-05] **Persistent Small-Scale Features of Ocean Winds and Waves**

★Invited Papers

*Lie-Yauw Oey[1,2] (1.National Central University, 2.Princeton University)

[AOS21-06] Effect of swells on the development of wind waves in the real ocean

*Kosei Komatsu[1,2], Hirotaka Omatsu[1,2], Kiyoshi Tanaka[2] (1.GSFS, Univ. Tokyo, 2.AORI, Univ. Tokyo)

Structure and evolution of the tropical synoptic-scale waves in the Indian Ocean-Maritime Continent region

*Fukutomi Yoshiki[1], Hidenori AIKI[1]

1. Institute for Space-Earth Environmental Reasearch, Nagoya University

This study investigates the dominant structure, characteristics, and origins of the tropical synoptic-scale waves (TSWs) in the Indian Ocean-Maritime continent region during austral summer. An extended empirical orthogonal function-based composite analysis is performed on 2-8-day filtered atmospheric circulation fields during December-February 1979/80-2015/16. The analysis results reveal the structure and evolution of the TSWs and associated extratropical-tropical interactions. The composite wave pattern exhibits a modified mixed Rossby-gravity wave-like structure over the Indian Ocean and a tropical depression-type wave-like structure over the Maritime continent. They form a wave train which is trapped in the mean monsoon westerly flow coupling with deep convection in the Indian Ocean intertropical convergence zone. The TSWs propagate westward from the Maritime Continent into the western Indian Ocean. Zonal wavelengths are about 6000-7000 km over the Indian Ocean and is about 3000-4000 km over the Maritime Continent. The westward phase speed is estimated to be about 8-12 m/s. Eastward amplification of wave troughs and ridges of the wave train due to group propagation occurs along the mean monsoon westerly flow. The eastward group speed is estimated to be 7m/s. A dispersive wave energy flux (WEF) formulation derived by Aiki et al. (2017, PEPS) is used to diagnose the eastward amplification of the waves along the mean monsoon westerly flow. The new WEF vectors are considered to be useful to assess energy dispersion characteristics of various types of waves in the tropics. The WEF diagnostics verify that wave energy propagation facilitates the eastward development of the synoptic-scale wave train, suggesting that the mean monsoon westerly flow acts as a tropical waveguide. Extratropical forcing mechanisms responsible for the development of the TSWs are explored. Two types of extratropical forcing of the TSWs are identified over the southwest Indian Ocean. One type is direct propagation of midlatitude synoptic-scale waves toward the tropics that induces the growth of the tropical waves through the Rossby wave energy dispersion from the subtropics into the tropics. The other type is meridional wind surges originated in the midlatitude that could intensify the TSW troughs and ridges. The surges are induced by the baroclinic development of the midlatitude synoptic-scale waves. The self-organizing map (SOM) technique is used to classify the TSW patterns. The SOM-based composite analysis successfully detects various types of the southerly and northerly wind surges which force the TSWs in the Indian Ocean--western Pacific region.

Keywords: Tropical synoptic-scale waves , Extratropical-tropical interaction, Wave energy dispersion, Asian-Australian monsoon

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Toward practical use of EFSO for weekly weather forecasts: Dynamics of propagation of observation impacts

*Akira Yamazaki[1], Takemasa Miyoshi[2,1], Takeshi Enomoto[3,1], Nobumasa Komori[1], Jun Inoue[4,1]

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An ensemble-based forecast sensitivity to observations (EFSO) diagnosis has implemented in an Atmospheric GCM–Ensemble Kalman Filter data assimilation system to estimate the impacts of specific observations in the quasi-operational global observing system on weekly short- and medium-range forecasts. EFSO can quantify how much each observation has improved or degraded the forecast without observing-system (another data assimilation) experiments, that is, an offline diagnosis. In order to examine whether EFSO values correctly quantify the impacts of a subset of observations performed in a specific geographical spot in 6-hour to 7-day forecasts, EFSO values were compared with actual observation impacts obtained from multiple data denial experiments in each of which a subset of three radiosonde observations launched from a geographical spot was excluded. The spots were selected from three latitudinal bands comprising (1) Arctic regions, (2) midlatitude regions in the Northern Hemisphere, and (3) tropical regions during the winter of 2015/16. The results showed that all EFSO values reasonably estimated the observation impacts on short-range (6-hour to 2-day) forecasts. Furthermore, it was found that the initial Arctic observation impacts, which could be estimated by EFSO, remained in medium-range (7-day) forecasts because the Arctic is located at the upstream of dynamical propagation toward the midlatitudes where small perturbations rapidly and spontaneously grow. Therefore, EFSO can be useful for weekly forecasts for anticipating impacts of specific observations by considering dynamical propagation.

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Numerical and Theoretical Study on the relationship between the amplitudes of tsunamis and the associiated atmospheric Lamb waves

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Major tsunamis excite significant atmospheric Lamb waves, i.e. low frequency ground trapped atmospheric waves that propagate with acoustic wave speed, and their signals can be useful for the inversion of tsunami sources (e.g. Arai et al 2011; Mikumo et al 2008). Here I will discuss (i) the result of numerical experiments on the response of compressible atmosphere to the vertical motion of ground surface representing tsunamis, (ii) its theoretical interpretation, and (iii) the suggested high potential as a practical tool for quantitative prediction of tsunamis.

The numerical experiment shows that three kinds of waves are excited responding to tsunamis, which are, acoustic waves that propagate upward with the speed of sound, internal gravity waves that propagate horizontally with the speed much slower than the speed of sound, and, Lamb waves that propagate horizontally with the speed of sound being trapped near the ground surface. Notably, it is shown that the pressure amplitudes and waveforms of the Lamb waves almost "duplicate" the heights and waveforms of tsunamis, being almost insensitive to the rise time of the tsunamis unless it is shorter than a L_t/c_s, where L_t is the length scale of tsunamis and c_s is the speed of sound. This last property is distinctly different from the traditionally used scaling for pressure amplitude of tsunami-induced infrasound waves, which has been haunted by the dependence on vertical velocity of tsunamis that is hard to obtain quickly.

The excitation property of Lamb waves can be understood in a straightforward manner considering the state of the atmosphere after "hydrostatic adjustment" (e.g., Bannon, 1995) in response to the uplift of lower boundary; the entire atmospheric column is lifted upward by the same amount to the rise of sea surface. Based on the theoretical consideration, one can derive a set of equation that can predict the excitation and propagation of tsunami induced Lamb waves. It is highly economic, being two-dimensional equations, and, at the same time, is capable of quantitatively reproduce the observed waveforms of pressure disturbances excited by major tsunamis.

The results indicate pressure measurement of Lamb waves is very useful for the prediction of tsunamis, including those excited by slow fault motions that are hard to be captured by conventional seismometers.

Keywords: tsunamis, atmospheric Lamb waves, hydrostatic adjustment

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Persistent Small-Scale Features of Ocean Winds and Waves

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Persistent small-scale winds over sea surface temperature gradients are now well-known. Less known, except for some remarkable local studies, are small-scale wind-driven waves and wave-driven winds. I will present observational evidence of the phenomenon, focusing on the latter over the North Pacific and other regions of the global ocean.

Keywords: Winds, Sea surface waves

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Effect of swells on the development of wind waves in the real ocean

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1. GSFS, Univ. Tokyo, 2. AORI, Univ. Tokyo

Wave-wave interaction plays main roles on the inter-scale exchange of several physical quantities such as energy and momentum. However, it is inherently accompanied by strong nonlinearity especially at the boundary of an open system, therefore it is difficult to understand accurately the realty of the wave-wave interaction occurring on the air-sea interface. Surface gravity wave induced by wind is one of the most energetic and influential phenomena that occur continuously at the sea surface, and it is classified conventionally into wind wave and swell. Wind waves are short waves with a typical period of a few to 7 seconds, which are developing under the energy input from the local wind. Swells, on the other hand, are longer waves with a typical period of ten to several tens of seconds that have propagated away from their generation region without receiving active energy input from the local wind. The interaction between wind waves and swells has not been understood completely still now, although the both waves compose the surface roughness that determines the drag coefficient while intermingling in the real oceans.
Interestingly, the wave-tank experiments of the past pointed out that swells suppressed the development of wind waves in the case of wind blowing in the same direction as the propagation of the swells, and inversely that swells promoted the development of wind waves in the case of wind blowing oppositely to the swell propagation. In contrast, theoretical studies presented that swells suppressed the wind wave development, regardless of whether wind blew in the same direction as the swells or not. This inconsistency between the previous experimental and theoretical studies has not still been solved, and moreover, it should be emphasized that these effects of swells on the development of wind waves have not been verified in the real oceans.
This study is the first to verify quantitatively the effects of swells on the development of wind waves in the real ocean. For this purpose, we analyzed 2D wave-energy spectra and wind velocity observed simultaneously and continuously by a buoy equipped with a GPS wave sensor and an ultrasonic anemometer, which had been moored over a four-year period in Otsuchi Bay on the Sanriku ria coast, Japan. Otsuchi Bay presents similar situations as the experimental conditions set up for a wind-wave tank with a plunger, because wind waves generated by local wind inside the bay are always coexistent with near-monochromatic swells which are originated from the offshore regions and propagate into the bay through the narrow bay mouth. The analysis revealed that the effects of swells on the development of wind waves were consistent with the conclusions of not the previous experimental studies but the theoretical studies. Energy of wind waves calculated from their spectral components was suppressed under the influence of swells in both the fair and opposite wind cases, comparing with that in the case when the influence of swells was inferred to be minimum from their smallest wave steepness. However, as for the opposite wind case, the energy of wind waves dispersed so widely that it indicated the probability of the wind-wave energy enhancement depending on the situation; the longer fetch leaded to the more remarkable enhancement. The discrepancy between this study and the previous experiments might be attributed to much smaller energy of swells simulated by monochromatic regular waves generated by a plunger in the wind-wave tank, in comparison with real swells in Otsuchi Bay. Moreover, wind waves in the wave-tank were under the local equilibrium between wind and wind waves, on the other hand wind waves in Otsuchi Bay were far from the local equilibrium. Detailed processes of the interaction between wind waves and swells have not been completely clarified still now. Spatial-temporal variation of the wind-wave energy needs to be analyzed for approaching the interaction processes in the future studies.

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Keywords: wind-generated surface waves, interaction between swells and wind waves, Otsuchi Bay

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS21] Dynamics of oceanic and atmospheric waves, vortices, and circulations

convener:Yuki Tanaka(Fukui Prefectural University), Ryo Furue(APL/JAMSTEC), Yukiharu Hisaki(University of the Ryukyus), Norihiko Sugimoto(Keio University, Department of Physics)

Oceanic and atmospheric dynamics aims at abstracting general principles from observed phenomena and constructing a system of mathematical models, thereby leading to the understanding, prediction, and parameterization of those phenomena. It provides perspectives for the advancement of sciences in various areas such as wind waves, swells, internal waves, Rossby waves, equatorial waves, tides, eddies, meandering of jets and fronts, general circulation, boundary layers, and ocean-atmosphere coupled modes. It has also been and will continue to be benefited by new uses of ideas and methods from such theories as resonance, nonlinear interaction, spectral analysis, probability, statistics, and dynamical systems. In this session, we solicit presentations on observational, experimental, numerical, and theoretical studies of oceanic and atmospheric dynamics and on exploratory use of new ideas and methods. We also welcome presentations on interdisciplinary studies in fields such as ecosystems, climate, and environment.

[AOS21-07] Causal Mechanism of Sea Level Rise in the South Pacific Ocean

★Invited Papers

*Ichiro Fukumori[1], Tangdong Qu[2], Ou Wang[1] (1.Jet Propulsion Laboratory, 2.University of California, Los Angeles)

[AOS21-08] Scale interactions in the tropical Pacific Ocean

★Invited Papers

*Kelvin John Richards[1] (1.University of Hawaii at Manoa)

[AOS21-09] Novel use of time-lapse seismic images and in-situ hydrographic data for detecting changes at the interface between oceanic water layers

*Vincent Tong[1], Qunshu Tang[2,3] (1.University College London, 2.CAS Key Laboratory of Ocean and Marginal Sea Geology, 3.Innovation Academy of South China Sea Ecology and Environmental Engineering)

[AOS21-10] Life-time independent approach to Lagrangian vortices detection

*Anass El Aouni[1], Arthur Vidard[1] (1.INRIA/LJK Grenoble, France)

[AOS21-11] Floating tracer clustering in divergent random flows modulated by an unsteady mesoscale ocean velocity field

*Konstantin Koshel[1,2], Pavel Berloff[3], Evgeny Ryzhov[1,3], Dmitry Stepanov[1] (1.V.I. Ilichev Pacific Oceanological Institute, FEB RAS, 2.Institute of Applied Mathematics, FEB RAS, 7, Radio Street, Vladivostok 690022, Russia, 3.Department of Mathematics, Imperial College London, London SW7 2AZ, United Kingdom)

[AOS21-12] **On the Stability of Discrete Vortex Structures in Geostrophic Models Two-Layer Rotating Fluid and Bessel Vortices**

*Leonid Kurakin[1,2], Irina - Lysenko[1], Irina - Ostrovskaya[1], Mikhail - Sokolovskiy[2,3] (1.Southern Federal University, Rostov on Don, Russia, 2.Water Problems Institute, RAS, Moscow, Russia, 3.Shirshov Institute of Oceanology, RAS, Moscow, Russia)

Causal Mechanism of Sea Level Rise in the South Pacific Ocean

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1. Jet Propulsion Laboratory, 2. University of California, Los Angeles

Sea level in the South Pacific Ocean east of New Zealand has, over the past two and a half decades, increased faster than the rate of global mean sea level rise (Figure). The excess increase in regional sea level has been associated with spin-up of the subtropical gyre, accompanied by deepening isopycnals and strengthening circulation. Here, in conjunction with satellite and in situ observations, we examine the causal mechanism of this change using the latest ocean state estimate of the Consortium for Estimating the Circulation and Climate of the Ocean (ECCO), Version 4 Release 4 (http://ecco-group.org).

The study identifies the mechanism responsible for the relative sea level rise by expanding the fluctuation into contributions from different forcings using the model's adjoint. Specifically, instead of a forcing directly over the region, we find trends in zonal wind stress east of where the sea level rise takes place causing the observed variation. The remote forcing drives low frequency planetary waves that propagate west across the basin. The islands of New Zealand arrest the propagation and limit the meridional extent of the variation.

The investigation illustrates the utility of ECCO's tools and products in identifying processes controlling the ocean. The ECCO estimate combines nearly all extant observations with a state-of-the-art general circulation model, providing a complete description of the ocean. The study highlights elements of this synthesis with an emphasis on the efficacy of the model's adjoint in analyzing the ocean, besides its use in assimilating data.

Keywords: Sea level rise, Decadal change, Ocean circulation, Adjoint model, State estimation, Data assimilation

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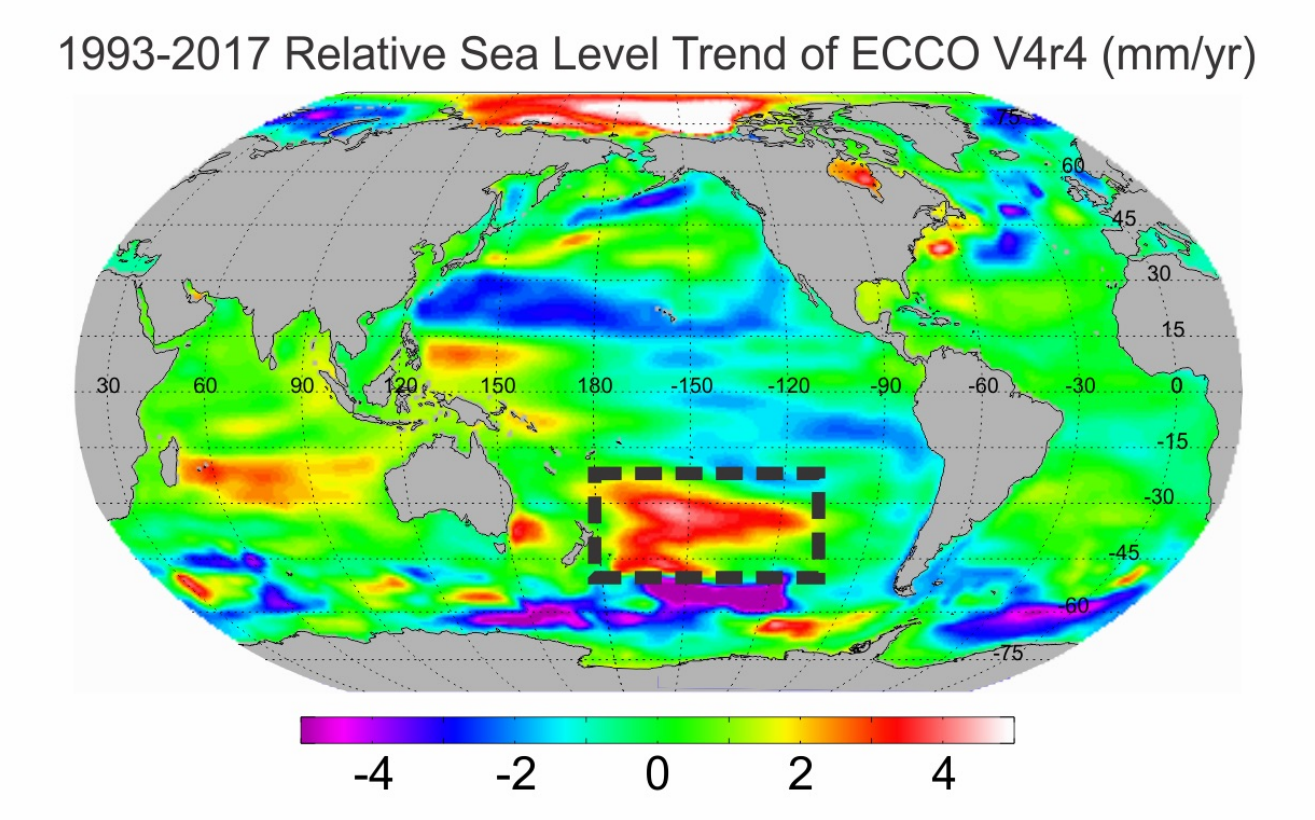

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Scale interactions in the tropical Pacific Ocean

*Kelvin John Richards[1]

1. University of Hawaii at Manoa

We examine the way various temporal and spatial scales of motion interact to impact the evolving ocean/atmosphere system in the tropical Pacific. A major focus is the link between wind variability, the production and propagation of internal wave activity, and changes to the thermocline that impact the cold tongue, which in turn affects ocean/atmosphere interactions. A key element is the fine-scale shear associated with small vertical scale inertia-gravity waves. An equatorial enhancement of wave activity is brought about by a combination of factors: a stronger superinertial component of the wind forcing close to the equator, wave action convergence at turning latitudes for equatorially trapped waves, and nonlinear wave-wave interactions between equatorially trapped waves. This equatorial enhancement leads to an enhancement of mixing in the equatorial thermocline. The small vertical scale nature of the waves means that they are often overlooked in observations and are not resolved in models, and thus we are missing a crucial element of interactions in the ocean. The good news is that with enough resolution the relevant scales can be captured in both observations and models. Future observational studies and the design of the next generation climate models need to take this into account.

Keywords: scale interactions, internal waves, equatorial Pacific

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Novel use of time-lapse seismic images and in-situ hydrographic data for detecting changes at the interface between oceanic water layers

*Vincent Tong[1], Qunshu Tang[2,3]

1. University College London, 2. CAS Key Laboratory of Ocean and Marginal Sea Geology, 3. Innovation Academy of South China Sea Ecology and Environmental Engineering

The presence of horizontally spreading interfaces between water layers in the ocean requires an equilibrium between processes that cause them to grow and those that destroy them. Results from numerical simulations show that such interfaces can be developed from weeks to decades in an idealized system. Owing to the sparse temporal and spatial coverage, it has not been possible to provide empirical constraints for these models. We here present a novel method of combining time-lapse seismic images and physical oceanographic data to provide the first robust observation constraint on the changes at the leading edge of an interface between two water layers. Based on our recently published results (Tang, Tong, Hobbs & Morales Maqueda, Nature Communications, 2019), we discuss the novel approach and its implications for studying the links from the mesoscale to the finescale and then to the microscale processes that control how interfaces evolve. We conclude by highlighting the potential of our approach to studying the dynamics of other physical oceanographic processes.

Tang, Q., Tong, V.C.H., Hobbs, R.W. *et al.* Detecting changes at the leading edge of an interface between oceanic water layers. *Nat Commun* **10,** 4674 (2019). https://doi.org/10.1038/s41467-019-12621-8

Keywords: time-lapse imaging, oceanic dynamics, water interfaces

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Life-time independent approach to Lagrangian vortices detection

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Lagrangian coherent structures (LCSs) are differentiated surfaces of trajectories in a dynamical system that exert significant effects on adjacent trajectories over a finite-time interval. These LCSs are mainly structured into three physical shapes, in the geophysical fluid dynamics field these structures are referred to as mesoscale and submesoscale filaments, jets and eddies. These latter structures are omnipresent in the ocean and usually exhibit different properties to their surroundings. They are known to stir and mix surroundings water masses as well as by their ability to trap and carry water properties in a coherent manner. In the present work, we are interested in those that remain coherent despite their chaotic environment. Such mesoscale eddies have an important role to play in climate change arising from their influence on the circulation by transporting temperature and salinity. As these mesoscale eddies have a remarkable impact on the global circulation, their systematic and precise detection has been of great concern over the last decade. Several Lagrangian vortex definitions have been introduced in the literature together with their automatic detection. Indeed, These methods identify and extract such eddies in a very coherent manner. However, they suffer from a conceptual point of view; they all require the sought eddies life-time to be exactly equal to the time interval of particles' advection. For example, by choosing a time interval of six months, such methods only extract eddies that do exist and remain coherent exactly six months. Thus, these methods miss several eddies that have existed within the time interval of advection but have life-times different from 6 months. In the present work, we present a life-time independent method that is able to lump eddies occurring over different time intervals into the same scalar field. Here, we reveal that such eddies can be identified based on the frequency-domain representation of their trajectories. We then identify and extract coherent vortices as material surfaces along which particles' trajectories share similar frequency components and life-time. The present method identifies all coherent eddies in an automatic manner, showing high eddies' monitoring capacity. We illustrate our new method by identifying and extracting Lagrangian coherent eddies in different fluid flows.

Keywords: Lagrangian coherent structures , Vortex dynamics, Mesoscale eddies, Lagrangian vortex detection, Coherent water transport

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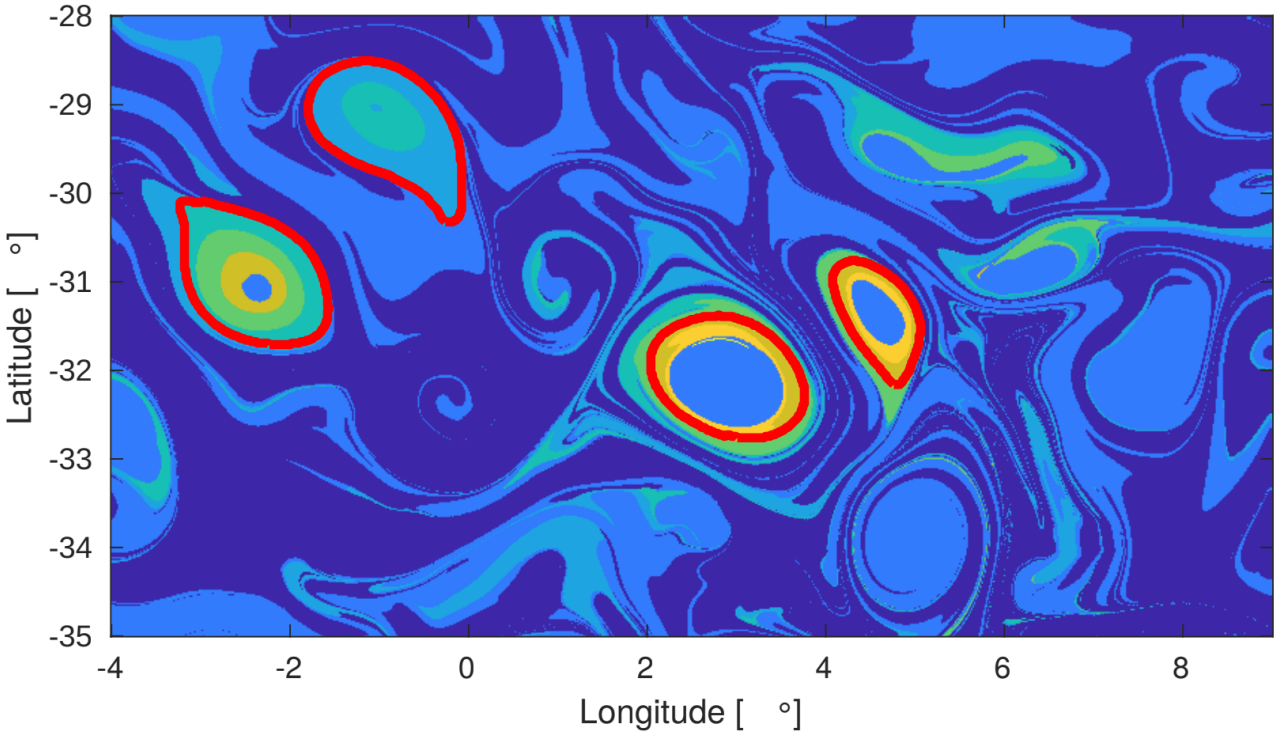

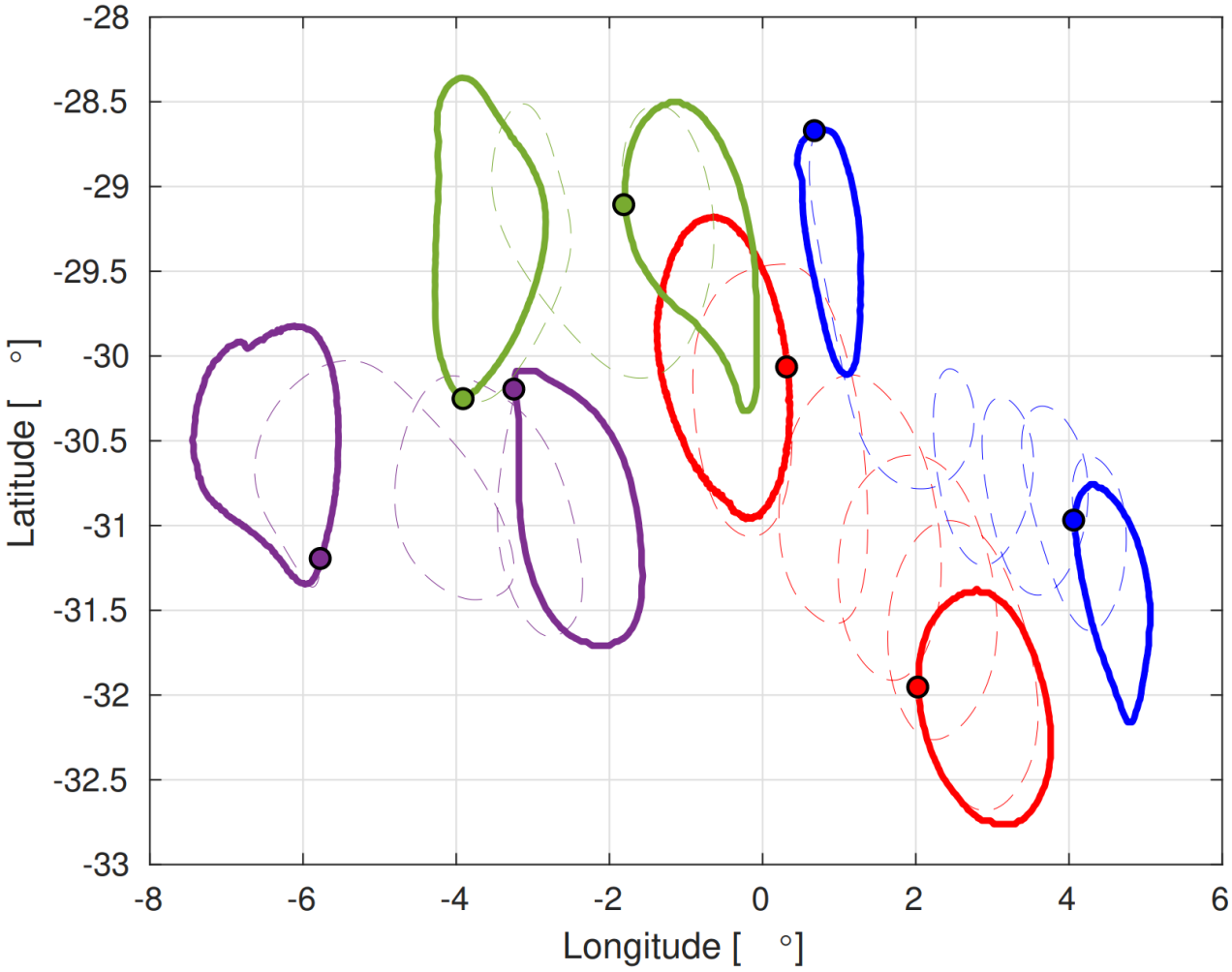

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Floating tracer clustering in divergent random flows modulated by an unsteady mesoscale ocean velocity field

*Konstantin Koshel[1,2], Pavel Berloff[3], Evgeny Ryzhov[1,3], Dmitry Stepanov[1]

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Surface evolution and clustering of floating tracer induced by a combination of a regular mesoscale field and kinematic random field mimicking the influence of the submesoscale is considered. The theory of exponential clustering in random velocity fields is applied to characterize possible clustering scenarios in steady and unsteady mesoscale flows, which are an hourly output of an eddy-resolving circulation model for the Japan/East Sea. The mesoscale field abounds in transient eddy-like structures that dominate the dynamical pattern by modulating various currents and their branching. The steady mesoscale component, obtained by time-averaging the hourly output, features coherent closed recirculation zones, where tracer can be entrapped. The submesoscale component is kinematically modeled using a divergent random velocity field with a prescribed correlation radius and variation. The linear superposition of the mesoscale and submesoscale fields sustains tracer clustering, which is the exponential growth of tracer density in patches of vanishing areas. Statistical topography integral characteristics are used to quantify the emerging clustering indicating drastic variations in clustering rates when subject to a steady or unsteady mesoscale component. A steady mesoscale component favors potent exponential clustering, similar to the theoretically tractable case of purely divergent random velocity fields without any constraints imposed by mean or regular flows. An unsteady component, on the other hand, hinders exponential clustering due to intense advection processes, which spread tracer out of enclosed eddying regions at faster rates compared to characteristic clustering ones. The aptitude of the proposed approach to studying tracer evolution at the ocean's surface is assessed arguing that a fine adjustment of the random velocity field parameters may prove useful in obtaining reliable estimates of the submesoscale influence at the ocean's surface.

Results are in Koshel et al. (2019); Stepanov et al. (2020).

Koshel, K.V., Stepanov, D.V., Ryzhov, E.A., Berloff, P. and Klyatskin, V.I., Clustering of floating tracers in weakly divergent velocity fields. Phys. Rev. E, 2019, 100, 063108.

Stepanov, D. V., Ryzhov, E. A., Zagumennov, A. A., Berloff, P., & Koshel, K. V. (2020). Clustering of floating tracer due to mesoscale vortex and submesoscale fields. Geophysical Research Letters, 48, e2019GL086504. https://doi.org/10.1029/2019GL086504

Figure. Example of tracer density evolution (density is color-coded) for the cyclonic eddy region for the unsteady regular velocity. The submesoscale influence changes according to EXP1-4.

EXP1 - no small scale velocity; EXP2 –nondivergent random velocity; EXP3 –divergent random velocity; EXP4 –combined divergent and solenoidal random velocity components. Upper panel: $t = 2x10^4$; bottom panel: $t = 4x10^4$.

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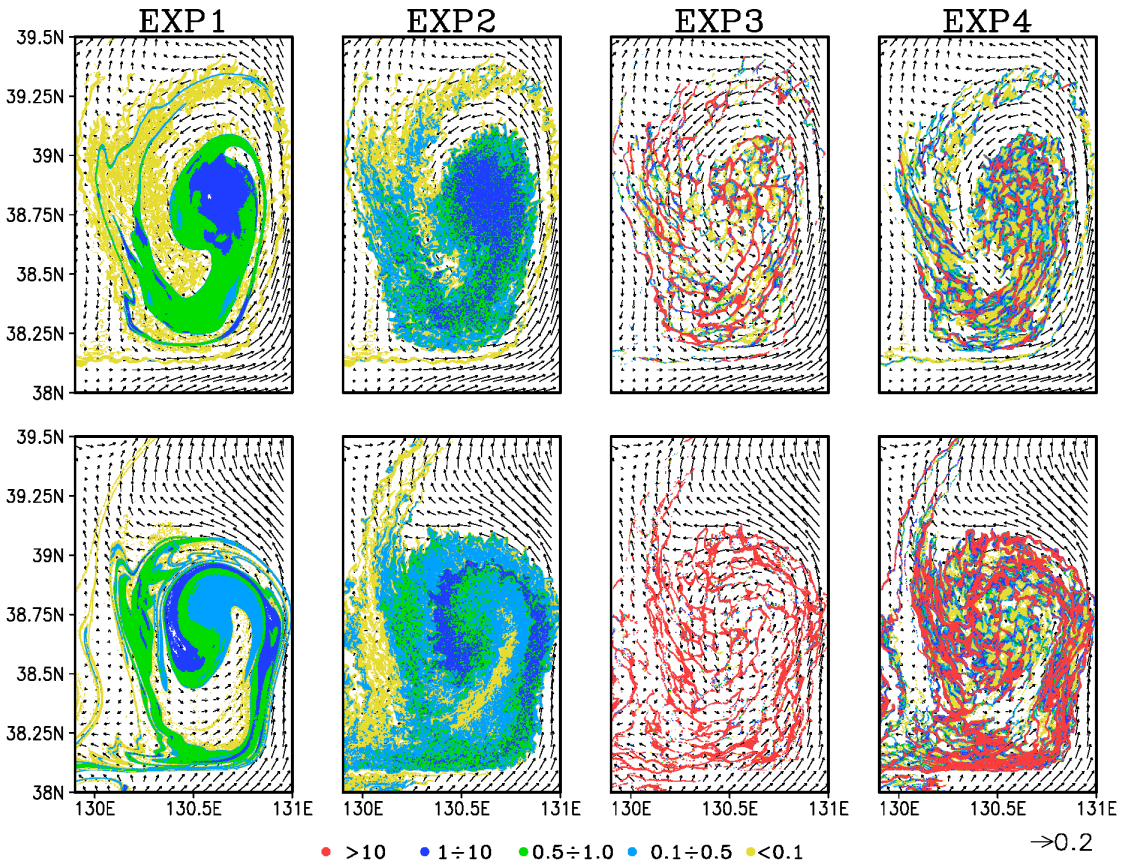
Keywords: Mesoscale, Submesoscale, Tracer, clustering, mixing, advection



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On the Stability of Discrete Vortex Structures in Geostrophic Models Two-Layer Rotating Fluid and Bessel Vortices

*Leonid Kurakin[1,2], Irina - Lysenko[1], Irina - Ostrovskaya[1], Mikhail - Sokolovskiy[2,3]

1. Southern Federal University, Rostov on Don, Russia, 2. Water Problems Institute, RAS, Moscow, Russia, 3. Shirshov Institute of Oceanology, RAS, Moscow, Russia

A two-layer quasigeostrophic model is considered. The stability analysis of the stationary rotation of a system of N identical point vortices lying uniformly on a circle of radius R in one of layers is presented. The vortices have identical intensity and length scale is $1/g>0$. The problem has three parameters: N, gR and b, where b is the ratio of the fluid layers thicknesses. The stability of the stationary rotation is interpreted as orbital stability. The instability of the stationary rotation is instability of system reduced equilibrium.
The quadratic part of the Hamiltonian and eigenvalues of the linearization matrix are studied.
The parameters space (N,gR,b) is divided on three parts: **A** is the domain of stability in an exact nonlinear setting, **B** is the linear stability domain, where the stability problem requires the nonlinear analysis, and **C** is the instability domain. The case **A** takes place for N=2,3,4 for all possible values of parameters gR and b. In the case of N=5 we have two domains: **A** and **B**. In the case N=6 part **B** is curve, which divides the space of parameters (gR,b) into the domains: **A** and **C**. In the case of N=7 there are all three domains: **A**, **B**, and **C**. The instability domain **C** takes place always if $N=2n>7$. In the case of $N=2l+1>7$ there are two domains: **B** and **C**.
Similar research of the stability has been carried out for the vortex structure consisting of a central vortex of arbitrary intensity G and two/three identical peripheral vortexes. The identical vortexes, each having a unit intensity, are uniformly distributed over a circle of radius R in a single layer. The central vortex lies either in the same or in another layer.
The stability of the Thomson vortex N-gon is also studied in the case of the model of the Bessel vortices for any N.
A number of statements about the stability is obtained for the systems of interacting particles with the general Hamiltonian depending only on distances between the particles.
The results of theoretical analysis are confirmed by numerical calculations of the vortex trajectories.
The main results are published in the papers [1-5].

I. Lysenko was supported by Ministry of Education and Science of the Russian Federation, Southern Federal University (Project No. 1.5169.2017/8.9), and the other three authors was supported by the Russian Foundation for Basic Research (Projects No. 20-55-10001).

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Keywords: Vortex dynamics, Stability, Point vortex

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS21] Dynamics of oceanic and atmospheric waves, vortices, and circulations

convener:Yuki Tanaka(Fukui Prefectural University), Ryo Furue(APL/JAMSTEC), Yukiharu Hisaki(University of the Ryukyus), Norihiko Sugimoto(Keio University, Department of Physics)

[AOS21-13] Data-driven improvement of coarse-resolution QG models

★Invited Papers

*Evgenii Ryzhov[1], Berloff Pavel[1], Kondrashov Dmitri[2], Agarwal Niraj[1] (1.Imperial College London, 2.UCLA)

[AOS21-15] Modified View of Barotropic Energy Conversion and its Application to the Kuroshio extension region

*Takuro Matsuta[1], Yukio Masumoto[1] (1.Graduate School of Science, The University of Tokyo)

[AOS21-16] Distribution and interaction of fronts and eddies in the Kuroshio Extension

*YUNTAO WANG[1], Rui Tang[1] (1.Second Institute of Oceanography Ministry of Natural Resources)

[AOS21-17] **Meridional heat transport in the Japan/East Sea from 1990 to 2010**

*Dmitry Stepanov[1] (1.Pacific Oceanological Institute, Far Eastern Branch, Russian Academy of Sciences)

[AOS21-18] Changes of Oyashio water properties due to multi-decadal and 18.6-year period variabilities

*Vigan Mensah[1], Kay I. Ohshima[1] (1.Institute of Low Temperature Science)

Data-driven improvement of coarse-resolution QG models

*Evgenii Ryzhov[1], Berloff Pavel[1], Kondrashov Dmitri[2], Agarwal Niraj[1]

1. Imperial College London, 2. UCLA

Geophysical turbulence remains a serious theoretical challenge, and its parameterizations are needed for practical modelling purposes. In this work we focus on oceanic mesoscale eddies, which can be viewed as 'oceanic weather'; for the foreseeable future, their parameterizations will remain indispensible for climate prediction models and other applications. The classical parameterization approach for this class of motions is via turbulent eddy diffusion, but it has many limitations involved. The new and powerful research trend is to aim at stochastic parameterizations of various geophysical processes, including the mesoscale eddies, and our approach is within this category. The stochasticity means that one makes use of random processes with prescribed correlations, which can be either inferred from the first principles or treated as data-driven. The latter is the main novelty of our approach, as it is data-driven in the sense that we aim to emulate the mesoscale eddies statistically and constrain them with all the available and relevant data. This approach takes advantage of not only rapidly growing amount of the real observations, but also of the available machine-learning technologies. Within the data-driven approach for improving coarse-resolution ocean models, we engaged in systematic analyses of the underlying dynamical interactions and the roles played by the smaller scales, which are to be parameterized. We considered an intermediate-complexity, classical, eddy-resolving, double-gyre ocean circulation model as the benchmark, and used its coarse-resolution equivalent as the test ground for a novel, data-driven eddy parameterization framework. The unresolved scales in the coarse-resolution model are associated with fast and small-scale motions (eddies) predicted by and extracted from the eddy-resolving benchmark solution, viewed as the high-resolution truth. First, the eddies are filtered out and characterized by standard statistical analyses. Second, as the essential step towards the eddy parameterization, the inferred spatio-temporal history of the eddy fields is nonlinearly coupled with the self-sustained coarse-resolution dynamics --- this results in significantly improved circulation solution.
However, this solution still lacks some important large-scale characteristics. We argued that using additional information (related to the large scales) from the benchmark reference solution can mitigate the discrepancies and further improve the coarse-resolution solution. Along this line we demonstrated that spatial resolution of the eddy fields is important and should be consistent with the spatial resolution of the non-eddying model, as affects the essential nonlinearities of the eddy/large-scale interactions. Our final goal is to investigate whether data-driven, statistically emulated eddy fields, rather than those statistically extracted from the eddy-resolving solutions, can be nonlinearly coupled to the coarse-gridded dynamics, as a successful eddy parameterization. In this talk we discuss challenges and caveats along this route and provide a research perspective.

Keywords: Oceanic Eddies, Eddy Forcing, Eddy Parameterisation

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Modified View of Barotropic Energy Conversion and its Application to the Kuroshio extension region

*Takuro Matsuta[1], Yukio Masumoto[1]

1. Graduate School of Science, The University of Tokyo

The Lorentz diagram is one of the simplest methods to estimate eddy-mean flow interactions. The 6-box Lorentz diagram is considered to deal with non-local interactions. However, the modified one include "the interaction energy flux", whose physical interpretation is vague. In this presentation, the interaction energy flux is shown to be the energy transfer through eddy-mean flow interactions. Moreover, we apply the modified diagram to the Kuroshio extension region to analyze the role of eddy-mean flow interactions. The interaction energy flux indicates that eddy-mean flow interactions transport the total kinetic energy from upstream to downstream and converted to the mean flow energy corresponding to the energy conversion rate. This result shows eddy-mean flow interactions deaccelerate(accelerate) the Kuroshio Extension jet in the upstream(downstream) region.

Keywords: The Lorentz diagram, eddy-mean flow interactions, The Kuroshio extension

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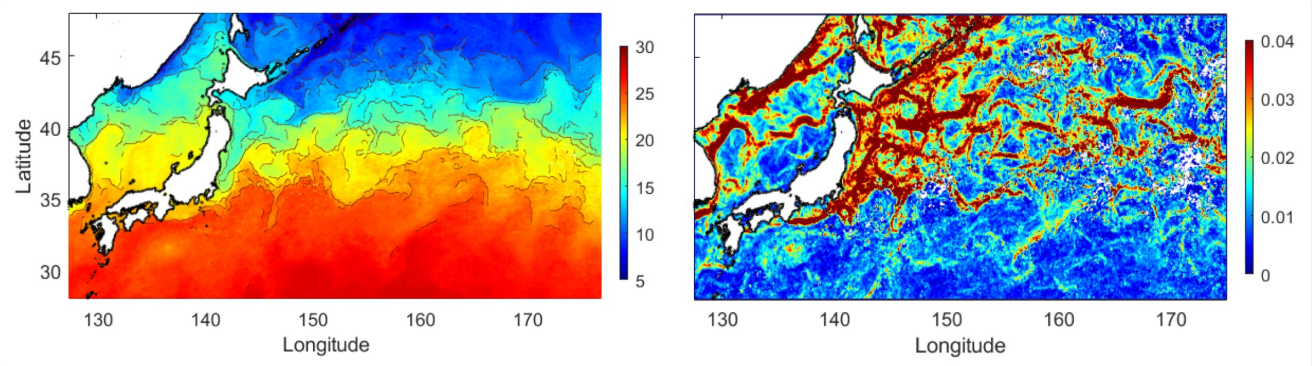
Distribution and interaction of fronts and eddies in the Kuroshio Extension

*YUNTAO WANG[1], Rui Tang[1]

1. Second Institute of Oceanography Ministry of Natural Resources

Fronts and eddies account for a large portion of mesoscale dynamics in the ocean. Front characters boundary among different water masses, while eddy can maintain a water mass inside its body. The relationship between front and eddy is an interesting scientific question require further investigation. The Kuroshio Extension region is characterized by strong mesoscale energy, which is used to conduct the study investigation the interaction among major mesoscale dynamics. In this study, sea surface temperature and sea level anomaly are used to detect front and eddy, respectively. A 15-year dataset from 2003 to 2018 is applied. The frontal activities are generally higher in the north, on the contrary, the number of mesoscale eddies is decreasing to the north. A prominent seasonal variability is identified for fronts that highest (lowest) frontal activities are identified during spring (summer). On the contrary, the eddy activities are predominately persistent all year round. Daily distribution of front and eddy are analyzed that there is less fronts being found within the perimeter of eddies. Consistently, the frontal filaments within each eddy are composed to generate a total frontal probability (FP) inside eddies. The FP within eddies are lower than outside, indicating the eddies are not favorable for the generation of fronts. The current study offers a first investigate for quantifying the relationship between front and eddy. And both eddies and fronts are unfavorable for generating the other class of dynamics.

Keywords: Front, Eddy, Seasonal Cycle, Correlation



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Meridional heat transport in the Japan/East Sea from 1990 to 2010

*Dmitry Stepanov[1]

1. Pacific Oceanological Institute, Far Eastern Branch, Russian Academy of Sciences

By using eddy-resolving ocean circulation model outputs, the meridional heat fluxes in the upper 300m layer, induced by the basin-scale circulation and mesoscale dynamics, are studied in the Japan/East Sea (JES) from 1990 to 2010. The estimation of the long-term mean meridional heat flux induced by the basin-scale circulation (MHF) showed that MHF was positive (northward) in the JES. In the southern JES, MHF is higher than that in the northern parts of the JES. The estimation of the long-term mean meridional heat flux induced by the mesoscale dynamics (MEHF) showed that the MEHF is positive over the JES and reaches maximal values at the separation latitude of the East Korea Warm Current. There are eddy-induced heat fluxes across the Subpolar Front along the western and eastern boundaries of the JES. This study has established that the eddy-induced heat transport is associated with the basin-scale currents in the JES. Analysis of the eddy kinetic energy budget showed that the baroclinic instability mechanism predominates over the barotropic instability mechanism to the mesoscale dynamics generation. At the same time, the barotropic instability promotes the mesoscale dynamics generation. The comparison of the MHF and MEHF has shown that the former exceeds the letter. At the same time, the MHF variances and MEHF variations are comparable, which points out the importance of the MEHF as a mechanism of the heat content variations in the JES. This work was supported by the Russian Scientific Foundation, project no. 19-17-00006.

Keywords: eddy-resolving numerical simulations, Japan/East Sea, mesoscale eddies, meridional eddy heat flux, baroclinic and barotropic instability

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Changes of Oyashio water properties due to multi-decadal and 18.6-year period variabilities

*Vigan Mensah[1], Kay I. Ohshima[1]

1. Institute of Low Temperature Science

Time series and bi-monthly climatologies of hydrographic properties (temperature, salinity, dissolved oxygen) in the Okhotsk Sea and the North Pacific are used to study the impact of long-term climate change and 18.6-year tidal cycle on the Oyashio water (OYW). Changes in the Okhotsk Sea Intermediate Water (OSIW) properties have the largest influence on the Oyashio water at densities greater than 26.8 σ_θ, whereas variability of the Western Subarctic Water (WSAW) transported by the East Kamchakta Current mainly affects OYW characteristics for densities less than 26.7 σ_θ.
The long-term trend is characterized by an increase of the OYW temperature (salinity) at all seasons and all sigma layers, which is due to the combined effect of the warming of OSIW and WSAW, and a reduced outflow of OSIW into the North Pacific Ocean (smaller mixing ratio). The long-term decrease of mixing ratio of OSIW is prominent in winter. During the high tidal period of the18.6-year cycle, the properties have opposite tendency to those of the long-term change, i.e. a significant decrease in temperature and salinity, and increase in dissolved oxygen. These changes are likely caused by the increase of the outflow of OSIW into the North Pacific Ocean, rather than due to changes in the OSIW properties, and are also prominent in winter. We further discuss the causes for the changes in properties and mixing ratio of the WSAW and OSIW for these two time scales.

Keywords: 18.6 year tide, Decadal variability, Dynamics, Sea of Okhotsk, NPIW

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS22] Physical, chemical and biological processes and variability in the Indian Ocean

convener:Yukio Masumoto(Graduate School of Science, The University of Tokyo), Hiroaki Saito(Atmosphere and Ocean Research Institute, The University of Tokyo)

The Indian Ocean has been recognized to play important roles in regional and global climate systems, material circulations, ecosystems, and their variability, with linked biophysical phenomena that span a wide range of spatial and temporal scales. These phenomena include, for example, diurnal cycling, intraseasonal disturbances, seasonal variations, Indian Ocean dipole events, and decadal to multi-decadal variations as well as secular trends under the global warming stress. In situ and remotely-sensed physical and biogeochemical observations using the Indian Ocean Observing System (IndOOS) and other means are now accumulating high quality data, and research efforts with numerical models and analyses of comprehensive datasets are also being conducted under International Indian Ocean Expedition-2 (IIOE-2) and the Eastern/Western Indian Ocean Upwelling Research Initiative (EIOURI/WIOURI). To advance our understanding of such Indian Ocean phenomena, disciplinary studies are essential, as are interdisciplinary investigations that elucidate the linkages between the physical and biogeochemical/ecological researches realms.
The objective of this session is to share our knowledge on, and to advance our understanding of, all facets of Indian Ocean variability. We invite papers on physical, biogeochemical and ecological aspects of the variability, as well as those related to atmosphere-ocean interactions, over the full spectrum of temporal and spatial scales. Discussions to facilitate mutual interactions among different research communities would also be expected and encouraged.

[AOS22-01] Assessing Organic Carbon on Coastal and Continental Shelf of Indonesia Waters Facing Indian Ocean

*Aan Johan Wahyudi[1], Edwards Taufiqurrahman[1], Afdal Afdal[1], Hanif Budi Prayitno[1], Hanny Meirinawati[1] (1.Research Center for Oceanography Indonesian Institute of Sciences)

[AOS22-02] Turbulent mixing in the Indonesian throughflow exit passages, the Lesser Sunda waters

*Adi Purwandana[1], Yannis - Cuypers[2], Pascale - Bouruet-Aubertot[2], Mochamad Furqon - Azis Ismail[1], Dewi - Surinati[1], Ahmad - Bayhaqi[1] (1.Research Center for Oceanography - Indonesian Institute of Sciences, 2.Laboratoire d'Océanographie et de Climatologie par Expérimentation et Approche Numérique (LOCEAN) - Sorbonne Université)

[AOS22-03] Characterisation of mesoscale eddies along the eastern boundary current off the southern coast of Java

*Mochamad Furqon Azis Ismail[1], Adi Purwandana[1], Asep Sandra Budiman[1], Dewi Surinati[1], Ahmad Bayhaqi[1] (1.Research Centre for Oceanography - Indonesian Institute of Sciences)

[AOS22-04] Estimation of phytoplankton size classes response to the tropical cyclone Ockhi over the Arabian Sea

*Rebekah Shunmugapandi[1], Shirishkumar Gedam[2], Arun B Inamdar[2] (1.PhD Student,Centre of Studies in Resources Engineering, Indian Institute of Technology Bombay, India, 2.Professor,Centre of Studies in Resources Engineering, Indian Institute of Technology Bombay, India)

[AOS22-05] Influences of the Interdecadal Pacific Oscillation on the locally amplified Ningaloo Niño

Natsumi Tanuma[1], *Tomoki Tozuka[1] (1.Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo)

[AOS22-06] The Mode Water formation in the South Indian Ocean

*Takuro Matsuta[1], Yukio Masumoto[1] (1.Graduate School of Science, The University of Tokyo)

Assessing Organic Carbon on Coastal and Continental Shelf of Indonesia Waters Facing Indian Ocean

*Aan Johan Wahyudi[1], Edwards Taufiqurrahman[1], Afdal Afdal[1], Hanif Budi Prayitno[1], Hanny Meirinawati[1]

1. Research Center for Oceanography Indonesian Institute of Sciences

Indonesia as part of the maritime continent affected by ocean dynamics and global climate. Following to the physical features, the marine ecosystem in Indonesia shows significant responses to the changes in ocean diurnal cycles, climatic variability, global warming, climate change, and ocean acidification. A proxy that reliable enough to detect responses or changes is the carbon biogeochemical cycles.
Spatio-temporal variability on carbon biogeochemical cycles can be observed and studied within coastal and continental shelf locus. Several approaches can be used, i.e. carbon profiling of particulate matters (suspended particulate matter/SPM or particulate organic matter/POM) and observation of carbon stock and sequestration variability by marine vegetation. Long term monitoring data with mesoscale spatial data will be useful to obtain comprehensive information on the spatio-temporal variability of carbon transport and flux that affected by maritime continent climatic variability. Here we present the result of the recent studies within Indonesia's territorial ocean as well as within the Exclusive Economic Zone (EEZ) facing the Indian Ocean. The studies including POM or SPM profiling, carbon stock of seagrass ecosystem, and potential research themes related to carbon flux in the Sumatra-Java upwelling system.

Keywords: carbon flux, coastal upwelling, continental shelf, coastal ecosystem, biogeochemistry, carbon cycle

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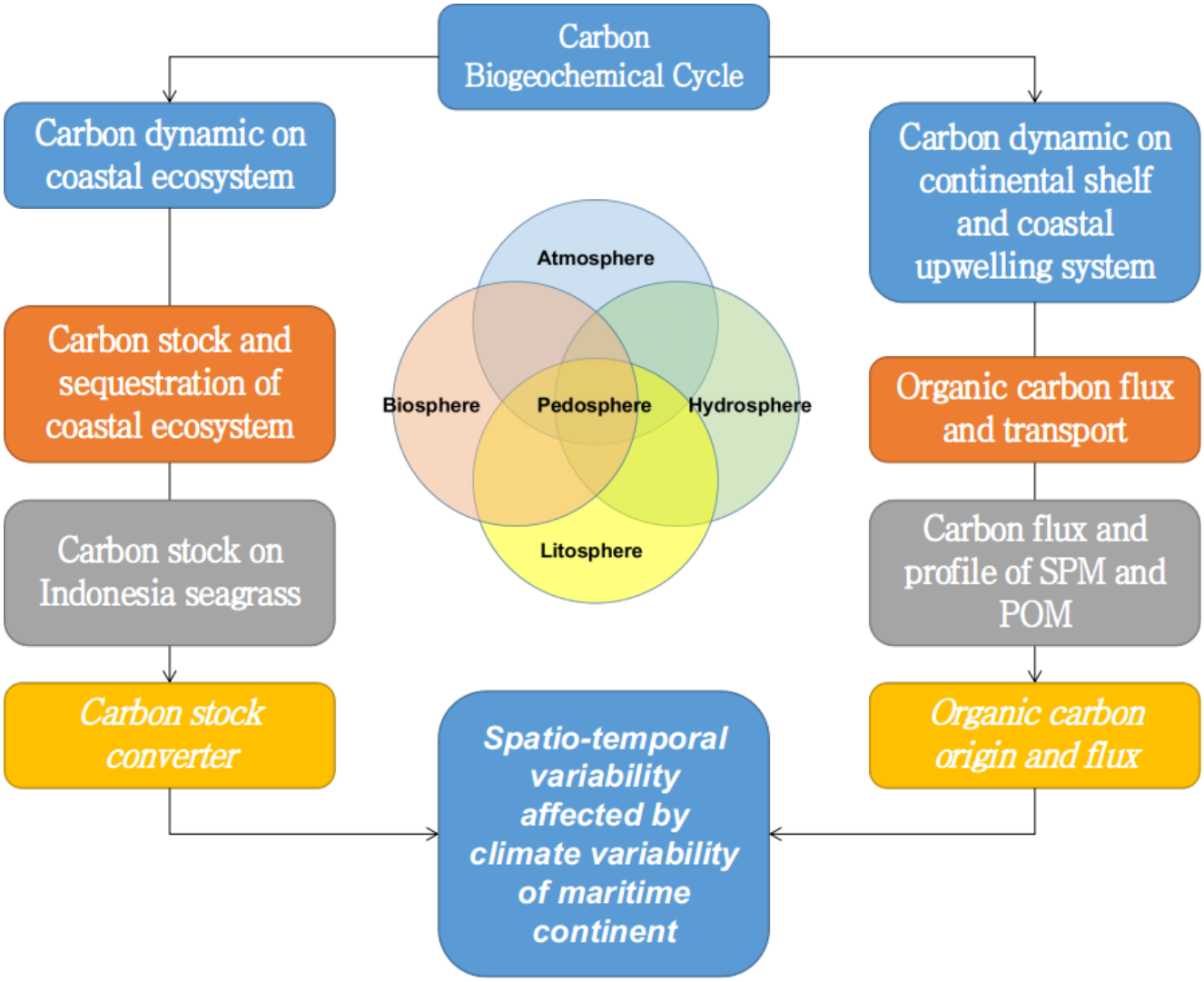

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Turbulent mixing in the Indonesian throughflow exit passages, the Lesser Sunda waters

*Adi Purwandana[1], Yannis - Cuypers[2], Pascale - Bouruet-Aubertot[2], Mochamad Furqon - Azis Ismail[1], Dewi - Surinati[1], Ahmad - Bayhaqi[1]

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Turbulent kinetic energy dissipation rates in the Indonesian throughflow (ITF) exit passages to the Indian Ocean, the Lesser Sunda waters, are inferred from archived CTD measurements and recent high-resolution time series data sets. Dissipation rates from archived data sets are inferred using an improved Thorpe scale method validated against microstructure measurements. Elevated dissipation rates ~[10^{-6}-10^{-7}] m^2s^{-3} were observed in the straits, where internal tides are generated. Tidal variations seemingly influence the dissipation rates and diffusivities as has been suggested from the yoyo profiling data sets. The spatial pattern of dissipation rates inferred from the high-resolution 3D hydrodynamics model output of Nagai et al (2015) shows a general agreement with the observations in the location of the mixing hot spots and suggests that the M_2 internal tide is the dominant factor driving the turbulent kinetic dissipation rates in this region. The bias in the model is possible due to the lack of representation of the ITF and mesoscale circulation in the model. We also investigate short temporal variability in one of the main passages in the region, the Lombok Strait, and found the turbulent kinetic energy dissipation rate inferred using Thorpe and Ellison scales of the order ~[10^{-6}-10^{-7}] $m^2\,s^{-3}$, with enhanced values in the thermocline layer, possibly driven by shear instabilities. From this study, we underlined that the use of Ellison scale is a promising alternative for indirectly estimating the dissipation rate from high-resolution time series data sets.

Keywords: Indonesian throughflow (ITF), dissipation rates, Thorpe scale, Ellison scale, vertical mixing

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Characterisation of mesoscale eddies along the eastern boundary current off the southern coast of Java

*Mochamad Furqon Azis Ismail[1], Adi Purwandana[1], Asep Sandra Budiman[1], Dewi Surinati[1], Ahmad Bayhaqi[1]

1. Research Centre for Oceanography - Indonesian Institute of Sciences

Mesoscale eddies are omnipresent in the ocean and have been observed in boundary current regions. These eddies contribute significantly to the export of high nutrients and elevated chlorophyll-a concentration beyond the coastal upwelling areas, as well as advecting plankton, fish larvae, and other ocean properties. Here, we documented for the first time the mean properties and spatiotemporal variability of mesoscale eddies using a suite of satellite observations for the Eastern Boundary Current (EBC) of the Indian Ocean off the coast of Java, one of the least studied regions of the EBC system. The mesoscale eddies are identified and tracked from generation to decay using an automated eddy detection and tracking algorithm that combines both geometric and dynamical properties of eddies. We find a total of 613 mesoscale eddies with lifetime > 7days for the period 2011 to 2019. This is an average of about 68 individual eddies per year. A total of 331 (54 %) cyclonic eddies and 282 (46 %) anticyclonic eddies are tracked in this region. These mesoscale eddies potentially play significant cross-shelf processes off the southern coast of Java.

Keywords: Eastern Boundary Current, Mesoscale eddies, cross-shelf processes, Indian Ocean

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Estimation of phytoplankton size classes response to the tropical cyclone Ockhi over the Arabian Sea

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The influence of extreme events like cyclone profoundly interferes the phytoplankton community distribution over the ocean surface. With the intention of investigating the above-mentioned case, this study aims to perceive the response and dynamics of phytoplankton communities in the Arabian Sea (AS) to the tropical cyclone (TC), the cyclonic event Ockhi (29 November- 6 December 2017). To start with, MODIS-Aqua satellite-derived chlorophyll-a concentration (chl-a) data were utilized as the primary data to retrieve phytoplankton size classes (PSCs) (i.e micro, nano and pico phytoplankton) using the abundance-based approach. The inconsistencies in the data due to overcast were resolved by reconstructing the chl-a data using an empirical orthogonal function: DINEOF method. Besides, the corresponding sea surface temperature, sea surface salinity and wind speed data were used to estimate the response of phytoplankton communities during the TC. The results indicate that microphytoplankton were found to be dominant in the eastern AS during the post-cyclone, particularly on the passage of Ockhi cyclone track. The above scenario denotes an unusual incident because the eastern lower latitudes of AS are oligotrophic (less light and nutrient condition) in nature which is usually dominated by picophytoplankton. Therefore, on comparing with the wind, surface salinity and sea surface temperature, it is found that the freshwater discharges (high in nutrients) triggered the microphytoplankton production relative to the other size classes that led a short term community shift at the region of cyclone passage. From the results, it is witnessed that the Ockhi cyclone invoked a transient suitable condition for microphytoplankton to proliferate in the south-eastern part of the AS. The overall study sensitized relevant insight into the short-term community shift of the PSCs due to the effects of tropical cyclones.

Keywords: Ockhi cyclone, Phytoplankton size classes, DINEOF, Arabian Sea

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Influences of the Interdecadal Pacific Oscillation on the locally amplified Ningaloo Niño

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Ningaloo Niño is associated with warm sea surface temperature (SST) anomalies off the west coast of Australia. Although recent increase in the occurrence of Ningaloo Niño is attributed to the swing to the negative phase of the Interdecadal Pacific Oscillation (IPO), its mechanism is not completely understood. In particular, the role of local air-sea interaction that has been shown to play an important role in the development of the Ningaloo Niño/Niña was not examined. Using observation/reanalysis data and outputs from a coupled general circulation model (CGCM), influences of the IPO on the frequency of the Ningaloo Niño/Niña and their mechanisms are investigated in this study. Furthermore, outputs from a regional ocean model and an atmospheric general circulation model (AGCM) are analyzed to examine their detailed mechanisms.

It is found that the Ningaloo Niño occurs more frequently and the ratio of the locally amplified events increases during the negative IPO in both observation and the coupled model. The increased occurrence of the locally amplified Ningaloo Niño during the negative IPO is due to positive interdecadal SST anomalies to the northwest of Australia that promote deep atmospheric convection and anomalous cyclone off the west coast of Australia through a Matsuno-Gill response. Based on a mixed layer heat budget analysis using outputs from a regional ocean model, it is shown that an enhanced warming of anomalously thin mixed layer by the shortwave radiation contributes dominantly to the interdecadal SST anomalies. The negative mixed layer depth anomalies are suggested to be generated by anomalously weak winds associated with the negative IPO. In addition, the importance of SST anomalies over the southern Indian Ocean is confirmed by a sensitivity experiment of an AGCM.

Keywords: coastal niño, interdecadal variation, Indian Ocean

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The Mode Water formation in the South Indian Ocean

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The low PV waters can induce Counter Currents through the baroclinic adjustment to Mode water intrusion in the subsurface. Mode Waters push up the upper thermocline and result in the density front. Since Counter Currents anchor SST fronts, they have great impacts on the air-sea interactions. Therefore, the spatial distribution of low PV pool is essential to understand the climate systems in the mid-lattidude. In this presentation, we show the 3D distributions of Mode Waters in the South Indian Ocean and its T-S properties using Argo data. Also, the formation sites of Mode Waters are investigated from virtual particle tracking.

Keywords: Counter Current, Mode Water, subduction, eddy

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS23] Atlantic climate variability, and its global impacts and predictability

convener:Ingo Richter(JAMSTEC Japan Agency for Marine-Earth Science and Technology), Hiroki Tokinaga(Research Institute for Applied Mechanics, Kyushu University), Andrea Taschetto(University of New South Wales), Noel S Keenlyside(Geophysical Institute Bergen)

The Atlantic Ocean is subject to pronounced climate variations that occur on a wide range of time scales, including interannual variability in the equatorial and subtropical regions, and Atlantic multi-decadal variability (AMV), which has been linked with the Atlantic meridional overturning circulation (AMOC). These are connected to other climate variations across the globe. The AMV, e.g., has long been known to have global impacts, such as changes in the Indian, Asian and South American summer monsoons, and changes in the Pacific associated with the "global hiatus". Interannual variability in the equatorial and subtropical Atlantic has also been shown to influence global climate, including over Asia, while the freshening of the North Atlantic by melting of the Greenland ice cap is expected to influence all ocean basins via atmospheric bridges. Likewise, misrepresentation of the Atlantic can have global ramifications in climate models. Misrepresentation of the AMOC, e.g., has been associated with model biases in the entire Northern Hemisphere.

This session seeks observational, modeling, and theoretical studies on the mechanisms that determine the Atlantic mean climate and variability, as well as the predictability and global impacts of such variability. We also seek studies that evaluate climate model performance in the region. Topics include atmosphere-ocean-cloud interactions in the tropical Atlantic; two-way interaction with other ocean basins; relationships between tropical and mid/high latitude variability; air-sea interaction along the Gulf Stream and its influence on cyclones and storm track evolution; variability in the Benguela upwelling region; influence of Agulhas leakage on the South Atlantic; coupled climate model biases in the region and their impacts; AMOC and long-term climate change.

[AOS23-01] **Revisiting Mechanisms of Atlantic Niño Phase Locking**

*Lin Chen[1], Tim Li[2,1], Ran Wang[1] (1.Nanjing University of Information Science and Technology, 210044, Nanjing, China, 2.University of Hawaii, Honolulu, HI, 96822, USA)

[AOS23-02] Seasonal forecasting of the Atlantic Niño

★Invited Papers

*Chloe Prodhomme[1,2], Javier García-Serrano[1,2], Eleftheria Exarchou[2], Aurore Voldoire[3], Noel Keenlyside[4] (1.Group of Meteorology, Universitat de Barcelona (UB), Barcelona, Spain, 2.Barcelona Supercomputing Center (BSC), Barcelona, Spain, 3.Centre National de Recherches Météorologiques (CNRM), Météo-France/CNRS UMR3589, Toulouse, France, 4.Bergen University, Bergen, Norway)

[AOS23-03] Atlantic Niño-Pacific connection and its implication for prediction under greenhouse warming

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[AOS23-04] **Walker Circulation strengthening due to an Atlantic Meridional Overturning Circulation collapse.**

*Luis Bryam Orihuela Pinto[1], Andrea Taschetto[1], Matthew England[1] (1.University of New South Wales)

[AOS23-05] Mechanisms of Atlantic Multidecadal Variability

*Rong Zhang[1] (1.NOAA Geophysical Fluid Dynamics Laboratory)

[AOS23-06] Bias of jet in the North Atlantic and its relation to SST in the PRIMAVERA air-sea coupled historical runs

*Fumiaki Ogawa[1], Noel S Keenlyside[1,2], Panos Athanasiadis[3], Reinhard Schiemann[4] (1.University of Bergen and Bjerknes Centre for Climate Research, Bergen, Norway, 2.NERSC, Norway, Bergen, 3.CMCC, Bologna, Italy, 4.University of Reading, Reading, UK)

Revisiting Mechanisms of Atlantic Niño Phase Locking

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Atlantic Niño is the most significant interannual variability in the equatorial Atlantic, influencing the precipitation of Atlantic coastal countries and the global climate. Based on diagnosing observational datasets and conducting numerical experiments, we reinvestigated the mechanisms for the Atlantic Niño phase locking behavior (i.e., interannual SST variability maximum in boreal summer). Our results show that the ocean dynamic processes and atmospheric thermodynamics processes play pivotal role in controlling the seasonal phase-locking behavior of Atlantic Niño. The transition of the aforementioned dynamic and thermodynamic processes is further regulated by the seasonal cycle of background mean state.

Keywords: Atlantic Nino, Dynamic and thermodynamic processes, Background Annual Cycle

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Seasonal forecasting of the Atlantic Niño

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The Atlantic Niño is the leading mode of interannual variability in the Tropical Atlantic, which has impacts not only on the African monsoon but also in remote regions. In the present study, we investigate the predictability of the Atlantic Niño's mature phase (June-July) at seasonal time-scale, as well as its conditioning. We analyze a large set of state-of-the art forecasts systems from the North American Multi-Model Ensemble (NMME) and Copernicus Climate Change Service (C3S) multi-models. The prediction skill of the ATL3 index has considerably improved as compared to previous forecast quality assessments, with Anomaly Correlation Coefficient (ACC) reaching up to 0.8 for the May start date. Most of the models achieve skillful prediction of the Atlantic Niño from the May start-date, and some outperform persistence. For the start-dates of April, March and February, most of the models perform better than persistence and some achieve significant correlation skill for ATL3. While there has been improvement in forecasting capability, overall the warm SST bias and associated drift remain large in the equatorial Atlantic in most of the systems. Our results suggests that the skill in predicting the Atlantic Niño in summer is weakly related to the local SST drift during the first month of the forecast, but not to the magnitude of the SST bias during the peak. In addition, we find evidence that the skill in the equatorial Atlantic is related to the ability of the models to properly represent the large-scale atmospheric circulation pattern in the South Atlantic (i.e. St. Helena high).

Keywords: Atlantic Niño, Seasonal forecasting, biases

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Atlantic Niño-Pacific connection and its implication for prediction under greenhouse warming

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Atlantic variability interacts with variability in the Pacific. For example, sea surface temperature (SST) variability in the equatorial eastern Atlantic, which is referred to as an Atlantic Niño (Niña) at its warm (cold) phase and peaks in boreal summer, dominates the interannual variability in the equatorial Atlantic. By strengthening of the Walker circulation, an Atlantic Niño favors a Pacific La Niña, which matures in boreal winter, providing a precursory memory for El Niño-Southern Oscillation (ENSO) predictability. How this Atlantic impact responds to greenhouse warming is unclear. Here, we show that greenhouse warming leads to a weakened influence from the Atlantic Niño/Niña on the Pacific ENSO. In response to anomalous equatorial Atlantic heating, ascending over the equatorial Atlantic is weaker due to an increased tropospheric stability in the mean climate, resulting in a weaker impact on the Pacific Ocean. Thus, as greenhouse warming continues, Pacific ENSO is projected to be less impacted by the Atlantic Niño/Niña and more challenging to predict.

Keywords: Atlantic Niño, El Niño Southern Oscillation, greenhouse warming

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Walker Circulation strengthening due to an Atlantic Meridional Overturning Circulation collapse.

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Changes in the Atlantic Meridional Overturning Circulation (AMOC) have been attributed as the driver of past abrupt climate changes, furthermore it is projected to slowdown in the future global warming scenario and it has the potential to shut down. Although a shutdown is not a very likely possibility, it is indeed a high impact one so, analysing the implications of this possible change is essential. In this study, we use a coupled climate model to simulate an AMOC shutdown and analyse its global effects with particular focus on a key area that is also a driver of the climate around the world: The Tropical Pacific. It is found that through a combination of pressure gradients, tropical basin teleconnections and a rearrangement of the Hadley cell and the Inter-Tropical Convergence Zone (ITCZ), the Walker Circulation in the Tropical Pacific gets intensified which could potentially counteract the weakening effect exerted on it by the greenhouse warming and have implications on the variability and characteristics of El Niño Southern Oscillation (ENSO).

Keywords: AMOC, Walker circulation, ITCZ

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Mechanisms of Atlantic Multidecadal Variability

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Atlantic Multidecadal Variability (AMV) has many important regional and global-scale climate impacts. Different mechanisms of AMV would have very different implications for future predictions of AMV-related climate impacts. Observational analyses reveal high coherence among subpolar North Atlantic sea surface temperature (SST), sea surface salinity (SSS), upper ocean heat and salt content, and the Atlantic Meridional Overturning Circulation (AMOC) fingerprint at low frequency. This key AMV feature cannot be explained as responses forced by atmospheric white noise, but are consistent with the ocean dynamics mechanism (e.g. low frequency AMOC variability). The correlation/regression between net surface heat flux and SST anomalies at low frequency have been identified as key indicators for the relative roles of oceanic vs. atmospheric forcing in SST anomalies, and they suggest that the oceanic forcing has a dominant role in the low frequency subpolar North Atlantic SST anomalies associated with AMV. The simulated linkages among AMOC, AMV, and associated climate impacts in CMIP5 models could be substantially hampered due to the underestimation of multidecadal AMOC variability. Some recent studies suggest that AMV is dominated by anthropogenic aerosols based on the similarity of the linearly detrended AMV index between observations and the externally forced response in some historical climate simulations. However, this similarity could be an artifact of linear detrending. Using the nonlinear detrending method with the signal associated with the global mean SST removed, the similarity disappears. This is because the simulated externally forced multidecadal SST signal is not unique to the Atlantic, but also appears in many other ocean basins and represents a global scale response to external forcings. On the other hand, the observed AMV is unique to the Atlantic and remains pronounced when the signal associated with the global mean SST is removed. Multivariate Empirical Orthogonal Function analysis has been applied to obtain a Multivariate AMV Index and reflect the observed multivariate nature of AMV. The simulated externally forced multivariate AMV in CMIP5 models disagrees strongly with that observed.

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Bias of jet in the North Atlantic and its relation to SST in the PRIMAVERA air-sea coupled historical runs

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There are evidences from previous numerical simulation studies using atmospheric general circulation models that capturing fine structures of midlatitude SST fronts are important to simulate the storm track and eddy driven jets with realistic intensity and latitude. Therefore, representation of midlatitude SST fronts appears important to reproduce the realistic stormtracks and jets also in air-sea coupled climate models such as the CMIP5 models.

However, the resolutions of CMIP5 models are not necessarily high enough to capture the fine SST structure, and the models are known to have biases in both jet stream and storm track in the North Atlantic. Climatological mean jet tends to be too zonally oriented, while storm track intensity is too weak compared to the observation. Interesting fact is that the CMIP5 models with relatively high resolution tend to better capture the zonal tilt of the North Atlantic jet and intensity of storm track in winter than the lower resolution ones. This implies a potential that using state-of-the-art climate models of higher resolution may reduce the atmospheric circulation biases through a better representation of midlatitude SST fronts.

In this study, we focus on the circulation bias of stormtrack and jet in the PRIMAVERA climate models which follows the CMIP6 HighResMIP protocol. The horizontal resolution in the models is 1 degree or finer, which is sufficient to represent the SST gradients relevant to the stormtrack and jets. We find that the jet and SST front in winter show consistent bias to be oriented too zonal in the PRIMAVERA models. Storm track activity is realistically strong but shifted equatorward and the associated bias of the westerly momentum-flux convergence is consistent with the bias of the jet. Therefore, the known climatological mean bias of too zonal jet in CMIP5 appears not so much explained by the horizontal resolution of climate models. Nevertheless, the observed low-frequency variability which shows a regime-like behavior of the North Atlantic jet is fairly well simulated in the PRIMAVERA models, where the probability of each regime’s occurrence is influenced by the strength of SST front in the PRIMAVERA models. As a superposition of the regimes, the SST front may still show a modest but significant contribution to better reproduce the observed climatological mean state.

Keywords: High resolution models, PRIMAVERA, circulation bias, SST front, Gulf Stream

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS24] Exploring new frontiers of oceanic mixing research in the next decade

convener:Toshiyuki Hibiya(Department of Earth and Planetary Science, Graduate School of Science, University of Tokyo), Ichiro Yasuda(Atmosphere and Ocean Research Institute, The University of Tokyo), Lakshmi Kantha(Aerospace Engineering Sciences, University of Colorado, Boulder, Colorado, USA)

Mixing plays many important roles in the global ocean through a variety of different processes. In the upper ocean, mixing affects the sea surface temperature and hence air-sea interactions, which in turn influence the state of the atmosphere on a variety of time scales. Mixing in the deep ocean maintains the abyssal stratification of the world's oceans and influences the global overturning circulation, which in turn affects long-term climate. Ocean mixing modulates the transport and dispersal of dissolved and suspended materials, including pollutants, plankton and fish larvae. It also plays an important role in the oceanic food chain in so far as primary productivity, which occurs predominantly in the euphotic zone, is affected by nutrient uptake from the deep associated with ocean mixing.

 Microstructure profilers are being increasingly and routinely used to measure turbulence in the oceans, including the deep. Mixing models with more inclusive physics are being developed. Increasing computer power is making it possible to include sophisticated mixing models in global circulation models. As such, it is time to take stock of where we stand at present and explore the frontiers of mixing research over the next decade to advance our knowledge and utilize it for societal benefit.

 This session encompasses a wide variety of aspects of mixing within the water column from the surface to the seabed, as well as the impact of mixing on key physical, biological, and chemical processes, such as those mentioned above, with special attention to new findings obtained through improvements in oceanographic instrumentation, mixing models and the use of supercomputers. Observational, theoretical, experimental, and numerical approaches are all welcome. In this session, we particularly encourage discussion that can confirm how far our understanding of related topics has advanced and help define the new frontiers of ocean mixing research to be tackled in the next decade.

[AOS24-01] Global modeling of internal tides and the internal gravity wave continuum

*Brian K Arbic[1] (1.University of Michigan Ann Arbor)

[AOS24-02] Direct numerical simulation of stratified turbulence generated by local instability of internal gravity waves

*Yohei Onuki[1], Sylvain Joubaud[2,3], Thierry Dauxois[2] (1.Center for Oceanic and Atmospheric Research, Research Institute for Applied Mechanics, Kyushu University, Japan, 2.Universite de Lyon, ENS de Lyon, Universite Claude Bernard, CNRS, Laboratoire de Physique, France, 3.Institut Universitaire de France, France)

[AOS24-03] **Development of efficient and autonomous microstructure measurement system using fast-response thermistors attached to CTD, glider and deep-profiling float, to elucidate vertical distribution**

*Ichiro Yasuda[1], Keunjong Lee[1], Maki Nagasawa[1], Shuo Zhai[1], Yusuke Sasaki[1], Daigo Yanagimoto[1], Shinzo Fujio[1], Mamoru Tanaka[1], Yasutaka Goto[2], Toshiya Nakano[2], Daisuke Sasano[2], Takahiro Tanaka[4], Shinya Kouketsu[3] (1.Atmosphere and Ocean Research Institute, The University of Tokyo, 2.Japan Meteorological Agency Japan, 3.Japan Agency of Marine-Earth Science and Technology, 4.Tohoku National Fisheries Research Institute, Fisheries Research and Education Agency)

[AOS24-04] Ocean State Estimation by Using Ocean Mixing Observations

*Shuhei Masuda[1], Satoshi Osafune[1] (1.Japan Agency for Marine-Earth Science and Technology)

[AOS24-05] **A new parameterization of tidal mixing enhanced over rough seafloor topography**

*Toshiyuki Hibiya[1] (1.Department of Earth and Planetary Science, Graduate School of Science, University of Tokyo)

[AOS24-06] Virtual tracer analysis of the Pacific meridional overturning circulation

*Takao Kawasaki[1], Hiroyasu Hasumi[1] (1.Atmosphere and Ocean Research Insitutute, the University of Tokyo)

Global modeling of internal tides and the internal gravity wave continuum

*Brian K Arbic[1]

1. University of Michigan Ann Arbor

I will describe work that I have done with many collaborators, over the last decade, on global modeling of internal tides and the internal gravity wave continuum. I will show results from the US Navy HYCOM operational model, and simulations of the MITgcm run on NASA supercomputers, and discuss related efforts at other ocean modeling centers in the US and Europe. Starting with the Navy model, several groups have implemented simultaneous atmospheric and tidal forcing in high-resolution (eddying) global ocean models. This work in turn builds upon earlier work in basin- and global-scale modeling of internal tides, done with tidal forcing only, by Niwa and Hibiya, Furiuchi et al., and others including the author. High-resolution simulations with simultaneous tidal and atmospheric forcing carry mesoscale eddies, near-inertial motions, and internal tides all at once. If the horizontal and vertical resolutions are sufficiently high, they also carry a partial internal gravity wave continuum, or Garrett-Munk spectrum. I will discuss several aspects of these simulations, including comparisons to in-situ and remotely sensed observations, the utility of such simulations to planning for the Surface Water Ocean Topography (SWOT) wide-swath altimeter mission, and first results with regional simulations, run at even higher resolutions, with lateral boundary conditions taken from the global models. I believe that these simulations have opened up a new frontier of ocean models that can be more meaningfully compared with oceanic observations, and used for improved regional ocean modeling studies, in regards to a more fully developed spectrum of high-frequency internal wave motions. As noted, such simulations are also very useful for planning future altimeter missions. As an example of our work, the attached figure displays the frequency spectrum in observations from moored McLane Profilers (MMPs), and in four different simulations of a regional MITgcm simulation in a 6 by 8 degree patch near Hawai'i. The "one-to-one" simulation has the same resolution as the parent global simulation. The "Smaller delta z" simulation has three times as many levels in the vertical direction, the "Smaller delta x" simulation has eight times as many gridpoints in each horizontal direction, and the "Smaller Both" simulation has finer grid spacings in both the horizontal and vertical directions. The latter simulation, with the highest resolutions, follows the expected frequency^-2 spectrum most closely, out to frequencies as high as N, the buoyancy frequency. This result shows that if regional models are forced at their boundaries by global models that carry the low-mode internal waves, and have very high resolutions--in this case, 250 m grid spacing in the horizontal and 300 vertical levels--they display an improved internal gravity wave spectrum.

Keywords: internal waves, tides, ocean modeling

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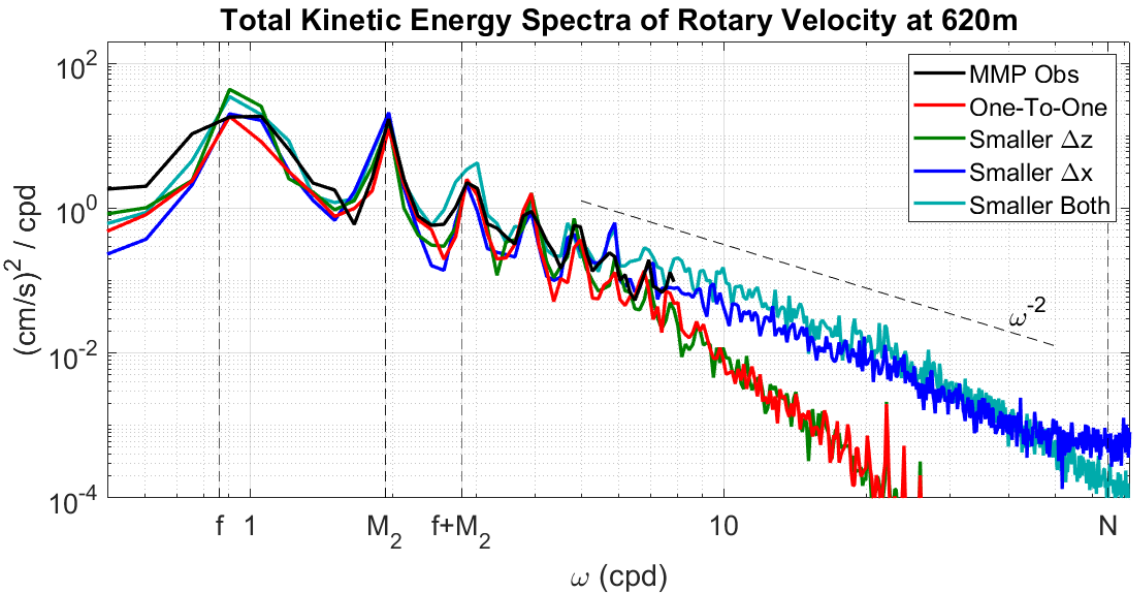

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Direct numerical simulation of stratified turbulence generated by local instability of internal gravity waves

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Turbulent mixing in the deep ocean is thought to be caused by the dissipation of internal gravity waves, but the mechanisms of wave breaking and how much it contributes to mixing remain open questions. In this study, we develop a new technique for direct numerical simulation of wave-driven turbulent mixing. Since the spatial scale of internal waves is typically much larger than the scales of turbulence, fully incorporating both the waves and turbulence in a model requires high computational cost, and thereby out of our scope. Alternatively, we cut out a small domain periodically distorted by an unresolved large-scale internal wave, and simulate the generation, evolution, and dissipation of turbulence within it. This method enables us to evaluate the conversion of both kinetic and potential energy from a wave to turbulence, unlike many previous studies that considered mixing caused by a vertically-sheared horizontal flow.

This time, we demonstrate a particular case, turbulence generation in a small-amplitude internal wave. Even though this wave does not cause any overturn or shear instabilities, a striped pattern of disturbance is exponentially amplified due to parametric instability. When the amplitude of this disturbance reaches a threshold level, secondary instability arises to produce much smaller-scale random fluctuations. Passing through these two stages, wave energy is transferred into turbulence energy and will be eventually dissipated. Different from the classical Kelvin-Helmholtz instability, a large part of the turbulent potential energy is supplied from the outer wave component and is directly used for mixing to raise the background potential energy. The resulting mixing efficiency is higher than the typical value in the ocean by several factors, a finding to be explored further in future studies.

Keywords: internal waves, turbulence, direct numerical simulation

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Development of efficient and autonomous microstructure measurement system using fast-response thermistors attached to CTD, glider and deep-profiling float, to elucidate vertical distribution

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A new efficient microstructure measurement with fast-response thermistors attached to CTD, underwater glider and deep float has been elaborated. The CTD-attached thermistor measurements were confirmed to be valid in the weak turbulent energy dissipation down to 10^{-11}W/kg by comparing with the one by free-fall instrument with the best accuracy, and revealed cross-Pacific top-bottom turbulence distribution. Vertical distribution of turbulent energy dissipationis found to be proportional withlocal squared buoyancy frequency N^2(representing density vertical gradient) and local internal tide energy generation and dissipation, indicating that energy dissipation of tide-induced turbulence occurs in the main thermocline. Thermistor measurements attached to gliders and deep floats were also confirmed to be useful to measure weak turbulence area as in the deep water as well as the water where double-diffusive convections work. These contribute to revising models of tide-induced three-dimensional distribution used in ocean/climate models, which will contribute to reproducing ocean meridional overturning circulation and oceanic heat/material circulation.

Keywords: Turbulence, observation

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Ocean State Estimation by Using Ocean Mixing Observations

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Ocean state estimation is a useful tool to reveal mechanisms of oceanic phenomena. Recently, turbulence observation data has been increasing by lots of effort of researchers. Here we synthesize pre-existing ocean data with newly-acquired turbulence data using state-of-art assimilation technique. Available observations of turbulence strength in the ocean, will be “blended” with temperature, salinity, sea surface height anomaly data applying dynamically self-consistent state estimation approach with 4D-VAR adjoint system. The control variables are mixing coefficients in addition to oceanic initial conditions and surface fluxes. We propose some new techniques and schemes to assimilate turbulence data. The obtained state estimation can better represent global bottom water warming.

Keywords: ocean, data assimilation

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A new parameterization of tidal mixing enhanced over rough seafloor topography

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It is believed that tidal interaction with rough seafloor topography can create mixing hotspots extending off the seafloor. Although there exist fine-scale parameterizations of tidal mixing enhanced over rough seafloor, they do not reflect the fact that the internal waves emanating from rough seafloor transform from internal tidal waves to internal lee waves as tide-seafloor interaction strengthens with $k_H U_0 / \omega$ exceeding unity where k_H is the dominant horizontal wavenumber of rough seafloor, U_0 is the amplitude of tidal flow, and ω is tidal frequency. Taking into account this fact, we formulate here the vertical decay scale of energy dissipation rates over rough seafloor by multiplying the theoretically obtained vertical group velocities of internal lee waves by the time scale of their nonlinear interaction with the background Garrett-Munk internal wave field. The resulting formulation explicitly shows that the vertical extent of mixing hotspots over rough seafloor becomes independent of k_H but proportional to U_0 squared, which agrees very well with the results of eikonal experiments and consistent with the available data from the Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean (DIMES).

Keywords: Parameterization, Energy dissipation rates , Vertical decay scale , Tidal flow , Rough abyssal seafloor , Internal lee waves

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Virtual tracer analysis of the Pacific meridional overturning circulation

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We simulate the Pacific meridional overturning circulation (PMOC) by using a realistically configured ocean general circulation model (OGCM). A three-dimensional distribution of turbulent energy dissipation rate derived from a tide model and recent microstructure measurement is employed. A global map of geothermal heating at the seafloor is also incorporated.

The northward volume transport of the Circumpolar Deep Water (CDW) is consistent with mooring observation. The radiocarbon age calculated from the simulated circulation has consistency with observations.

A virtual dye tracer is utilized to investigate the upwelling of deep water and the returning current at the upper deep layer. A virtual particle tracer experiment is also conducted to obtain the fraction of the deep water returning to the Southern Ocean or inflowing to the Indian Ocean.

Keywords: Pacific meridional overturning circulation, Ocean General Circulation Model, particle tracer, tidal mixing, geothermal heat

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS24] Exploring new frontiers of oceanic mixing research in the next decade

convener:Toshiyuki Hibiya(Department of Earth and Planetary Science, Graduate School of Science, University of Tokyo), Ichiro Yasuda(Atmosphere and Ocean Research Institute, The University of Tokyo), Lakshmi Kantha(Aerospace Engineering Sciences, University of Colorado, Boulder, Colorado, USA)

Mixing plays many important roles in the global ocean through a variety of different processes. In the upper ocean, mixing affects the sea surface temperature and hence air-sea interactions, which in turn influence the state of the atmosphere on a variety of time scales. Mixing in the deep ocean maintains the abyssal stratification of the world's oceans and influences the global overturning circulation, which in turn affects long-term climate. Ocean mixing modulates the transport and dispersal of dissolved and suspended materials, including pollutants, plankton and fish larvae. It also plays an important role in the oceanic food chain in so far as primary productivity, which occurs predominantly in the euphotic zone, is affected by nutrient uptake from the deep associated with ocean mixing.

 Microstructure profilers are being increasingly and routinely used to measure turbulence in the oceans, including the deep. Mixing models with more inclusive physics are being developed. Increasing computer power is making it possible to include sophisticated mixing models in global circulation models. As such, it is time to take stock of where we stand at present and explore the frontiers of mixing research over the next decade to advance our knowledge and utilize it for societal benefit.

 This session encompasses a wide variety of aspects of mixing within the water column from the surface to the seabed, as well as the impact of mixing on key physical, biological, and chemical processes, such as those mentioned above, with special attention to new findings obtained through improvements in oceanographic instrumentation, mixing models and the use of supercomputers. Observational, theoretical, experimental, and numerical approaches are all welcome. In this session, we particularly encourage discussion that can confirm how far our understanding of related topics has advanced and help define the new frontiers of ocean mixing research to be tackled in the next decade.

[AOS24-07] Diagnostic evaluation of vertical mixing effects on meridional overturning circulatoin

*Yutaka Yoshikawa[1], Takao Kawasaki[1], Hiroyasu Hasumi[1] (1.Graduate School of Science, Kyoto University)

[AOS24-08] Role of deep ocean mixing on climate change assessed by an Earth system model

*Michio Watanabe[1], Akitomo Yamamoto[1], Tomohiro Hajima[1], Hiroaki Tatebe[1] (1.Japan Agency for Marine-Earth Science and Technology)

[AOS24-09] Eddy-resolved ocean characteristics of the MIROC coupled model incorporating effects of tidal mixing of the 18.6-yr modulation

*Tomonori Matsuura [1], Hiromasa Tatebe[2], Ichiro Yasuda[1] (1.The University of Tokyo , 2.Japan Agency for Marine-earth Science and Technology)

[AOS24-12] Enhanced vertical mixing along a shelf-slope front east of Japan

*Sachihiko Itoh[1], Eiji Masunaga[2], TSUTSUMI EISUKE[1], Takashi T Sakamoto[1], Ishikawa Kazuo[1], Daigo Yanagimoto[1], Hitoshi Kaneko[1], Yasuhiro Hoshiba[1], Daisuke Hasegawa[3], Toshi Nagata[1] (1.Atmosphere and Ocean Research Institute, The University of Tokyo, 2.Center for Water Environment Studies, Ibaraki University, 3.Tohoku National Fisheries Research Institute)

Diagnostic evaluation of vertical mixing effects on meridional overturning circulatoin

*Yutaka Yoshikawa[1], Takao Kawasaki[1], Hiroyasu Hasumi[1]

1. Graduate School of Science, Kyoto University

Abyssal vertical mixing is well known to affect meridonal overturning circulation (MOC). However, how the mixing affects MOC remains unclarified. For example, the stronger vertical mixing is sometimes said to promote upwelling and intensifies the MOC by making the deeper water less dense. However, close look at some previous simulations reveals that, for certain horizontal distribution of vertical diffusivity, the stronger vertical mixing can induce weaker MOC while it makes the deeper water less dense. To make clear dynamical relation between the vertical mixing and MOC, we revisited MOC simulated in an idealized rectangular ocean forced by surface differential heating/cooling, and diagnosed its vorticity balance. It is found that geostrophy dominated in the large-scale MOC, and that the vertical mixing effect on the large-scale MOC is to change hydrostatic pressure fields (geostrophic flow fields) rather than to promote the upwelling. In this case, the stronger mixing can either intensify or weaken the large-scale geostrophic MOC. On the other hand, if the mixing was localized, ageostrophic divergent/convergent flows were induced to form the localized MOC. In this small-scale MOC, the stronger mixing always promotes the upwelling and intensifies the MOC. The simulation results presented in this study emphasize scale dependence of the vertical mixing effects on MOC.

Keywords: Vertical mixing, Meridional overturning circulation, Diagnostic evaluation of vorticity balance, Numerical experiments, Process-oriented study

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Role of deep ocean mixing on climate change assessed by an Earth system model

*Michio Watanabe[1], Akitomo Yamamoto[1], Tomohiro Hajima[1], Hiroaki Tatebe[1]

1. Japan Agency for Marine-Earth Science and Technology

Incorporating biogeochemical processes into general circulation models (GCMs), Earth system models (ESMs) have been developed for future climate projection. Micro-scale turbulent mixing in the deep ocean due to the tide-induced internal wave breaking is a key process to determine the strength and pattern of the meridional overturning circulation (MOC), which redistributes the absorbed heat in the ocean. In addition, strong carbon uptake is found in the deep and bottom water formation regions in the high latitudes, and the absorbed carbon is also redistributed by the MOC, so that the deep ocean mixing has a strong impact on the global carbon cycle. However, the distribution of the intensity of deep ocean mixing is not clear and the impact of the deep ocean mixing on the global carbon cycle has not been well discussed. In this study, employing each of two implementation of deep ocean mixing, we execute an Earth system model under the preindustrial forcing, then under increasing atmospheric CO_2 concentration by 1 % per year. Our results show the strong impact of the distribution of the intensity of deep ocean mixing on the ocean carbon and heat uptakes, the carbon and heat transports down to the deeper ocean, as well as the transient climate response. Better parameterizations for deep ocean mixing processes could contribute to reducing uncertainties in future climate projections.

Keywords: Earth system model, Transient Climate Reponse, ocean carbon uptake, Meridional Overturning Circulation, ocean heat uptake

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Eddy-resolved ocean characteristics of the MIROC coupled model incorporating effects of tidal mixing of the 18.6-yr modulation

*Tomonori Matsuura [1], Hiromasa Tatebe[2], Ichiro Yasuda[1]

1. The University of Tokyo , 2. Japan Agency for Marine-earth Science and Technology

A comparative study of long-term simulations (200-500 years) of three versions of the MIROC coupled model (MIROC3.2, MIROC5.2, and MIROC6.subhi) was performed. This model incorporates the effects of the 18.6 tidal period into the ocean mixing process. It is revealed that in Miroc6.subhi, the main factors of ocean-atmosphere interaction (SST, SSH, SLP) and the internal structure distribution of the ocean (potential temperature, salinity, potential density, and current) were the most consistent with the observations. Long-term variability (decadal to multidecadal) was evident in the waters off the Kuril-Aleutian and off Southeast Asia where tidal and topographical interactions are prominent.

Keywords: MIROC coupled model, 18.6-yr tidal period, eddy-resolving modeling, Kuril-Aleutian lalands, off Southeast Asia, long-term variability

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Enhanced vertical mixing along a shelf-slope front east of Japan

*Sachihiko Itoh[1], Eiji Masunaga[2], TSUTSUMI EISUKE[1], Takashi T Sakamoto[1], Ishikawa Kazuo[1], Daigo Yanagimoto[1], Hitoshi Kaneko[1], Yasuhiro Hoshiba[1], Daisuke Hasegawa[3], Toshi Nagata[1]

1. Atmosphere and Ocean Research Institute, The University of Tokyo, 2. Center for Water Environment Studies, Ibaraki University, 3. Tohoku National Fisheries Research Institute

Off the Sanriku Coast, east of Japan, three characteristic water masses from the Tsugaru Warm Current (TWC), the Oyashio (OY) and the Kuroshio warm-core rings (WCR) often form complex fronts along a narrow shelf. The sharp gradient of the environment and occasional mixing processes associated with these fronts are known to play important roles in fresh water/material exchanges and biological productivity. While the internal tides are constantly excited around the shelf-edge, vertical mixing processes have yet to be understood, mainly because of the occurrences of the sharp oceanic fronts around the shelf. In order to clarify the structure of the front, interaction with internal tides and the vertical mixing processes, we conducted high-resolution observations using an underway CTD (UCTD) and vertical microstructure profilers across the shelf off the Sanriku Coast, in four different seasons in 2018 and 2019. The UCTD sections with intervals of 0.4–1.5 km resolving submesoscale, revealed the frontal structure and its seasonal variability, caused by the interactions of three water masses. The front was most clearly formed at a shelf-slope boundary in summer and fall between the warn/saline TWC on the shelf and cold/fresh OY or warm and more saline WCR in the slope area. This shelf-slope contrast became unclear by early spring due to the cooling of the TWC water on the shelf, while an extremely sharp thermohaline front, warm/saline inshore and cold/fresh offshore, emerged again in late spring when the TWC and OY became intensified. One-day repeated observations suggested occurrences and propagations of short-wavelength internal waves all around the shelf. While turbulent energy dissipation rate ε were elevated at various areas/layers, marked band-like structure of high ε was observed along the front during the stratified season. Analyses considering the balanced Richardson number and Rossby number suggests that strong vertical shear of horizontal velocity enable subinertial internal waves with respect to the local inertial frequency to exist within the frontal band. These waves might be trapped within the frontal band and broken to yield enhanced vertical mixing.

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS24] Exploring new frontiers of oceanic mixing research in the next decade

convener:Toshiyuki Hibiya(Department of Earth and Planetary Science, Graduate School of Science, University of Tokyo), Ichiro Yasuda(Atmosphere and Ocean Research Institute, The University of Tokyo), Lakshmi Kantha(Aerospace Engineering Sciences, University of Colorado, Boulder, Colorado, USA)

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[AOS24-14] **The observational evidence of double diffusive instability in the Arabian Sea during winter and spring**

*ASHIN KURIAKOSE[1], Jofia Joseph[1], Girishkumar M. S.[1], Sureshkumar N[1], Sivaprasad S[1], Thangaprakash V P[1], Pattabhi Ram Rao E[1] (1.ESSO - Indian National Centre for Ocean Information Services)

[AOS24-16] Temporal variations of nutrient concentration east of Taiwan and its influence on downstream area

*Xinyu Guo[1], Yingying Hu[2], Yoshikazu Sasai[3], Chung-Chi Chen[4], Sen Jan[5] (1.Center for Marine Environmental Studies, Ehime University, 2.National Marine Environmental Forecasting Center, Ministry of Natural Resources of China, China, 3.Japan Agency for Marine-Earth Science and Technology, Japan, 4.Department of Life Science, National Taiwan Normal University, Taiwan, 5.Institute of Oceanography, National Taiwan University, Taiwan)

[AOS24-17] Flow-topography interaction within the Kuroshio and energy dissipation: observation and numerical simulation in the Tokara Strait south-west of Japan and the I-Lan Ridge east of Taiwan

*Eisuke Tsutsumi[1], Takeshi Matsuno[2], Takeyoshi Nagai[3], Daisuke Hasegawa[4], Hirohiko Nakamura[5], Ayako Nishina[5], Tomoharu Senjyu[2], Takahiro Endoh[2], Ming-Huei Chang[6], Yiing Jang Yang[6], Sen Jan[6], Sachihiko Itoh[1], Xinyu Guo[7] (1.Atmosphere and Ocean Research Institute, The University of Tokyo, 2.Research Institute for Applied Mechanics, Kyushu University, 3.Department of Ocean Sciences, Tokyo University of Marine Science and Technology, 4.Tohoku National Fisheries Research Institute, Japan Fisheries Research and Education Agency, 5.Faculty of Fisheries, Kagoshima University, 6.Institute of Oceanography, National Taiwan University, 7.Center for Marine Environmental Studies, Ehime University)

[AOS24-18] The long lasting strong turbulence along the Kuroshio flowing over seamounts in the Tokara Strait

*Takeyoshi Nagai[1], Eisuke Tsutsumi[2], Daisuke Hasegawa[3], Hirohiko Nakamura[4], Ayako Nishina[4], Takeshi Matsuno[5], Tomoharu Senjyu[5] (1.Department of Ocean Sciences, Tokyo University of Marine Science and Technology, 2.The Atmosphere and Ocean Research Institute, The University of Tokyo, 3.Tohoku National Fisheries Research Institute, Japan Fisheries Research and Education Agency, Miyagi, 4.Faculty of Fisheries, Kagoshima University, 5.Research Institute for Applied Mechanics, Kyushu University)

The observational evidence of double diffusive instability in the Arabian Sea during winter and spring

*ASHIN KURIAKOSE[1], Jofia Joseph[1], Girishkumar M. S.[1], Sureshkumar N[1], Sivaprasad S[1], Thangaprakash V P[1], Pattabhi Ram Rao E[1]

1. ESSO - Indian National Centre for Ocean Information Services

The presence of prominent thermohaline interleaving layers has been documented in the Arabian Sea. As reported by earlier studies in the Arabian Sea these interleaving layers are conducive for the formation of double diffusive convection. However, the presence of double diffusion instability, its intensity, and its spatial coherence during different seasons is not yet documented in the Arabian Sea. In this study, the measurements of the microstructure of temperature, and shear using Vertical Microstructure Profiler (VMP 250), collected from three different cruises during winter and Spring is utilized to document the double diffusive instability. Our measurements indicate that non turbulent double diffusion states, dominated by moderately strong to strong salt fingering regime. The two order difference between ε and χ further confirm the presence of double diffusion instability. Besides, we have also performed the validation of the existing empirical form of effective heat diffusivity for salt fingers using observation data.

Keywords: Arabian sea, Double diffusive instability, Salt fingering

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Temporal variations of nutrient concentration east of Taiwan and its influence on downstream area

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1. Center for Marine Environmental Studies, Ehime University, 2. National Marine Environmental Forecasting Center, Ministry of Natural Resources of China, China, 3. Japan Agency for Marine-Earth Science and Technology, Japan, 4. Department of Life Science, National Taiwan Normal University, Taiwan, 5. Institute of Oceanography, National Taiwan University, Taiwan

Kuroshio transports a amount of materials (e.g., nutrient) in the ocean from the tropics to mid-latitudes. As an upstream area, the Kuroshio east of Taiwan has significant effects on the environments in the downstream area such as the East China Sea, the seas southeast of Japan, and even the Tsushima Strait. This study uses in-situ data, satellite data and model results to understand seasonal and interannual variations of nitrate concentration along a transect across the Kuroshio east of Taiwan (KTV1 transect) and its influence to downstream area.

In summer, a clear increasing of nitrate concentration can be found at onshore side of KTV1 transect. This increasing is maximum at depth around 50 m. It forms a band from the east coast of Taiwan to the East China Sea up to near 29˚N at 45 m depth while at surface, this increasing of nitrate concentration has both small magnitude and area limited to south of 24˚N. Both satellite and model results show a corresponding increase of surface chlorophyll-a/phytoplankton. The increasing of phytoplankton reaches to ~26˚N in the model results.

Using EOF analysis, the interannual variation is extracted as the second mode. The increasing of nitrate concentration in onshore area due to interannual variation affects nitrate distribution further downstream to more than 30˚N northward and affects a larger magnitude and area of phytoplankton increasing than the seasonal variation does. The mechanism of the interannual variation is arrival of mesoscale eddies generated along North Pacific subtropical countercurrent. As the eddies arrive east of Taiwan, they can dramatically change the axis position, width and surface velocity of Kuroshio east of Taiwan.

Keywords: Kuroshio, Nutrient, East of Taiwan, Seasonal Variation, Interannual Variation

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Flow-topography interaction within the Kuroshio and energy dissipation: observation and numerical simulation in the Tokara Strait south-west of Japan and the I-Lan Ridge east of Taiwan

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The Kuroshio is the western boundary current constituting a part of North Pacific sub-tropical gyre, which carries heat and materials from low- to mid- latitude ocean. There are many small-scale topographic features such as small islands, seamounts, and shallow ocean ridges in the route of the Kuroshio. In recent years, interaction of western boundary currents with small-scale topography draws increasing attention because it can dissipate significant fraction of the wind-driven large-scale energy and the associated turbulent mixing could promote ocean biological productivity. In the Kuroshio, recent microstructure surveys have revealed that the Kuroshio interaction with small-scale topography induces strong turbulent mixing through hydraulic control, boundary-layer shear instabilities, internal waves and submesoscale vortices. However, the energy pathways to dissipation have not been identified yet. In this study, we investigate energy dissipation processes of the Kuroshio in the Tokara Strait south-west of Japan and in the I-Lan Ridge east of Taiwan, where the Kuroshio strongly interacts with small-scale shallow topographies. Shipboard surveys with microstructure profiler revealed that in both area, turbulent kinetic energy dissipation rate was elevated to O(10^{-5}) W kg^{-1} at a shallow sill (water depth < 100 m) associating with hydraulic control and shear instability. High-resolution numerical model simulation forced by the Kuroshio and barotropic tides successfully reproduced the observed nature of flow and turbulent dissipation at the sill and it suggests that O(1) GW of the Kuroshio energy is directly dissipated or converted to super-inertial energy.

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The long lasting strong turbulence along the Kuroshio flowing over seamounts in the Tokara Strait

*Takeyoshi Nagai[1], Eisuke Tsutsumi[2], Daisuke Hasegawa[3], Hirohiko Nakamura[4], Ayako Nishina[4], Takeshi Matsuno[5], Tomoharu Senjyu[5]

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Flow over the topography is known to induce strong turbulent mixing. Hydraulic jump and internal lee waves are often considered to be causes of the strong turbulence above the topographic features. In contrast, recent high-resolution numerical simulations showed that the negative potential vorticity generation caused by the subinertial geostrophic flow along the bottom slope can induce submesoscale flow instability, followed by microscale irreversible diapycnal turbulent mixing. On the other hand, recent observational results by the authors showed that the bands of strong turbulence associated with the near-inertial internal waves in the Kuroshio flowing over the seamounts in the Tokara Strait. However, due to the lack of sufficient resolutions of the observations, it is still unclear how these near-inertial internal waves are generated, and how the vorticity distributions including that of potential vorticity affect the microscale turbulence. In this study, we found 1000-fold enhancement of turbulent kinetic energy dissipation rates along the Kuroshio over 100 km in the Tokara Strait. The results from the analyses for the in-situ observation data and a nested high-resolution simulation suggest the importance of the vorticity and near-inertial internal waves to maintain this long-lasting strong turbulence along the Kuroshio.

Keywords: Negative PV, Near-inertial internal waves, Tokara Strait

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS24] Exploring new frontiers of oceanic mixing research in the next decade

convener:Toshiyuki Hibiya(Department of Earth and Planetary Science, Graduate School of Science, University of Tokyo), Ichiro Yasuda(Atmosphere and Ocean Research Institute, The University of Tokyo), Lakshmi Kantha(Aerospace Engineering Sciences, University of Colorado, Boulder, Colorado, USA)

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[AOS24-19] Effects of nutrient supply with strong turbulent mixing on lower-trophic level ecosystem around the Tokara strait

*Naoki Yoshie[1], Kazuki Ohgi[1], Anri Kabe[1], Yuma Hayashi[1], Toru Kobari[2], Eisuke Tsutsumi[3], Daisuke Hasegawa[4], Joji Ishizaka[5] (1.Center for Marine Environmental Studies, Ehime University, 2.Faculty of Fisheries, Kagoshima University, 3.Atmosphere and Ocean Research Institute, The University of Tokyo, 4.Tohoku National Fisheries Research Institute, Japan Fisheries Research and Education Agency, 5.Institute for Space-Earth Environmental Research Nagoya University)

[AOS24-20] Observation of anticyclonic eddies in the western subarctic North Pacific

*Ueno Hiromichi[1], Ryo Dobashi[2], Yuki Okada[2], Takahiro Tanaka[3], Jun Nishioka[4], Toru Hirawake[1], Atsushi Ooki[1], Sachihiko Itoh[5], Yoshikazu Sasai[6], Hideharu Sasaki[6], Ichiro Yasuda[5] (1.Faculty of Fisheries Sciences, Hokkaido University, 2.Graduate School of Fisheries Sciences, Hokkaido University, 3.Tohoku National Fisheries Research Institute, Japan Fisheries Researh and Education Agency, 4.Institute of Low Temperature Science, Hokkaido University, 5.Atmosphere and Ocean Research Institute, The University of Tokyo, 6.Japan Agency for Marine-Earth Science and Technology)

[AOS24-21] Importance of the intermediate water nutrient pool and mixing around island chains for constructing HNLC region in the subarctic Pacific

*Jun Nishioka[1,2], Hajime Obata[3], Toru Hirawake[2,4], Youhei Yamashita[5], Hiroshi Ogawa[3], Ichiro Yasuda[3] (1.Institute of low temperature sciences, Hokkaido University, 2.Arctic Research Center, Hokkaido University, 3.Atmosphere and Ocean Research Institute, The University of Tokyo, 4.Faculty of Fisheries Sciences, Hokkaido University, 5.Faculty of Environmental Earth Science, Hokkaido University)

[AOS24-22] Decadal variation of biological settling particle fluxes controlled by physical process in the subarctic western North Pacific.

*Naomi Harada[1], Makio Honda[1], Maki Noguchi Aita[1], Miyako Sato[1], Fujiki Tetsuichi[1], Minoru Kitamura[1], Ueno Hiromichi[2] (1.Japan Agency for Marine-Earth Science and Technology, 2.Hokkaido University)

[AOS24-23] Geographical distributions of primary production phenology and nutrient/iron supply in the subarctic North Pacific Ocean

*Toru Hirawake[1], Jun Nishioka[2], Hajime Obata[3] (1.Faculty of Fisheries Sciences, Hokkaido University, 2.Institute of low temperature sciences, Hokkaido University, 3.Marine inorganic chemistry division, Atmosphere and Ocean Research Institute, University of Tokyo)

Effects of nutrient supply with strong turbulent mixing on lower-trophic level ecosystem around the Tokara strait

*Naoki Yoshie[1], Kazuki Ohgi[1], Anri Kabe[1], Yuma Hayashi[1], Toru Kobari[2], Eisuke Tsutsumi[3], Daisuke Hasegawa[4], Joji Ishizaka[5]

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In recent years, the effects of nutrient supply with strong turbulent mixing on the lower-trophic level ecosystem have received a lot of attention around the Tokara strait, where many seamounts and small islands exist within the route of the Kuroshio in the East China Sea. To investigate these effects, we conducted Lagrangian observations along the Kuroshio from the upstream of the Tokara Strait to the downstream in the autumn of 2017 and 2018. We also investigated responses of phytoplankton assemblages to various nutrient supplies by incubation experiments. The incubation experiments showed significant growth of phytoplankton under the nutrient conditions supplied by the turbulent mixing around Tokara. Although biomass and large-sized fraction of phytoplankton observed in the downstream were higher than those in the upstream, the phytoplankton assemblages in the downstream were affected not only by the turbulent mixing but also by the intrusion of coastal water. Therefore we estimated fractions of the coastal water intruded in the downstream by salinity differences with assuming isopycnal mixing, and removed them to clarify the effects of the turbulent mixing. The biomass of phytoplankton removed the effects of coastal water were smaller than those expected by the incubation experiments without meso-zooplankton grazing. The phytoplankton biomass reduced in the downstream might be due to the meso-zooplankton grazing, and the nutrients supplied with the turbulent mixing might be contributed to maintain meso-zooplankton biomass in the downstream regions.

Keywords: Nutrient, Phytoplankton, Turbulent mixing, East China Sea

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Observation of anticyclonic eddies in the western subarctic North Pacific

*Ueno Hiromichi[1], Ryo Dobashi[2], Yuki Okada[2], Takahiro Tanaka[3], Jun Nishioka[4], Toru Hirawake[1], Atsushi Ooki[1], Sachihiko Itoh[5], Yoshikazu Sasai[6], Hideharu Sasaki[6], Ichiro Yasuda[5]

1. Faculty of Fisheries Sciences, Hokkaido University, 2. Graduate School of Fisheries Sciences, Hokkaido University, 3. Tohoku National Fisheries Research Institute, Japan Fisheries Researh and Education Agency, 4. Institute of Low Temperature Science, Hokkaido University, 5. Atmosphere and Ocean Research Institute, The University of Tokyo, 6. Japan Agency for Marine-Earth Science and Technology

Mesoscale eddies in the subarctic North Pacific have a significant impact on the heat, freshwater, macro- and micro-nutrient and biota exchanges between shelf and offshore regions and thus play an important role in the marine ecosystem of the offshore region. In the offshore western subarctic North Pacific, we conducted a cross-section observation of two mesoscale eddies (Eddies A and B) on board T/S Oshoro-maru in June–July 2016. Satellite data analysis revealed that Eddy A formed along the Alaskan Peninsula, and Eddy B formed in the observation area. Unexpectedly, it was found that iron and chlorophyll concentrations were low both inside and outside of the eddies. Satellite chlorophyll concentration was high inside of Eddy A along the Aleutian Islands and for a while after it detached from the Aleutian Islands, suggesting that iron originated from coastal region was lost during 2-year journey in the offshore region to the Oshoro-maru observation area. Oshoro-maru observation also revealed that the vertical diffusivity was low both inside and outside of Eddies A and B. This weak vertical mixing could be another reason for low iron and thus low chlorophyll concentration inside Eddies A and B. Analysis of the output data of high-resolution model suggested that the weak vertical mixing could be attributed to the seasonality of the vertical velocity inside mesoscale eddies and the weakness of Eddies A and B.

Keywords: mesoscale eddy, western subarctic North Pacific

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Importance of the intermediate water nutrient pool and mixing around island chains for constructing HNLC region in the subarctic Pacific

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A comprehensive and correct understanding of the biogeochemical system at the termination of the global ocean conveyor belt circulation is critical for understanding the global carbon cycle and its changes in geological time scale. Comprehensive observed data of macro-nutrients in the subarctic Pacific and marginal seas indicate the processes that determine the chemical properties of intermediate waters. In the western Bering Sea basin, intermediate water, which is extremely rich in phosphate (PO_4) but low in dissolved Oxygen (DO), was observed in the wide density range of 26.6–27.6 σ_θ. The calculated percentage of regenerated (reg-) PO_4 out of the total PO_4 ((AOU×$R_{P:DO}$)/observed PO_4×100) in the intermediate water indicates that more than half the total PO_4 in the density range of 26.8–27.6 σ_θ is reg-PO_4. The intermediate water with high proportion of the reg-PO_4 is also observed in the same density range in the subarctic Pacific, indicating that the reg-PO_4-rich intermediate water in the Bering sea basin is widely propagated in the subarctic Pacific trough the intermediate water circulation. That is, high nutrients are pooled in the subarctic intermediate water (26.8–27.6 σ_θ); we henceforth call the water the “subarctic intermediate nutrient pool (SINP)”. The formation of the chemical properties of the SINP can only be explained by the consumption of DO and regeneration of PO_4, as particulate organic matter that sink from the surface productive areas decomposes during the intermediate water circulation in the subarctic Pacific and its marginal seas. The enhanced mixing around the Kuril and the Aleutian island chains, combined with winter surface mixing, plays an important role in the supply of nutrient-rich waters from the SINP to the surface and in maintaining HNLC waters in the surface layer of the subarctic Pacific. The intermediate water formation processes play a major role in the connection of nutrients between the deep water and the surface water above it, and sustain biological production, at the termination of the global nutrient circulation.

Keywords: subarctic Pacific, North Pacific Intermediate Water, nutrient pool

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Decadal variation of biological settling particle fluxes controlled by physical process in the subarctic western North Pacific.

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The subarctic western North Pacific is one of the most effective area in terms of biogenic pCO_2 draw down in the world (Takahashi et al., 2002). Aquatic resource is also rich there. In order to understand processes linking between physical, chemical and biological production to create the rich productivity and marine ecosystem and effective biogeochemical dynamics in the subarctic western North Pacific, new interdisciplinary study, “Ocean Mixing Processes: Impact on Biogeochemistry, Climate and Ecosystem (OMIX)” is ongoing in Japan. As a part of OMIX study, we have a time-series mooring system at St.K2 (47N, 160E) in the subarctic western North Pacific to observe biogenic fluxes by sediment trap to find missing link between physical processes, nutrient supply and associated biological production there. According to decadal data from 2005 to 2017 at St.K2, total mass fluxes changed ranging from 0.07 to 949.5mg m^{-2} day^{-1} composed to mainly opal which is the frustules of diatom, silicoflagellate, and radioralia. There is a seasonal change namely, relatively high in the beginning of summer to autumn and low during winter-spring. The total mass, opal and organic carbon fluxes showed decreasing trend since Jan 2011. On the other hand, alkenone flux which is the biomarker of *Emiliania huxlyei*, coccolithophorid showed increasing trend since Jan 2011. *Emiliania huxleyi* distributes mainly in subtropical and transition area in the western North Pacific (Harada et al., 2006) and thus the increasing of alkenone flux since 2011 implies the north migration of subarctic frontal zone (SAF). We also showed the alkenone/diatom sterol (which is the biomarker of diatom) ratio that relatively high values continue since 2011. What physical mechanism control the decadal variation of biogenic flux and component through the latitudinal migration of SAF? We have compared the decadal variation of the Pacific Decadal Oscilation index and the strength of local jet current with biogenic fluxes. We will discuss the potential physical process to controle the decada variation in the biological responses in the subarctic North Pacific.

Keywords: Biological particle flux, Subarctic in the North Pacific, Pacific Decadal Oscilation, Isoguchi Jet

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Geographical distributions of primary production phenology and nutrient/iron supply in the subarctic North Pacific Ocean

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The subarctic North Pacific is one of the most productive regions where has the largest biological CO_2 drawdown in the world. Nutrient and iron rich waters discharged from the sub-polar marginal seas (the Bering and Okhotsk Seas) through the intermediate water support high primary production of phytoplankton in this region. However, spatio-temporal distributions of primary production and nutrient/iron are asymmetric and ununiform. Therefore, a linkage between nutrient/iron supply and primary production in the subarctic North Pacific has not been sufficiently understood. In this study, we investigate relationship between geographical distributions of primary production phenology pattern obtained from satellite data and ship-based nitrate and dissolved iron concentrations in the subarctic North Pacific. The phenological patterns in primary production were classified into 23 clusters. The highest difference between actual primary production and estimated one from nitrate concentration (residual) was found in the cluster distributed around Aleutian Islands. Primary production phenology in this cluster suggests existence of process to supply nutrient/iron continuously and spatial pattern of in-situ surface iron concentration in this region during summer supported the process. The phenological patterns of other clusters also imply existence of the area where both nutrient and iron deplete after spring bloom, and the area where iron depletion causes high nutrient and low chlorophyll (HNLC) condition. These patterns could almost be explained by the existing ship-based dissolved iron and nitrate observational data.

Keywords: primary production, iron, nutrients

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS25] Continental-Oceanic Mutual Interaction: Planetary scale Material Circulation

convener:Yosuke Alexandre Yamashiki(Earth & Planetary Water Resources Assessment Laboratory Graduate School of Advanced Integrated Studies in Human Survivability Kyoto University), Yukio Masumoto(Graduate School of Science, The University of Tokyo), Swadhin Behera(Climate Variation Predictability and Applicability Research Group, Application Laboratory, JAMSTEC, 3173-25 Showa-machi, Yokohama 236-0001), Takanori Sasaki(Department of Astronomy, Kyoto University)

The main purpose of this session is to promote discussion on mutual interaction between Continental zone and Oceanic zone. The global-scale material circulation induced by River runoff through oceanic general circulation as major topic on Continental-Oceanic Interaction, where the ENSO / IOD influence into continental climate as major topics on Oceanic-Continental Interaction. Numerical simulation and field observation of radionuclide transport from continental zone into ocean and its potential impact is also important topics of this session. The session also extend discussion on planetary hydrology and oceanography focusing on subsurface ocean in Jupiter's moon & Ancient Martian Oceanography & Hydrology by possible application of terrestrial GCM into Ancient Mars. In addition, impact of planetary radiation environment induced by Solar Energetic Particles on the transition of surface hydrological environment will be focused.

[AOS25-01] Impact of Extreme UV fluxes on Atmospheric Escape of the Hadean Earth and Earth-like Exoplanets

★Invited Papers

*Vladimir Airapetian[1,2], Jared Bell[1], Alex Glocer[1] (1.NASA Goddard Space Flight Center, 2.American University, DC)

[AOS25-02] Lunar water exploration expands human activity in space

★Invited Papers

*Yuko Inatomi[1] (1.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency)

[AOS25-03] The inner edge of habitable zone for terrestrial exoplanets

★Invited Papers

*Takanori Kodama[1] (1.University of Bordeaux)

[AOS25-04] Plant culture system as a water recycling device in space farming

*Kitaya Yoshiaki[1] (1.Graduate School of Life and Environmental Sciences, Osaka Prefecture University)

[AOS25-05] Probabilistic Risk Assessment of Solar Particle Events Considering the Cost of Counter Measures to Reduce the Aviation Exposure Dose

*Moe Fujita[1], Yosuke Yamashiki[1], Tatsuhiko Sato[2] (1.Graduate School of Advanced Integrated Studies in Human Survivability Kyoto University, 2.Japan Atomic Energy Agency)

[AOS25-06] Space educational program: Space camp at Biosphere 2

*Masahiro Terada[1], Yosuke Ymashiki[1], Takao Doi[1] (1.Kyoto University)

Impact of Extreme UV fluxes on Atmospheric Escape of the Hadean Earth and Earth-like Exoplanets

*Vladimir Airapetian[1,2], Jared Bell[1], Alex Glocer[1]

1. NASA Goddard Space Flight Center, 2. American University, DC

Upper atmospheres of the Hadean Earth and Earth-like exoplanets were (are) exposed to large fluxes of X-ray and Extreme UV radiations. To understand the impact of XUV fluxes on atmospheric erosion, we adapted the Earth Global Ionosphere-Thermosphere Hydrodynamic Model (GITM). In particular, we examined the response of the upper atmospheres when the solar/stellar flux is increased up to 100 times of the current solar XUV flux. We find that while the early (Hadean) Earth’ s atmospheric erosion is driven by ion (O^+ and N^+) escape via polarization electric field, atmospheres of Earth-like exoplanets located in habitable zones around active K and M dwarfs should undergo massive hydrodynamic escape. We model the atmospheric expansion of both N_2-dominated atmospheres and quantify the effect of its potential enhancement to the rate of atmospheric escape. We also derive the response of the key cooling mechanisms: CO_2 and NO at an Earth-like exoplanet and discuss their observational signatures in the mid-IR band.

Keywords: Hadean Earth, exoplanets, atmospheric escape

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Lunar water exploration expands human activity in space

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1. Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency

On October 18, 2019, the Japanese government decided to participate in the U.S.-led international space exploration (Artemis program). The Artemis program is the sum of all programs relating to manned landings on the Moon, including the Gateway, SLS, Orion, Human Lander, CLPS, and other lunar activities. NASA is aiming not only for lunar exploration but also for manned landings on Mars in the 2030s, aiming to acquire the necessary technology through sustained lunar activity. In this way, it can be said that the era of considering and implementing exploration of the Moon and Mars within the framework of international cooperation, including its political significance, is no longer in science fiction novels but is approaching us with reality.

This is a great opportunity for academia who has been involved in the related research activities. In particular, it is important to deepen the discussion on whether lunar water is really available, how it can be used, and how Japan will be involved in the Artemis program proposed by the U.S. Numerous scientific data have been reported indicating the presence of water on the lunar surface. However, the amount, existence form and depth of the water are not well understood. Under such circumstances, international space exploration activities have emphasized the importance of exploring water as a resource. However, it is clear that lunar water exploration has high scientific significance. And engineering to realize the science is expected to contribute to concept of future space observation and deep space exploration not limited to lunar exploration.

In light of these rapid changes in space exploration, let's first imagine a sustainable society built in space in order to expand human activity in space. In order to minimize the reliance on materials and energy transport from distant Earth, and to build and develop a highly-independent society in space, it is necessary to address a very wide range of issues. As part of this effort, it is essential to discuss beyond the framework of conventional national policy of space development and space activities, without being limited to the development of science and technology to enable the sustainable activities of humans in space. For example, the objectives of human activities, the establishment of economic activities, the enhancement of institutions and education, and the development of culture can be considered as issues.

The present talk will introduce the recent efforts of JAXA on international space exploration, the status of studies from a scientific and engineering perspective about Japan's participation in the Artemis program, and trends in human planetary habitation activities in Japan and overseas.

Keywords: Water exploration, Moon, Artemis program, Human activity

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The inner edge of habitable zone for terrestrial exoplanets

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1. University of Bordeaux

A large number of exoplanets has been detected from 1995. Some of these are expected to be Earth-sized rocky planets, probably with liquid water on their surface. Most of studies for habitable planets assumed planets with a large amount of water on its surface and estimated the climate using one-dimensional climate model. Recently, estimates using three-dimensional climate models have begun. They focus on the spatially non-uniform distribution of water in its atmosphere. However, exoplanets should have a different amount of water from the Earth's ocean.

We have investigated the climate and discussed the habitability for a planet with a small amount of water on its surface. As a result, we found that the habitable zone, in which a planet can maintain liquid water on its surface for a long term, strongly depends on the water distribution on its surface and a planet with a small amount of water on its surface has wider habitable zone than that for a planet with a large amount of water on the planetary surface.

In this presentation, we summarize the climate and the habitability for the terrestrial exo-planet and discuss perspective of habitable planets in the near future.

Keywords: Exoplanet, Habitable planet

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Plant culture system as a water recycling device in space farming

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Plant growth in space has recently been of greater concern as the possibility of realizing manned space activity over a long duration increases. The feasibility of achieving long-duration manned space missions for moon and other planets will be highly dependent on plants in space farming within Controlled Ecological Life Support Systems. Plants will play important roles in food production, CO_2/O_2 conversion and water purification. In this study, I focused on the capabilities of water purification and water recycling, and also food production and CO_2/O_2 conversion in plant culture systems for future long-term manned space activities. As the result of a quantitative study, it was shown that 54 m^2 sweet potato culture area can supply food and oxygen necessary for securing one person and also180 L of clean water per day.

Keywords: Controlled Ecological Life Support System, Water recycling, Sweet potato

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Probabilistic Risk Assessment of Solar Particle Events Considering the Cost of Counter Measures to Reduce the Aviation Exposure Dose

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1. Graduate School of Advanced Integrated Studies in Human Survivability Kyoto University, 2. Japan Atomic Energy Agency

Radiation exposure to flight crews and passengers, called aviation exposure, is an important topic in radiological protection. In order to develop an integrated insurance approach for the risk of aviation exposure, particularly against severe solar particle events (SPE), we examined eight flight routes to calculate the maximum doses during five ground level enhancements (GLE). Four-dimensional (altitude, latitude, longitude, and time) dose data evaluated by WASAVIES were used in this calculation. Then, we estimated the probability of the occurrence of harmful GLE events that would bring the maximum flight route dose over 1.0 mSv and 0.08 mSv/h, based on past records of GLE as well as historically large SPE observed by the cosmogenic nuclide concentrations in tree rings and ice cores. Our calculation suggests that average probability of exceeding the threshold value of EII and PEI becomes 0.011 to 0.012, corresponding to an occurrence every 86 to 90 years. Our calculations suggest that aviation exposure with flight route doses over 1 mSv may occur approximately once every 90 years. The dose can be reduced by lower-altitude aviation with compensation of fuel consumption, which would be much cheaper than flight cancellation. Extremely severe SPE, such as the Miyake event in 774-775 AD, may cause the maximum flight route dose to become greater than 10 mSv. Low-altitude aviation may effectively reduce the costs and risks of aviation exposure, which can be used in designing an insurance product for SPE risk.

Keywords: Aviation Exposure, Solar particle event, Ground-level enhancement, Risk Evaluation, Insurance

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Space educational program: Space camp at Biosphere 2

*Masahiro Terada[1], Yosuke Ymashiki[1], Takao Doi[1]

1. Kyoto University

Recently, space agency, such as NASA and JAXA, has the plan to send human to Moon or Mars. And, astronauts must spend time in closed environment during human space mission. So, we need to know the mental or emotional changes during space mission. Therefore, it is very important to understand how we are affected during space staying and what we should do for staying in other planets. To recognize the important factors for future space mission, we, Unit of Synergetic Studies for Space (USSS) at Kyoto University, performed an intensive summer space program entitled as Space Camp at Biosphere 2 (SCB2) on 5-10 August, 2019. In this program, USSS collaborated with University of Arizona. In this time, 5 students were selected as participants from Kyoto University and University of Arizona, respectively. So, total 10 students participated this Space Camp.

Keywords: Biosphere 2, Space Camp

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-OS Ocean Sciences & Ocean Environment

[A-OS25] Continental-Oceanic Mutual Interaction: Planetary scale Material Circulation

convener:Yosuke Alexandre Yamashiki(Earth & Planetary Water Resources Assessment Laboratory Graduate School of Advanced Integrated Studies in Human Survivability Kyoto University), Yukio Masumoto(Graduate School of Science, The University of Tokyo), Swadhin Behera(Climate Variation Predictability and Applicability Research Group, Application Laboratory, JAMSTEC, 3173-25 Showa-machi, Yokohama 236-0001), Takanori Sasaki(Department of Astronomy, Kyoto University)

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[AOS25-07] Impacts of riverine discharges on the overturning circulation and material circulation in the Sea of Okhotsk and the North Pacific Ocean

★Invited Papers

*Humio Mitsudera[1], Toru Miyama[2], Hatsumi Nishikawa[1] (1.Institute of Low Temperature Science, Hokkaido University, 2.JAMSTEC)

[AOS25-08] **The AI/ML based IOD predictions**

*Swadhin Behera[1], J Venkata Ratnam[1] (1. Application Laboratory, VAiG, JAMSTEC, 3173-25 Showa-machi, Yokohama 236-0001)

[AOS25-09] Space Architecture Reinforced by Internal Ocean on the Moon

★Invited Papers

*Takuya ONO[1], Makiko NAGURA[1] (1.Kajima Corporation)

[AOS25-10] Ultra-high resolution numerical weather simulation on the heavy rainfall event over the western Japan 2018

*Tsutao OIZUMI[1,2], Kazuo Saito[1,3,2], Duc Le[1,2], Junshi Ito[3,2] (1.The Japan Meteorological Business Support Center, 2.Meteorological Research Institute, 3.The Atmosphere and Ocean Research Institute)

[AOS25-12] Bioparticle deposition at a stratospheric altitude

*Kenji Miki[1] (1.Tokyo Institute of Technology Earth-Life Science Institute)

Impacts of riverine discharges on the overturning circulation and material circulation in the Sea of Okhotsk and the North Pacific Ocean

*Humio Mitsudera[1], Toru Miyama[2], Hatsumi Nishikawa[1]

1. Institute of Low Temperature Science, Hokkaido University, 2. JAMSTEC

The Sea of Okhotsk is a semi-closed marginal sea adjoining the Eurasian Continent, with a substantial water exchange with the North Pacific Ocean through the Kuril Straits. The Okhotsk Sea collects a large amount of freshwater from the Amur River, one of top 10 largest rivers in the world, as well as from other rivers and local precipitation. Further, rivers carry a lot of nutrients and materials, such as iron, and discharge to the ocean. It is now well known that high primary production in the Oyashio region is attributed to iron transport from the Sea of Okhotsk. In this talk, we present results of ocean modeling that simulates the impacts of the riverine discharge on the overturning circulation and material circulation in the Sea of Okhotsk and the western North Pacific. Specifically, we focus on the 2 issues: (1) Impact of the riverine freshwater discharges to the dense shelf water (DSW) produced over the northern continental shelves due to brine rejection, which ventilates the intermediate layer of the Sea of Okhotsk and the North Pacific Ocean; (2) Circulation of materials discharged from the Amur River, paying attention to iron, an essential micronutrient for the phytoplankton growth.

The first issue concerns the DSW salinity, which controls strength of the ventilation of surface water to the intermediate layer. Before conducting numerical modeling, we analyzed hydrographic data in the Sea of Okhotsk collaboratively with Russian scientists which were collected by a Russian institute, the Far Eastern Region Hydrometeorological Research Institute. It was found that the DSW salinity is correlated significantly with a remote salinity anomaly originating in the Bering Sea and the subarctic North Pacific. Further, the precipitation over the Kamchatka Peninsula, not only over the ocean but also over the land, exhibits significant correlation with the DSW salinity variations. Motivated by these observations, we conducted numerical experiments with and without riverine freshwater discharge. We have found that the riverine discharge from the Kamchatka Peninsula has substantial influences on the DSW salinity. On the other hand, freshwater discharge from the Amur River does not give much impact on the DSW salinity because its river mouth locates downstream of the DSW production area.

The second issue concerns material circulations, where we pay attention to circulation of iron from the Amur River. Iron concentration is extremely high in the Amur River, since it flows through vast wetlands. However, most of iron is sedimented at the river mouth area where the riverine water meets the sea water. Nevertheless, the DSW entrains sediment, which contains a lot of iron, and carries it from the northern shelf in the Sea of Okhotsk to a vast area of the North Pacific Ocean through the intermediate layers. This intermediate-layer iron transport was successfully reproduced in our numerical model. Further, another route, a surface route, of the iron transport is suggested. Iron is carried by a coastal current along the Sakhalin together with sea ice, and flows out to the North Pacific as the Coastal Oyashio adjacent to the east coast of Hokkaido, where primary production is particularly high during spring season.

Keywords: Overturning circulation, salinity, freshwater, iron

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The AI/ML based IOD predictions

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The Indian Ocean Dipole (IOD), with opposite sea surface temperature anomalies off Sumatra and off East Africa, affects the climate of many parts of the world; especially that of East Africa, Australia, India, Japan, and Europe through atmospheric teleconnections. Therefore, accurate prediction of IOD is important for societal benefit. State of the art coupled climate models, such as the SINTEX-F, is used for the prediction of the phenomenon. However, these sophisticated models need large computers and data storage. Here for the first-time, we have shown the usefulness of the machine learning (ML) techniques to predict the IOD. The ML technique used in the study is based on the artificial neural networks (ANNs) and requires much less computational resources. The IOD forecasts are generated for May to November from February-April observed initial conditions with the attributes derived from sea surface temperature, 850hPa and 200hPa geopotential height anomalies, using a correlation analysis for the period 1949-2018. An ensemble of ANN forecast is generated using 500 samples with replacement using jackknife approach. The skill score of the ensemble mean is found to be superior to the skill score obtained from the persistence forecasts that one would guess from the observed data. The ANN models also perform far better than the models of the North American Multi-Model Ensemble (NMME) with higher correlation coefficients and lower root mean square errors (RMSE) for all the target prediction months of May-November.

Keywords: IOD, AI, ML, Indian Ocean, prediction

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Space Architecture Reinforced by Internal Ocean on the Moon

*Takuya ONO[1], Makiko NAGURA[1]

1. Kajima Corporation

Humans are expected to inhabit the outer space soon, e.g., the moon or Mars. When scientists and travelers start constantly living in outer space, the residence of maintenance crews and service staff will be needed to support them. If the duration of residence is prolonged, families would be expected to join them. This means that in such an era, space would be inhabited by regular households. As per our conjecture, gravity, and the sea would be primarily important to live in space.

The first requirement—Earth’s gravity (i.e., 1 G), is vital for humans and other living beings but cannot be transported from Earth. It is highly likely that without gravity, mammals cannot undertake the birthing process properly. Even if birthing is possible, normal growth cannot be expected in low gravity. Without healthy bones (that produce blood cells), blood health may also be affected. The negative effects of low gravity may not be limited to animals but may include plants. Furthermore, humans that grow up in low gravity will not be able to withstand Earth’s gravity. This means that life in space would produce “lunar humans” and “Martian humans” with weak legs, which could create community conflicts in the future. Although this issue may be solved in the distant future, it is too dangerous for humans to start living in low gravity, from now onwards.

We, therefore, believe that a rotating artificial gravity facility in outer space, which generates a gravity approximating that of Earth’s, would be useful. To approximate the 1 G environment, centrifugal force would be used in microgravity space while both gravitational and centrifugal forces are combined on celestial bodies. The other topic of our study is transportation systems in space, including means of inter-facility travel and artificial gravity transportation facilities connecting celestial bodies. People would live in the artificial gravity facilities for work and research; for leisure, they would use the low gravity environment unique to the moon and Mars, and the microgravity of outer space. These facilities would allow humans to have safe childbirths and maintain bodies that could return to Earth at any time. Recognizing that 1 G gravity is essential for humans to live in space, we propose an artificial gravity network, which supports human expansion to outer space.

Next, we propose that reproducing an Earth-like ocean is essential for humans to live in outer space. Water is crucial for ecology, and the ocean and flowing water have a significant visual impact on our mental health. The monotonous environment of the moon and Mars would soon become boring to people who are used to Earth’s rich global environment. However, if people could continue to enjoy marine sports and have landscapes such as the ocean and rivers, humans would be able to lead abundant lives away from Earth. Life on Earth was first born in the sea, and humans continue to have a close relationship with the sea. This suggests that the ocean is as important as gravity.

In addition, water is known to be effective at shielding from cosmic rays. With the ocean created on the proposed artificial gravity facility, the free water surface adheres to the floor due to the centrifugal force and becomes parabolic. By ensuring the necessary water depth, the ocean can also serve as a protective wall against cosmic rays.

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In conclusion, the reproduction of artificial gravity and seas would enhance the feasibility of human expansion to space. Without these two requirements met, humans will not be able to leave Earth.

Keywords: ocean, space architecture, cylinder architecture, artificial gravity by revolving, lunar lava tube, parabolic architecture

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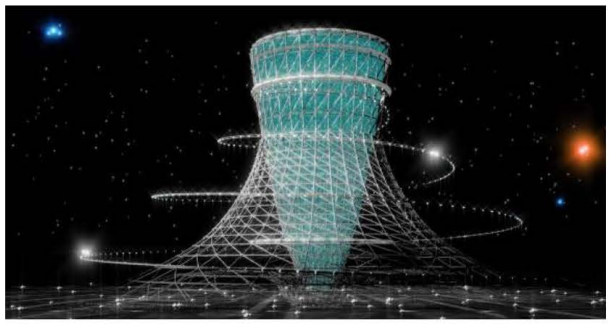
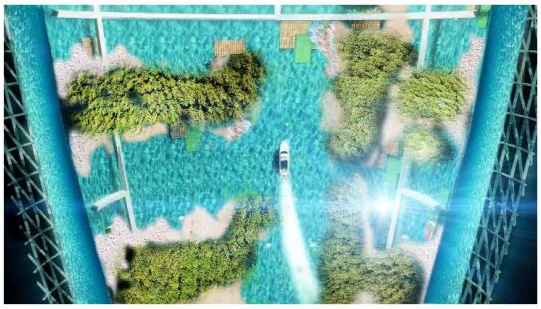
Space theater

(Artificial gravity facilities under microgravity conditions)



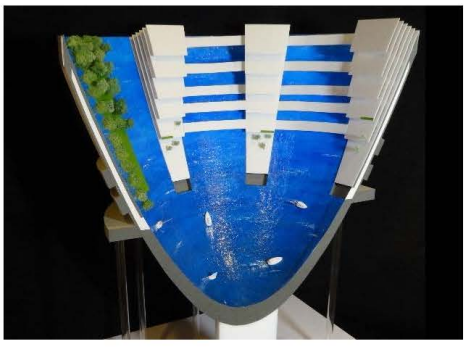
Artificial gravity facilities on the moon (Lunar glass)



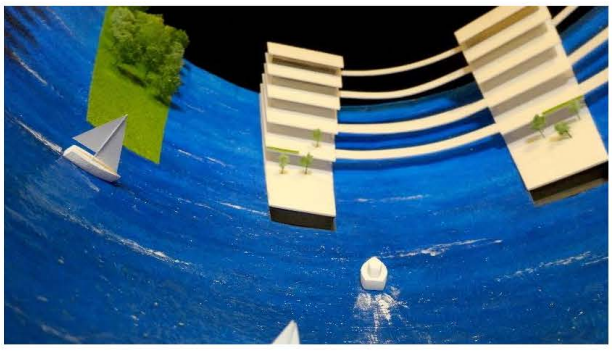
Lunar glass: Interior



Lunar glass: Details



Artificial gravity facilities on the Mars (Mars glass)



Mars glass: Interior

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Ultra-high resolution numerical weather simulation on the heavy rainfall event over the western Japan 2018

*Tsutao OIZUMI[1,2], Kazuo Saito[1,3,2], Duc Le[1,2], Junshi Ito[3,2]

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In this study, we simulated a heavy rainfall event that occurred in western Japan in July 2018 using a high-resolution numerical weather prediction (NWP) model with a large model domain. The objectives of this study are to investigate the impacts of NWP model factors (grid spacing and model domain size) on the heavy rainfall simulation. The Japan Meteorological Agency Non-Hydrostatic Model and the K computer which was the flagship supercomputer in Japan were used for this huge simulation. One of the features of this simulation was that the high-resolution model (500-m grid spacing) was run on a very large model domain (3160*2600 km).
The model resolution showed to play a crucial role. The 500-m grid spacing model showed the best performance. The 2-km grid spacing models showed clearly better performance than 5-km models. One of the interesting findings was that in the long time simulation, the model with a larger domain showed better performance than the model with a smaller domain. Overall, we have demonstrated the benefit of using the high-resolution model (500-m grid spacing) with a large model domain.

Keywords: Numerical wheather prediction model, high-resolution, Western Japan heavy rainfall

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Bioparticle deposition at a stratospheric altitude

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Understanding the dynamics of a bioparticle in the stratosphere is important to discuss astrobiological subjects such as the possibility of panspermia or the survivability of microbes in an extraterrestrial environment. In this presentation, the motion of a particle controlled by the gravity, air resistance, solar light pressure, the gravitational effect from the sun, and the photophoresis force with various diameters, densities, and drop heights will be discussed.

Keywords: stratosphere, astrobiology, bioaerosol

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-HW Hydrology & Water Environment

[A-HW30] Hydrology & Water Environment

convener:Ayumi Kotani(Graduate School of Bioagricultural Sciences, Nagoya University), Takeshi Hayashi(Faculty of Education and Human Studies, Akita University), Keisuke Fukushi(Institute of Nature & Environmental Technology, Kanazawa University), Masahiro Tanoue(School of Engineering, The University of Tokyo)

We focus on various issues of water cycle and environment and aim to answer questions of hydrological and earth system sciences; 1) surface, subsurface and evapotranspiration processes of water cycle, 2) natural and anthropogenic hydrothermal systems, 3) environments issues and studies on a watershed or global scale, 4) water-related issues with ecological, environmental, and geochemical aspects, and 5) other issues in hydrological sciences. We welcomes presentations regarding various kinds of approaches and techniques such as field survey, remote sensing, isotope tracers, numerical simulation, and theoretical analysis. This session is jointly hosed by societies of water-related geoscience (Geochemical Society of Japan, Japanese Association of Groundwater Hydrology, Japanese Association of Hydrological Sciences, and Japan Society of Hydrology and Water Resources), and accepts wide-range research topics related to water cycle and environment described above.

Introduction

[AHW30-01] Comparing tritium concentrations and water transit times in the Chikuma and Fujikawa River basins, Japan

*Maksym Gusyev[1], Naofumi Akata[2], Tsutomu Yamanaka[3], Kimio Hirabayashi[4], Masashi Toyota[4], Uwe Morgenstern[5], Michael Stewart[5] (1.International Centre for Water Hazard Risk Management, Public Works Research Institute, 2.Hirosaki University, Japan, 3.University of Tsukuba, Japan, 4.Shinshu University, Japan, 5.GNS Science, New Zealand)

[AHW30-02] Variation of carbon isotope ($\delta^{13}C$ and $\Delta^{14}C$) of organic matter in suspended solids at Lake Kiba-gata

*Seiya Nagao[1], Kohei Sakaguchi[2], Tetsuya Matsunaka[1], Shinya Ochiai[1], Naoya Katsumi[3] (1.Institute of Nature and Environmental Technology, Kanazawa University, 2.Graduate School of Natural Science and Technology, Kanazawa University, 3.Department of Environmental Science, Ishikawa Prefectural University)

[AHW30-03] Integrating Method of Waste Water Treatment and Desalination: Opportunities for Innovation

*Mst. Shamsun Nahar[1] (1.Safety- Hygiene Department, Earth Consultant Co. Ltd, Toyama, Japan)

[AHW30-04] Water Scarcity Assessment in Thailand River Basin Using Geo-Informatics Technology

*pudtraporn napang[1] (1.Kasetsart University)

[AHW30-05] Migration and aggregation of foamed plastic debris in the urban river of Mongolia

*Batdulam Battulga[1], Masayuki Kawahigashi[1], Bolormaa Oyuntsetseg[2] (1.Department of Geography, Tokyo Metropolitan University, Tokyo, 192-0397, Japan , 2.Department of Chemistry, National University of Mongolia, Ulaanbaatar, 210646, Mongolia)

Comparing tritium concentrations and water transit times in the Chikuma and Fujikawa River basins, Japan

*Maksym Gusyev[1], Naofumi Akata[2], Tsutomu Yamanaka[3], Kimio Hirabayashi[4], Masashi Toyota[4], Uwe Morgenstern[5], Michael Stewart[5]

1. International Centre for Water Hazard Risk Management, Public Works Research Institute, 2. Hirosaki University, Japan, 3. University of Tsukuba, Japan, 4. Shinshu University, Japan, 5. GNS Science, New Zealand

To understand surface-groundwater interactions, we investigated temporal variability of rain and river water tritium concentrations from June to Oct 2018 and estimated tritium-tracer mean transit times (MTTs) in the Chikuma and Fujikawa River basins, Japan. Tritium is an environmental tracer with a half-life of 12.32 years and is utilized to characterize water circulation from precipitation to surface water via groundwater in the catchment scale. In 2018, we collected monthly precipitation from June to October at four locations between 400 and 1,350 m above sea level and river water samples at normal and below normal discharge in Ueda of the Chikuma River basin and in two Kofu locations of the Fuefuki and Kamanashi Rivers in the Fujikawa River basin. Tritium concentrations of rain and river water samples were analyzed with medium accuracy in Japan and selected river water samples were analyzed with ultra-low level analysis at GNS Science Tritium Laboratory in New Zealand. For the Chikuma basin, an average tritium concentration of Ueda river water is 1.99 TU and is slightly lower than Fujikawa average tritium concentrations of 2.17 TU and 2.28 TU in the Fuefuki and Kamanashi Rivers, respectively. These tritium concentrations were utilized to estimate mean transit times (MTTs) at sampled locations using exponential-piston flow (EPM) models with scaling factor of 1.44 estimated based on measured tritium in local rainfall for monthly tritium concentrations in Chiba (Gusyev et al., 2016; 2019). To evaluate uncertainty of model parameters, we varied EPM ratio from 19 to 0.01 and MTTs from 1 to 200 years. For the Chikuma basin, the MTTs of river flow are between 18 and 34 years, similar to those of Fujikawa river water MTTs between 12 and 32 years. In the next step, we plan to investigate the possibility of much younger MTTs due to the tritium scaling factor and the mixture of young and old river waters.

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Gusyev M.A., Morgenstern U., Nishihara T., Hayashi T., Akata N., Ichiyanagi K., Sugimoto A., Hasegawa A., Stewart, M.K. (2019). Evaluating anthropogenic and environmental tritium effects using precipitation and Hokkaido snowpack at selected coastal locations in Asia. Science of the Total Environment 659: 1307-1321, doi: 10.1016/j.scitotenv.2018.12.342

Gusyev M.A., Morgenstern U., Stewart M.K., Yamazaki Y., Kashiwaya K., Nishihara T., Kuribayashi D., Sawano H., Iwami Y. (2016). Application of tritium in precipitation and baseflow in Japan: a case study of groundwater transit times and storage in Hokkaido watersheds. Hydrol. Earth Syst. Sci., 20, 1-16, doi:10.5194/hess-20-1-2016

Keywords: rainfall, surface water, tritium scaling factor, tritium-tracer transit times

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Variation of carbon isotope ($\delta^{13}C$ and $\Delta^{14}C$) of organic matter in suspended solids at Lake Kiba-gata

*Seiya Nagao[1], Kohei Sakaguchi[2], Tetsuya Matsunaka[1], Shinya Ochiai[1], Naoya Katsumi[3]

1. Institute of Nature and Environmental Technology, Kanazawa University, 2. Graduate School of Natural Science and Technology, Kanazawa University, 3. Department of Environmental Science, Ishikawa Prefectural University

In Lake Kiba-gata which is located at Komatsu City, annual average of chemical oxygen demand (COD) concentration in lake water is 6-7mg/L and over 3mg/L of the environmental standard relating to water pollution in this lake type. We need to elucidate the cause of organic pollutant in Lake Kiba-gata. Previous research by our laboratory shows a positive correlation between dissolved COD and dissolved organic carbon concentration, and particulate COD and particulate organic carbon (POC) concentration during April 2017- January 2018. Therefore, information and data on dynamics of organic matter is important to make reducing COD from the present level at Lake Kiba-gata. The aim of this study is to understand dynamics of organic matter in the lake by using carbon isotopes ($\delta^{13}C$ and $\Delta^{14}C$) of particulate organic matter because simulative use of $\delta^{13}C$ and $\Delta^{14}C$ provides information on sources of organic matter. We carried out monthly sampling at a site of inflow river and five sites in the lake from April 2015 to December 2018. The suspended solids samples were isolated from 60 L of surface lake water collected at center of the lake by using continuous flow centrifugation method.

The POC concentration shows seasonal variation with 0.44 mg/L to 5.0 mg/L: the higher concentration was observed at summer season and lower concentration was observed at winter season. $\delta^{13}C$ value of POC has variation from -32.2‰ in winter to -22.8‰ in summer. The higher $\delta^{13}C$ value shows the contribution of phytoplankton in the lake. $\Delta^{14}C$ value of POC shows similar seasonal variation. There is positive correlation between the $\delta^{13}C$ value and $\Delta^{14}C$ value except for the winter samples during December to February. The $\Delta^{14}C$ value also positively correlates with POC concentration (the unit of mg/l and %). The higher $\Delta^{14}C$ value and POC concentration indicate the higher contribution of apparently younger organic matter to suspended solids. These results indicate that the POC concentration is controlled by the activity of phytoplankton in the lake during spring to autumn season.

Keywords: lake water, organic pollution, COD

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Integrating Method of Waste Water Treatment and Desalination: Opportunities for Innovation

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This work reveals the chemical and electrolysis method for the waste water treatment in industrial and urban areas subsequently fresh water generation by considering time, cost and evaluating the characteristics of contaminant. We considered leather, textile, and dye industries in Dhaka Urban. Waste water treatment cost and energy are the biggest issues in developing countries because of the high water consumption in some industries like textiles and dyeing Industries. The salt (NaCl, Na_2SO_4 etc.) is an essential compound for coloring of yarn/cloth (25–75 kg/m^3) in dye solutions. As a result, fresh watercourses turned saline downstream from dye Industries. Hypoxic to anoxic low dissolve oxygen (DO) (< 0.85 mg/L critical level) with high content of chromium (Cr) (Nahar et al. 2014) in Buriganga and Shitalakshya were detected in Dhaka leather industries areas.The final goal of the research is to determine the waste water treatment method to achieve the highest beneficial use of cost effective and environmental concerns.

Keywords: Dhaka Urban, Dyeing Industries, Electrolysis Method, Desalination

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Water Scarcity Assessment in Thailand River Basin Using Geo-Informatics Technology

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1. Kasetsart University

In Thailand, water resources are going to be concerned because the demand for water is increased while supplies decrease which leads to water scarcity and give a negative effect on economic development and food security. Therefore, it is important to consider the amount of water availability and water consumption in each sector. This study purposes the integrated geo-informatics technology as tools to evaluate the water scarcity in 25 Thailand river basins focusing on water consumption in domestic, agriculture, industrial, livestock and environmental water requirement by using the water stress index as an indicator. The result shows the scarcity in each sector mostly occurs in the central part of Thailand as an area of agriculture, industry and densely populated. The study gives an overview of water scarcity in the Thailand river basin and useful for decision-support, planning of water distribution and water management in the future.

Keywords: water scarcity, water consumption

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Migration and aggregation of foamed plastic debris in the urban river of Mongolia

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Foamed plastic material is one of the most commonly produced and consumed anthropogenic products in the world. An extensive use of foamed plastic materials produces their debris followed by scattering of these plastic waste as marine and freshwater debris. Their transport by rivers accompanied by degradation and fragmentation of the plastic foams in the river environment is considered as the important processes in order to understand their distribution and fate. Regarding to the various processes affecting to the migration of environmental plastics, current study aimed to investigate the distribution, degradation, and fragmentation of foamed plastic debris and their potential to form plastic aggregates in the urban river environment in Mongolia. Foamed debris particularly polystyrene foams (PSFs) are collected from the six sampling sites along the shore of Tuul River in Ulaanbaatar, capital of Mongolia. The triplicate quadrats with 100 m^2 were set on the shore and collected all visible PSF samples. In terms of chemical structural properties, PSF samples and adhered microplastics (MPs) were evaluated using a digital microscope and a micro-Fourier transform infrared (FTIR) spectroscopy after the separation of the aggregates.

Various sized PSF particles are recorded with an average of 741 pieces in the transect. Micro-sized PSF which has <5mm length was the dominant piece of plastics at all sites in Tuul River. This study adopted the carbonyl index (CI) to figure out surface oxidation of PSFs through photodegradation. The CI of PSFs ranging between 0.00 and 1.09 indicates diverse stages of photooxidation status in the environment. Furthermore, the linear relationships between mega- and macro-sized ($p < 0.01$ and $r^2 = 0.80$), macro- and meso-sized ($p < 0.01$ and $r^2 = 0.94$), and meso- and micro-sized ($p < 0.01$ and $r^2 = 0.52$) PSFs were a proof of on-site fragmentation at the field. The results of predominance of micro-sized PSFs illustrate that solar radiation and freeze-thaw cycles are probably the major reason of degradation and fragmentation of PSFs. The abundance of adhered MPs which extracted from the surface of PSFs varied from 5 to 141 items on a piece of PSF. The aggregates of PSFs and MPs were common status of PSFs based on surface morphological changes of PSFs in the environment.

PSFs actively interact with a variety of secondary sourced MPs and travel together. Regarding migration and aggregation, plastic items have the potential to aggregate with other plastic particles and contaminants, and hotspots were determined in the downstream of the river. More detail mechanisms, the interaction between plastic-plastic aggregates and effects from hydrodynamic processes are necessary to focus on further research in the river environment.

Keywords: Foamed plastic, Tuul River, Mongolia, Degradation, Aggregates, Adhered microplastics

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-HW Hydrology & Water Environment

[A-HW30] Hydrology & Water Environment

convener:Ayumi Kotani(Graduate School of Bioagricultural Sciences, Nagoya University), Takeshi Hayashi(Faculty of Education and Human Studies, Akita University), Keisuke Fukushi(Institute of Nature & Environmental Technology, Kanazawa University), Masahiro Tanoue(School of Engineering, The University of Tokyo)

We focus on various issues of water cycle and environment and aim to answer questions of hydrological and earth system sciences; 1) surface, subsurface and evapotranspiration processes of water cycle, 2) natural and anthropogenic hydrothermal systems, 3) environments issues and studies on a watershed or global scale, 4) water-related issues with ecological, environmental, and geochemical aspects, and 5) other issues in hydrological sciences. We welcomes presentations regarding various kinds of approaches and techniques such as field survey, remote sensing, isotope tracers, numerical simulation, and theoretical analysis. This session is jointly hosed by societies of water-related geoscience (Geochemical Society of Japan, Japanese Association of Groundwater Hydrology, Japanese Association of Hydrological Sciences, and Japan Society of Hydrology and Water Resources), and accepts wide-range research topics related to water cycle and environment described above.

[AHW30-06] MERIT Hydro: a new global hydrography map based on multiple satellite observations, and its application to model-satellite integration in global river hydrodynamic simulations

★Invited Papers

*Dai Yamazaki[1] (1.Institute of Industrial Sciences, The University of Tokyo)

[AHW30-07] **Assessment of Climate Change Effects on the Rice Water Requirements for Hsin-Chu Irrigation Area in Taiwan**

YUAN-TUNG HSU[2], MEI-CHANG CHEN[2], SHU-HUE CHU[2], TA-WEI CHIEN[2], *SHIH-WEI CHIANG[1] (1.Agricultural Engineering Research Center, 2.Taiwan Hsinchu Irrigation Association)

[AHW30-08] Land use / land cover and discharge in the Altamaha River 1992-2016, Georgia, USA

*James Deemy[1], Kimberly Takagi[1], Cameron Atkinson[1], Nicholas Harris[1], Nellie Little[1] (1.College of Coastal Georgia Department of Natural Sciences)

[AHW30-09] **Role of colloids on the (im)mobility of toxic elements in mine drainage systems with acidic and circumneutral pH**

*Frances Chikanda[1], Tsubasa Otake[2], Tatsuya Matsui[1], Sereyroith Tum[1], Tsutomu Sato[2] (1.Division of Sustainable Resources Engineering, Graduate School of Engineering, Hokkaido University, 2.Division of Sustainable Resources Engineering, Faculty of Engineering, Hokkaido University)

[AHW30-10] Source Identification of Molybdenum in Natural Water Around Erdenet City, Mongolia

*Solongo Tsetsgee[1,3], Fukushi Keisuke[1], Altansukh Ochir[3], Takahashi Yoshio[2], Munemoto Takashi[4], Akitoshi Akehi[1], Ariuntungalag Yunden[3], Enkhjin Odgerel[3], Taivanbat Batbold[3], Noriko Hasebe[1] (1.Kanazawa University, 2.The University of Tokyo, 3.National University of Mongolia, 4.Industrial Research Institute of Ishikawa)

[AHW30-11] **Spatio-temporal changes of hydrochemical properties and factors controlling hydrochemistry of springs in the Seyfe Basin**

*Cansu Yurteri[1] (1.Hacettepe University)

MERIT Hydro: a new global hydrography map based on multiple satellite observations, and its application to model-satellite integration in global river hydrodynamic simulations

*Dai Yamazaki[1]

1. Institute of Industrial Sciences, The University of Tokyo

High-resolution raster hydrography maps are a fundamental data source for many geoscience applications. Here we introduce MERIT Hydro, a new global flow direction map at 3sec resolution derived from the latest elevation data (MERIT DEM) and water body data sets (G1WBM, Global Surface Water Occurrence, and OpenStreetMap). We developed a new algorithm to extract river networks near automatically by separating actual inland basins from dummy depressions caused by the errors in input elevation data. After a minimum amount of hand editing, the constructed hydrography map shows good agreement with existing quality-controlled river network data sets in terms of flow accumulation area and river basin shape. MERIT Hydro improves on existing global hydrography data sets in terms of spatial coverage (between N90 and S60) and representation of small streams, mainly due to increased availability of high-quality baseline geospatial dataset. We then integrated the MERIT Hydro into the global river hydrodynamic model CaMa-Flood, to utilize the advantage of high-accuracy topography datasets for global river and floodplain simulations. The new CaMa-Flood simulation with MERIT Hydro showed better agreement to various satellite observations of surface waters, compared to the old simulation with SRTM and HydroSHEDS. Flooding of swamp forest was better represented with MERIT Hydro, due to the tree canopy bias removal in MERIT Hydro. Also, direct comparison of absolute water surface elevations between satellite altimetry and hydrodynamic models was first achieved, since absolute elevation bias (up to 10m in SRTM) was removed. Given that the uncertainty in the baseline topography data was largely reduced by the development of MERIT DEM, the direct comparison of surface water dynamics between model and satellite became meaningful. For example, we cannot attribute the error in simulated variables (water level, inundation extent, and discharge) to a specific cause (runoff, bathymetry) if baseline topography has large uncertainty. We introduce our latest activity on utilizing direct satellite-model comparison to estimate channel bathymetry in JpGU presentation.

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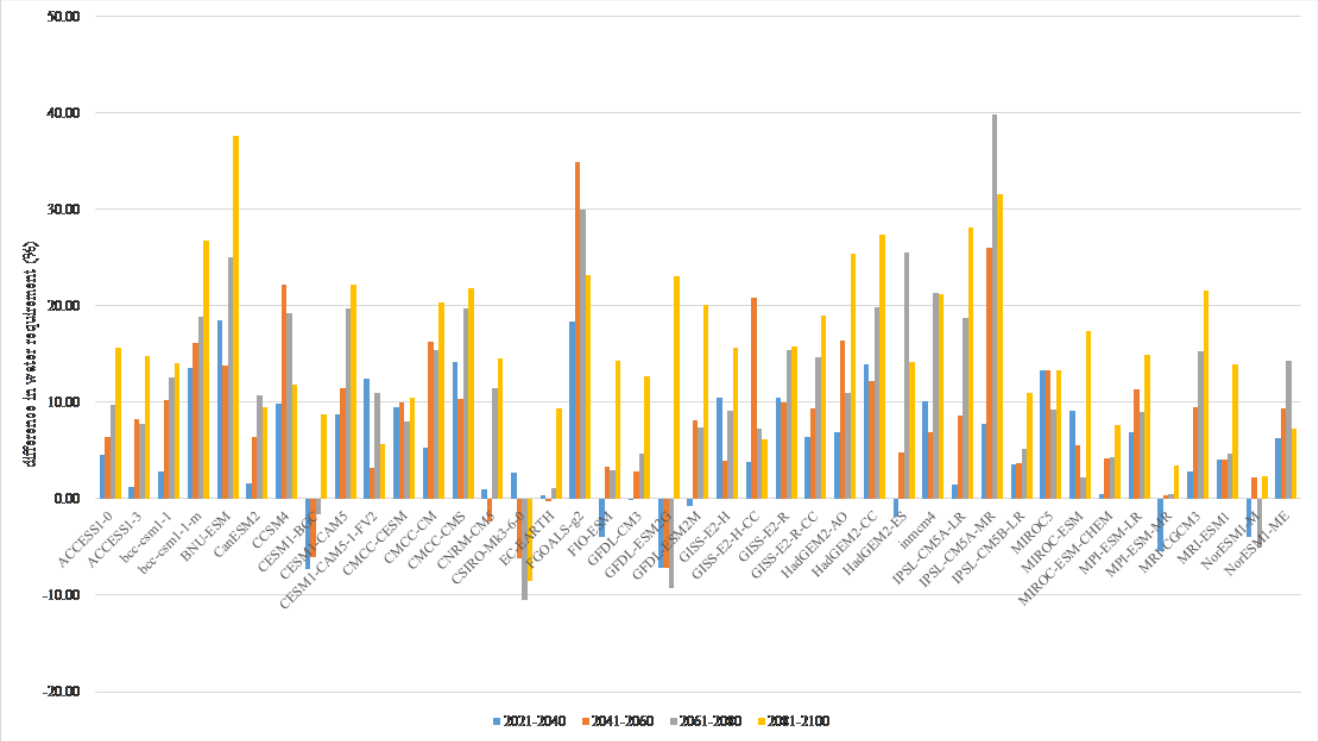
Assessment of Climate Change Effects on the Rice Water Requirements for Hsin-Chu Irrigation Area in Taiwan

YUAN-TUNG HSU[2], MEI-CHANG CHEN[2], SHU-HUE CHU[2], TA-WEI CHIEN[2], *SHIH-WEI CHIANG[1]

1. Agricultural Engineering Research Center, 2. Taiwan Hsinchu Irrigation Association

Agriculture irrigation accounts for 70% of water use worldwide and is sensitive to climate change. There is strong evidence that climate change will influence the rainfall pattern and intensity, which will further increase possibility of droughts. The purpose of this study is to evaluate how changing temperature and rainfall condition affect the rice water requirements. In this study, Hsin-Chu irrigation area in northern Taiwan was chosen as a study case. The climate change related parameters used for calculation are sourced from the fifth Assessment Report (AR5) by the Intergovernmental Panel on Climate Change (IPCC). Representative Concentration Pathways (RCPs) are used to describe possible range of greenhouse gas concentration in the future. There are four statistical downscaling RCPs (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) scenarios with four time periods (2021-2040,2041-2060,2061-2080 and 2081-2100) provided by the Taiwan Climate Change Projection and Information Platform (TCCIP). The CROPWAT model developed by the Food and Agriculture Organization of the United Nations (FAO) was used to quantify the rice water requirements with considering the changes in temperature and rainfall. With the worst-case scenario, RCP8.5, the calculation shows that average water requirements will increase by 5.16% in 2021-2040, 8.41% in 2041-2060, 11.14% in 2061-2080 and 15.74% in 2081-2100 for early rice while increase by 0.52% in 2021-2040, 1.86% in 2041-2060, 2.6% in 2061-2080 and 4.35% in 2081-2100 for late rice.

Keywords: Climate Change, RCP, Rice Water Requirements, CROPWAT



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Land use / land cover and discharge in the Altamaha River 1992-2016, Georgia, USA

*James Deemy[1], Kimberly Takagi[1], Cameron Atkinson[1], Nicholas Harris[1], Nellie Little[1]

1. College of Coastal Georgia Department of Natural Sciences

Watershed land use / land cover (LULC) is a driver of the quality and quantity of discharge from rivers. Stream discharge may more likely to be affected by the land use / land cover in close proximity than more distant areas of the watershed. Additionally, different LULC classes may stream affect discharge equally across scales and thus scale may be more relevant when managing some LULC at greater distances from streams. Our objectives were to 1) determine if LULC changes in the greater Altamaha are associated with discharge metrics; 2) determine which LULC classes are most related to our focal discharge distribution; and 3) determine spatial scales at which LULC changes are most strongly associated with our focal discharge metrics. The Altamaha River Watershed encompasses five sub-watersheds (The Altamaha, Ocmulgee, Little Ocmulgee, Oconee, and Ohoopee) and covers 35,000 km^2 of Georgia. Stream discharge data were downloaded from the USGS Water Watch program (Altamaha river at Doctortown: station 02225000). Discharge data was selected for 3 year windows centered on the year of each NLCD LULC dataset. Three-year minimum, median, mean, first & third quantiles, and peak recorded discharge were selected as focal discharge metrics. Subsequently, correlations between each discharge metric and aggregate land use / land cover were calculated at each buffer scale. Forest land use was positively correlated with first quantile discharge at the 50 and 500 m stream buffers. Developed LULC near streams was negatively correlated with first quantile discharge at all spatial scales. Wetlands were negatively correlated with the 3rd quantile discharge at the 50 m steam buffer. In several sub-watersheds, agricultural and forest land use strongly correlated with the median and minimum recorded discharge at the 50 and 500 m stream buffers. Developed and wetland land use cover near streams was negatively correlated with minimum recorded discharge in most sub-watersheds. Discharge metrics appear to be most strongly associated with LULC in the immediate vicinity of the stream (50 m) and within larger buffers (500 m). Increased developed LULC may drive decreased discharge through increased surface runoff generating flashier hydrographs. Higher minimum recorded discharges associated with high forest cover and agricultural LULC could result from greater baseflow. These results are may be applicable to planning watershed management as well as targeting forest management and restoration plans.

Keywords: discharge, land use / land cover, Altamaha

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Role of colloids on the (im)mobility of toxic elements in mine drainage systems with acidic and circumneutral pH

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Passive treatment systems are continually gaining popularity with regards to mine drainages due to their sustainability. Among other contaminants, pollution by heavy metals is prevalent and requires a detailed understanding of the systems to develop an effective wastewater treatment system. In passive treatment systems, some sequestration mechanisms include coprecipitation and adsorption, however, the significant factors controlling these processes may vary from system to system because of variations in geochemical properties. Therefore, this study clarifies the mechanisms that influence the attenuation behaviours of contaminants in two mine drainages of varying properties.
Ainai mine drainage and Shojin river have circumneutral and acidic pH respectively but are both high in Fe. The thermodynamic properties of Fe allow for the formation of Fe colloids that assist in the sequestration of these elements. In order to clarify the distribution of metals (e.g., As, Zn, Pb and Cd) in the drainages, the dissolved and colloidal fractions obtained from micro- and ultrafiltration were analysed. Despite the pH variations in Ainai (avg 7.1) and Shojin (avg 3.1), Fe colloid formation was observed in both systems. However, a detailed observation of the trends suggests that pH >3.1 may efficiently allow for colloid formation and toxic element sequestration. Trends of As were similar to those of Fe, indicating efficient sequestration by the Fe colloids. Pb and Zn are comparatively less sequestered due to competitive adsorption and pH dependence of the elements to be efficiently adsorbed. Hence, Pb and Zn were majorly present in dissolved fractions, despite the presence of LDH that partially reduced the Zn concentrations in Ainai mine drainage. Aggregation is observed in both systems which results in a deposition of the colloid aggregates and hence an efficient removal of Fe and As, and minimally, Pb and Zn from the mine drainages. This study demonstrates the significance of colloidal particles for the sequestration of metals and the significance of detailed characterisation of colloids in the environment.

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Source Identification of Molybdenum in Natural Water Around Erdenet City, Mongolia

*Solongo Tsetsgee[1,3], Fukushi Keisuke[1], Altansukh Ochir[3], Takahashi Yoshio[2], Munemoto Takashi[4], Akitoshi Akehi[1], Ariuntungalag Yunden[3], Enkhjin Odgerel[3], Taivanbat Batbold[3], Noriko Hasebe[1]

1. Kanazawa University, 2. The University of Tokyo, 3. National University of Mongolia, 4. Industrial Research Institute of Ishikawa

Erdenet city is second biggest city and located northern part of Mongolia. Increase of population, the environmental pollution is becoming serious concern. Erdenet mine is one of the largest copper –molybdenum mine in the world and mainly produced Cu –Mo. Surface water contaminated with high concentrations of molybdenum (Mo), but amount of Cu concentration is lowest with neutral pH. This study was systematically determining the source identification of Mo from rivers in Erdenet city. The water samples were collected from three rivers. Govil river flows from north west of the study area and merge to the Erdenet river. That two rivers are become a Khangal river.

Based on the spatial and temporal distribution of Mo concentration indicated the contaminated area and source of Mo was derived in August 2019. Govil river and Erdenet city centers are less than 30 μg/L. On the other hand, Erdenet and Khangal rivers are exceeds the WHO guideline 70 microgram per liter (μg/L) and higher than the world average. The tailing pond and ash pond seepage water was continuously drain to the downstream of the Erdenet and Khangal rivers. Due to sources of Mo is coming from mine tailing pond and ash pond of the power plant ranging 280 - 1700 μg/L. Groundwater was containing high concentration of Mo about 600 μg/L. Results suggest that the pond seepage water and groundwater are may main source of Mo contamination in the surface environment.

Acknowledgments:

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Keywords: Erdenet city, Surface water, Source identification

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Spatio-temporal changes of hydrochemical properties and factors controlling hydrochemistry of springs in the Seyfe Basin

*Cansu Yurteri[1]

1. Hacettepe University

The aim of this study is to determine the hydrochemical properties of water resources in the Seyfe Basin and to understand processes involving water chemistry using statistical techniques such as principal component analysis (PCA) and cluster analysis. Seyfe Lake closed basin is located west of Kirsehir (Turkey) in the Central Anatolia. Considering the importance of the Seyfe Lake Basin for its water resources potential and due to its fragile ecosystem, a detailed hydrogeological characterization of the basin has been undertaken. In order to characterize hydrogeological system accurately, water samples were collected from springs, wells and drainage channels during September and December 2019 field campaigns from the Seyfe Lake wetland basin. The temperature, pH, total dissolved solids (TDS) and specific electrical conductance ($EC_{25^{\circ}C}$) were measured at the field and spatio-temporal changes of major ions are evaluated. The waters have neutral to slightly alkaline character, and most of the water samples are saturated with calcite, dolomite and aragonite minerals. According to the results obtained from Gibbs, Piper plot, and PCA, the water-rock interaction takes place without any remarkable ion exchange reactions. Water facies identified with the Piper diagram, supports this view. Water types are determined as Ca-HCO_3 for springs; Na-HCO_3 for wells; Na-SO_4 for drainage channel in the dry season and Na-Cl in the rainy season. In Ihe study area; ionic compositions of the springs are not affected by seasonal changes. The high sulfate concentration is probably related to the weathering of evaporitic rocks in the basin. The waters are grouped according to the results, and the difference observed within the groups are related to the lithology of aquifers and flow path of the waters.

Keywords: Hydrochemistry, Major ions, Kirsehir, Seyfe Closed Basin, Spatio-temporal changes, Central Anatolia

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-HW Hydrology & Water Environment

[A-HW30] Hydrology & Water Environment

convener:Ayumi Kotani(Graduate School of Bioagricultural Sciences, Nagoya University), Takeshi Hayashi(Faculty of Education and Human Studies, Akita University), Keisuke Fukushi(Institute of Nature & Environmental Technology, Kanazawa University), Masahiro Tanoue(School of Engineering, The University of Tokyo)

We focus on various issues of water cycle and environment and aim to answer questions of hydrological and earth system sciences; 1) surface, subsurface and evapotranspiration processes of water cycle, 2) natural and anthropogenic hydrothermal systems, 3) environments issues and studies on a watershed or global scale, 4) water-related issues with ecological, environmental, and geochemical aspects, and 5) other issues in hydrological sciences. We welcomes presentations regarding various kinds of approaches and techniques such as field survey, remote sensing, isotope tracers, numerical simulation, and theoretical analysis. This session is jointly hosed by societies of water-related geoscience (Geochemical Society of Japan, Japanese Association of Groundwater Hydrology, Japanese Association of Hydrological Sciences, and Japan Society of Hydrology and Water Resources), and accepts wide-range research topics related to water cycle and environment described above.

[AHW30-12] Hydrology and astrobiology on early Mars: Insights from hydrology in cold semiarid areas in central Aria, Mongolia

★Invited Papers

*Yasuhito Sekine[1,2], Keisuke Fukushi[2] (1.Tokyo Institute of Technology, 2.Kanazawa University)

[AHW30-14] Advantages of continuous modelling for design hydrograph estimation in small and ungauged basins

*Salvatore Grimaldi[1,4], Maria Cristina Rulli[2], Aldo Fiori[3], Elena Volpi[3] (1.Università degli Studi della Tuscia, Italy, 2.Politecnico di Milano, Italy, 3.Universita' Roma Tre, Italy, 4.International Association of Hydrological Sciences)

[AHW30-15] Comparison of speciation and solubility of arsenic, lead, and cadmium in contaminated soils from Kamegai mine tailing, Toyama, Japan

*Baasansuren Gankhurel[1], Keisuke Fukushi[1], Akitoshi Akehi[1], Yoshio Takahashi[2], Xiaolan Zhao[3], Kazuo Kawasaki[4] (1.Kanazawa University, 2.The University of Tokyo, 3.Chang'an University, 4.University of Toyama)

[AHW30-16] Amount effect on the diurnal isotopic composition of precipitation in the Kra Isthmus of Thailand

*Jeerapong Laonamsai[1], Kimpei Ichiyanagi[1], Kiattipong Kamdee[2] (1.Kumamoto University, 2.Thailand Institute of Nuclear Technology)

[AHW30-17] Seasonal fluctuation of Tritium concentration in precipitation at Akita, north east Japan

*Takeshi Hayashi[1] (1.Faculty of Education and Human Studies, Akita University)

Hydrology and astrobiology on early Mars: Insights from hydrology in cold semiarid areas in central Aria, Mongolia

*Yasuhito Sekine[1,2], Keisuke Fukushi[2]

1. Tokyo Institute of Technology, 2. Kanazawa University

The surface of current Mars is hyperarid and cold; however, early Mars would have been wetter and warmer in ~4 billion years ago as evidenced by the widespread occurrence of valley networks, lake deposits, and clay minerals. Despite of the geological and geochemical evidence for surface liquid water, climate models suggest that a long-term, wet and warm Mars is not sustainable. Instead, recent climate modeling and geochemical modeling have proposed relatively short-term semiarid climates for early Mars to explain the geological and geochemical observations (Wordsworth et al., 2015; Bishop et al., 2018; Fukushi et al., 2019). Although theoretical models are used to investigate past climates on Mars, hydrological cycles on early Mars remain poorly constrained based on geological evidence. Did groundwater supply sustain surface water? Was surface runoff required to support surface water? Was the water chemistry of the surface water same as that of groundwater? These questions remain unsolved due to lack of the constraints on groundwater chemistry and subsurface hydrological cycles on early Mars. In this regard, terrestrial analogs of saline lakes at semiarid climates may provide insights into the fluvial/lacustrine environments on early Mars.

Here, we report results of geological survey for subsaline closed-basin lakes in the Khangai and Gobi-Altai mountains transition zone in southern Mongolia. The Valley of the Gobi Lakes is semiarid, where evaporation predominates precipitation (Szuminska, 2016). The water source of the Valley of the Gobi Lakes replies largely on the supply from snow melting and permafrost degradation of the Khangai mountains. These characteristics of the climate, hydrology, and possibly biology may allow this area as a promising and unique terrestrial analog for closed-basin lake systems developed on semiarid early Mars.

Keywords: Mars, hydrology, aqueous environments

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Advantages of continuous modelling for design hydrograph estimation in small and ungauged basins

*Salvatore Grimaldi[1,4], Maria Cristina Rulli[2], Aldo Fiori[3], Elena Volpi[3]

1. Università degli Studi della Tuscia, Italy, 2. Politecnico di Milano, Italy, 3. Universita' Roma Tre, Italy, 4. International Association of Hydrological Sciences

Estimating the design hydrograph (DH) is a crucial problem in practical hydrology and hydraulics. The development of reliable DHs is particularly challenging in small and ungauged basins due to the lack of observed discharge data that are needed for calibrating advanced models. For such basins, the modeler is often forced to adopt simple and conceptual modelling like the so called event-based approach. It consists in selecting a design rainfall event, which is related to an assigned return period, estimating the rainfall excess and then transforming it into the DH. In recent years, the continuous modelling approach was introduced. This relies on generating a long synthetic rainfall time series at sub-daily resolution that feeds a continuous rainfall–runoff model. Then, a discharge time series is produced that allows for estimating the DH. In this work, we would like to emphasize the added value of the continuous modelling approach in providing a more reliable estimation of the DH.

Keywords: design hydrograph, event-based approach, Continuous modelling, rainfall-runoff modelling.

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Comparison of speciation and solubility of arsenic, lead, and cadmium in contaminated soils from Kamegai mine tailing, Toyama, Japan

*Baasansuren Gankhurel[1], Keisuke Fukushi[1], Akitoshi Akehi[1], Yoshio Takahashi[2], Xiaolan Zhao[3], Kazuo Kawasaki[4]

1. Kanazawa University, 2. The University of Tokyo, 3. Chang'an University, 4. University of Toyama

Mining extraction and processing generate large volumes of metal-rich waste tailings. This tailing considered to be a principal cause of soil contamination in mining areas. Once these toxic metals are introduced into soils with surface water, they can be transported deeply into the soil and groundwater, threatening environmental health. This study determined speciation and solubility of As, Pb, and Cd in soils from the mine tailing area, by employing a sequential extraction (SEP) and X-ray absorption fine structure (XAFS).

The results revealed that most of As in the soil is pentavalent oxidation states and is adsorbed on primarily goethite and secondarily ferrihydrite. The As(V) favorably can adsorb to the ferric oxides under acidic conditions, while it prefers to desorb from the minerals under alkaline conditions. Results showed most of Pb was adsorbed on goethite which is rich in the soil sample. Based on the SEP, the high ionic strength and/or slightly lower pH solution can lead to the significant release of Pb to solutions. Cd is mainly adsorbed on clay minerals. Due to the high cation exchange capacity of clay minerals, Cd placed in the interlayer can be released with the other cations with high concentrations in the surrounding solutions.

The river water in this area is characterized by low ionic strength and slightly alkaline pH. The concentrations of Pb and Cd in the river are always less than 0.07 ug/L, while that of As in the river sometimes exceeds 10 ug/L. The solubilities of heavy metals in the river in this area are consistent with those predicted by the chemical speciation.

Keywords: arsenic, cadmium, lead, solubility, contaminated soil

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Amount effect on the diurnal isotopic composition of precipitation in the Kra Isthmus of Thailand

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1. Kumamoto University, 2. Thailand Institute of Nuclear Technology

Diurnal variability of stable isotopes in precipitation and its controlling factors are poorly understood, especially in the tropics. This study investigated the diurnal variability of stable isotopes in rainfall observed at Ranong Province in the Kra Isthmus of southern Thailand. Rainfall samples were collected at daily intervals from 1st March 2013 to 25th September 2015. The oxygen and hydrogen isotopic compositions (δ^{18}O and δ^{2}H) of the rainwater varied from −15.86‰ to 1.42‰ and from −121.65‰ to 10.61‰, respectively, and the d-excess varied from 0.73‰ to 18.51‰. The observations revealed that diurnal variation in isotope was not statistically correlated with rainfall amount for the entire period. However, the precipitation amount was highly significant when increasing timescale. At monthly timescale, the δ^{18}O is highly correlated to the average precipitation amount (in term of rainfall intensity) rather than an accumulative amount. It can be attributed to the adjoining sea surface which is the dominant source of water vapor to the observed site, providing for shorter water vapor trajectories and characterizing less accumulative isotopic fractionation. Moreover, the gradual depletion of δ^{18}O was found to be correlated with the Madden-Julian oscillation, which organizes the passage of regional convective activity from Indian Ocean to Pacific Ocean. Furthermore, the differences in moisture source and ratio of stratiform/convective rain rate might affect the isotopic composition of rainfall in the tropics. This showed that the precipitation events of the Kra Isthmus were provided by various air masses and moisture sources between the Indian and Pacific Oceans.

Keywords: Amount effect, Hydrogen-2, Oxygen-18, Rainfall, Kra Isthmus, Thailand

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Seasonal fluctuation of Tritium concentration in precipitation at Akita, north east Japan

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1. Faculty of Education and Human Studies, Akita University

Akita Univ. has joined the Global Network of Isotopes in Precipitation (GNIP), IAEA since 2016. We also provided a batch of precipitation samples which was collected in the Oga peninsula between Jan. 2015 and Jan. 2017. Tritium concentration, $d^{18}O$, and dD of these samples have been analyzed by IAEA. We will report the characteristics of time series and seasonal fluctuations of Tritium concentration in both sampling sites in this presentation.
The sampling locations of both sites are as follows; Akita Univ.: the rooftop of a three-storied building in Akita Univ. (ground EL: 9 m), the Oga peninsula: Hachiboudai hill which is located in the northwestern part of the peninsula (EL: 184 m). The sampling periods of both sites are two weeks (Akita Univ.) and one month (Oga peninsula), respectively.
Tritium concentration in the precipitation largely varied (from 1.6 to 9.1 TU) between Jan. 2015 and Sep. 2018. The time series of Tritium concentration showed an obvious seasonal fluctuation called "Spring peak" and increased between February and June. However, the Tritium concentration showed large fluctuations even in the Spring peak season. Accordingly, we estimated the origins of air mass and water vapor of the precipitation events which were the major events in each sampling period based on hourly satellite images, hourly precipitation, and daily weather maps (after Japan Meteorological Agency). As a result, the origins of air mass and water vapor were considered to affect the Tritium concentrations. For example, in the winter season, although the air mass that contains a high concentration of Tritium comes from the northeastern part of the Eurasian continent to Japan, the huge amount of water vapors with very low Tritium concentration is supplied to the air mass from the Sea of Japan. Thus, the precipitation, mostly snow, at Akita contains low Tritium concentration. On the other hand, in the spring season, the air mass still comes from the Eurasian continent, but the volume of water vapor that is supplied from the Sea of Japan largely decreases. Therefore, the precipitation at Akita contains relatively high Tritium concentration.

Keywords: precipitation, Tritium, Sea of Japan, spring peak

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-HW Hydrology & Water Environment

[A-HW30] Hydrology & Water Environment

convener:Ayumi Kotani(Graduate School of Bioagricultural Sciences, Nagoya University), Takeshi Hayashi(Faculty of Education and Human Studies, Akita University), Keisuke Fukushi(Institute of Nature & Environmental Technology, Kanazawa University), Masahiro Tanoue(School of Engineering, The University of Tokyo)

We focus on various issues of water cycle and environment and aim to answer questions of hydrological and earth system sciences; 1) surface, subsurface and evapotranspiration processes of water cycle, 2) natural and anthropogenic hydrothermal systems, 3) environments issues and studies on a watershed or global scale, 4) water-related issues with ecological, environmental, and geochemical aspects, and 5) other issues in hydrological sciences. We welcomes presentations regarding various kinds of approaches and techniques such as field survey, remote sensing, isotope tracers, numerical simulation, and theoretical analysis. This session is jointly hosed by societies of water-related geoscience (Geochemical Society of Japan, Japanese Association of Groundwater Hydrology, Japanese Association of Hydrological Sciences, and Japan Society of Hydrology and Water Resources), and accepts wide-range research topics related to water cycle and environment described above.

[AHW30-18] Remobilization mechanism of sediments phosphorus under microbial activity in a polluted river, South China

*Rui Li[1], Jianyao Chen[1], Lei Gao[1] (1.Sun yat-sen Univ.)

[AHW30-19] **Hydrogeochemical and Isotopic Evidence of Groundwater Evolution and Characterization in Upper Walawe Basin, Sri Lanka**

*Sachintha Lakshan Senarathne[1], J.M.C.K Jayawardana[1], Rohana Chandrajith[2], E.A.N.V Edirisinghe[3] (1.Sabaragamuwa University of Sri Lanka, 2.University of Peradeniya, Sri Lanka, 3.Sri Lanka Atomic Energy Board)

[AHW30-20] Application of Optimization Model for Urban Drainage Layout Design under Street Flow and Operation of Pumping Station

*Chien-Lin Huang[1], Nien-Sheng Hsu[1], Gene Jiing-Yun You[1], Sih-Wen Cheng[1], Hung-Ren Liu[1] (1.National Taiwan University, Taiwan)

[AHW30-21] **Estimation of Evapotranspiration Fluxes using METRIC Model over Sub-tropical Moist Deciduous Forest in Doon Valley, India**

*Saurabh Purohit[1,2], N R Patel[1], Bhaskar R Nikam[1], S P Aggarwal[1], Triparna Sett[1], Prakash Chauhan[1] (1.Indian Institute of Remote Sensing, Dehradun, India, 2.Forest Research Institute Deemed to be University, Dehradun, India)

[AHW30-22] Effect of precipitation on interannual variability of permafrost active layer thickness at larch forests in eastern Siberia

*Ayumi Kotani[1], Tetsuya Hiyama[2], Taro Nakai[3], Takeshi Yamazaki[4], Trofim Maximov[5] (1.Graduate School of Bioagricultural Sciences, Nagoya University, 2.Institute for Space-Earth Environmental Research, Nagoya University, 3.School of Forestry and Resource Conservation, National Taiwan University, 4.Graduate School of Science, Tohoku University, 5.Institute for Biological Problems of Cryolithozone)

Discussion

Remobilization mechanism of sediments phosphorus under microbial activity in a polluted river, South China

*Rui Li[1], Jianyao Chen[1], Lei Gao[1]

1. Sun yat-sen Univ.

Reductive dissolution of iron (Fe) oxyhydroxides is considered as a key factor of phosphorus (P) endogenous release from sediments in water body. However, the cycling of sulfur (S) can decouple the phosphorus-iron relationship. In this study, the vertical profile of labile-S, Fe, and P concentrations in sediments were measured using the DGT technique in the Danshui River (Huizhou, China) to investigate the remobilization and release characteristics of P in heavily polluted river. Sediment and water samples were collected in January, July, and November, respectively, to explore the controlling factor of P release mechanic. Sediments of the Danshui River showed higher P accumulation and release risk than the Xizhi River. The labile-P concentration in the surface sediment interstitial water increased sharply with depth and reached a maximum in the sub-surface layer (1-2 cm). The highest concentration of labile-P in sediment interstitial water was occurred in the Danshui River in July. The increase of temperature accelerated the mineralization and decomposition of organic matter in the sediments and promoted the reductive dissolution of iron oxyhydroxides. In addition, a strong sulfate reduction was observed in the surface sediments of Danshui River in July, which consumed dissolved ferrous ions and promoted the transformation of P from the solid phase to the liquid phase. We found that the community composition of sulfate-reducing bacteria was different between Xizhi River and Danshui River. The abundance of Desulfomicrobium had a significantly positive correlation ($r=0.631$, $p<0.05$) with labile-S in sediments, and it played an important role in sulfate reduction.

Keywords: DGT technology, phosphorus endogenous release, iron oxyhydroxides, sulfate reduction

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Hydrogeochemical and Isotopic Evidence of Groundwater Evolution and Characterization in Upper Walawe Basin, Sri Lanka

*Sachintha Lakshan Senarathne[1], J.M.C.K Jayawardana[1], Rohana Chandrajith[2], E.A.N.V Edirisinghe[3]

1. Sabaragamuwa University of Sri Lanka, 2. University of Peradeniya, Sri Lanka, 3. Sri Lanka Atomic Energy Board

A detail hydrogeological investigation was carried out in the Walawe River Basin (WRB), the 4th largest river basin in Sri Lanka that flows to the southern lowlands, to identify the groundwater evolution and recharge in the metamorphic hard rock aquifers. The basin is one of the most economically and geologically important river systems. Due to rapid increase of the population and the expansion of agricultural the demand for water in the WRB is rapidly increasing. Water samples were collected from rivers (6), deep (16) and shallow wells (15), and natural springs (3) for hydrogeochemical and isotopic measurements. Gibbs' and elemental ratio plots indicated that groundwater in the region is strongly influenced by rock-water interactions, whereas silicate weathering and ion exchange processes being the leading processes that control the groundwater geochemistry. Ca-HCO_3 type water was found to be the prominent water type while irrigation suitability calculations indicated that low sodium hazard of groundwater. The water isotope data suggested that the groundwater in the basin is recharged from the northeast monsoon rain while some deep groundwater showed a trend of evaporation. The result of this study highlights that the groundwater of the basin is highly vulnerable due to over exploitation and urgently need better water resource management.

Keywords: Environmental Isotopes, Rock-Water Interactions

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Application of Optimization Model for Urban Drainage Layout Design under Street Flow and Operation of Pumping Station

*Chien-Lin Huang[1], Nien-Sheng Hsu[1], Gene Jiing-Yun You[1], Sih-Wen Cheng[1], Hung-Ren Liu[1]

1. National Taiwan University, Taiwan

Considering the uncertainty of urban rainfall-runoff, this study establishes the urban flood control optimization model which embed a street flow simulation model under the pump operation and detention facilities for flows into the street and sewer system. The optimization model is developed by defining and formulating the objective function, constraints and decision variables, in which the flood reduction Benefit/Cost ratio is set to be the objective function. The reasonable range of the height of curbs and the elevation to operate pumps are considered as constraints. The decision variables are specially designed as the height of curbs and the elevation to operate the pumps. Hereafter, the flooding situation before and after the construction of the flood control facilities during each return period is simulated by Storm Water Management Model (SWMM) and solved by the Simulated Annealing (SA) algorithm. Subsequently, the Annual Benefit/Cost Ratio is calculated to optimize the layout design of drainage facilities and pumping operation. This study selected the Min-Sheng community in Taipei city as the test site to evaluate the flooding reduction benefit. Results show that the street flow space has a better effect on the flood control during low return period while the detention facilities have a better reduction on the flood during the high return period. The simulation-optimization outcomes illustrated that the side curbs in street flow space can better flood control in the low-lying area and less effective in the narrow street area. Moreover, the detention facilities improve the flow control in the highland, while with no significant effect in the surrounding area of the end of the sewer. Furthermore, the detention facilities in the highland and large catchment retain high-flow flood; those at the end of the sewer, hold middle-flow flood; and those in the small catchment, impound low-flow flood.

Keywords: Street Flow, Pump Operation, Detention Facilities, Urban Flood Control, SWMM, Simulated Annealing

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Estimation of Evapotranspiration Fluxes using METRIC Model over Sub-tropical Moist Deciduous Forest in Doon Valley, India

*Saurabh Purohit[1,2], N R Patel[1], Bhaskar R Nikam[1], S P Aggarwal[1], Triparna Sett[1], Prakash Chauhan[1]

1. Indian Institute of Remote Sensing, Dehradun, India, 2. Forest Research Institute Deemed to be University, Dehradun, India

Knowledge of Forest Evapotranspiration (ET) provides insights on the role of forests in the hydrological budget. Higher spatial resolution (30 m) ET maps can be helpful to assess its variability associated with the forests at the finer scale. METRIC (Mapping Evapotranspiration at high Resolution with Internalized Calibration) model estimates the amount of actual evapotranspiration of each pixel of the satellite image. Sal (*Shorea robusta Gaertn.f)* forest is the important and the dominant forest type covering Doon valley and there is little investigation to estimate ET using the presented model. There are fewer studies on the forest ET in this region using the remote sensing-based surface energy-based models. The present study was done to evaluate the performance of the METRIC (Mapping Evapotranspiration at high Resolution with Internalized Calibration) model for ET estimation at the Landsat scale (30 m) over the sub-tropical *Shorea robusta Gaertn.f* forest in Doon Valley located in foothills of Himalaya in India. Total of 12 cloud-free Landsat 8 scenes over the study area for the year 2018 were processed using the water package in R Environment for the estimation of ET. Results for daily ET of the cloud-free images were compared with the Eddy Covariance (EC) Flux Tower installed in the Barkot Reserve Forest for 2018. Overall results showed good agreement between the daily ET derived from METRIC model and estimated from Flux Tower data with value of coefficient of determination (r^2) 0.76, Mean Absolute Error (MAE) 0.68, Root Mean Square Error (RMSE) 0.72 mm, Nash Sutcliffe Efficiency (E) 0.85 and Wilmott Index (d) 0.70. Comparison of monthly ET derived from METRIC model and Flux Tower data for January to June 2018 showed similar trends however, METRIC model overestimated ET for months of March to May. The present study is one of the first attempts to prepare high-resolution ET maps at the Landsat scale for the Sal Forests of Doon valley using METRIC model and its validation with the Flux Tower data. It will enhance our knowledge in understanding the energy balance dynamics in the forest.

Keywords: Evapotranspiration, METRIC, Eddy Covariance

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Effect of precipitation on interannual variability of permafrost active layer thickness at larch forests in eastern Siberia

*Ayumi Kotani[1], Tetsuya Hiyama[2], Taro Nakai[3], Takeshi Yamazaki[4], Trofim Maximov[5]

1. Graduate School of Bioagricultural Sciences, Nagoya University, 2. Institute for Space-Earth Environmental Research, Nagoya University, 3. School of Forestry and Resource Conservation, National Taiwan University, 4. Graduate School of Science, Tohoku University, 5. Institute for Biological Problems of Cryolithozone

Seasonal freeze and thaw cycle of permafrost active layer in terrestrial ecosystem depends on both climate and physical characteristics of the vegetation cover and active layer soils. This study investigated interannual variability of active layer thickness with focus on effect of precipitation and accordingly soil water in the active layer. We analyzed two field data obtained at two larch-dominated forests mixed with birch and willow, in the southern and middle parts of the Lena basin. One is the Spasskaya Pad station (SP) on alluvial terrace near Yakutsk (62° 15´N, 129° 14´E). The other is Elgeeii (EG) station (60° 0´N, 133° 49´E) located at erosional plain, 300 km southeast of Yakutsk. Reflecting different geographical location. Sensitivity of active layer thickness was tested with the land surface model.

Based on continuous measurement of soil temperature and water, we found difference of temperature and its seasonal pattern is larger in freezing period than thawing period. Soils at EG freeze slower with longer zero curtain period, especially in the deeper layer. Length of the zero curtain period depends on soil water. Therefore, the minimum temperature was higher and recorded in one month later at EG, compared to SP site. As a result, the difference in soil temperature just before thawing is higher at EG. Deeper snow accumulation at EG also could act as insulation to impede decreasing temperature. In contrast, the difference in temperature during thawing period was small. In spite of the lower temperature before thawing at SP, higher penetrating solar radiation to the forest floor and thinner organic accumulation layer could promote energy input into the active layer. Dependency of seasonal thawing speed on the soil water was complicated, compared to the freezing period. Although the wetter soil condition promoted thawing because of high thermal conductivity, these relationships was unclear close to the ground surface, in which the air and surface temperature dominates thawing speed in the drier soil condition.

This work was carried out by ArCS (Arctic Challenge for Sustainability) project and joint research program for Space-Earth Environmental Research, Nagoya University.

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-HW Hydrology & Water Environment

[A-HW31] Surface and subsurface hydrologic models: From uncertainty analysis to water management

convener:Tomochika Tokunaga(Department of Environment Systems, University of Tokyo), Rene Therrien(Laval University), Philip Brunner(Center for Hydrogeology and Geothermics, University of Neuchatel), Jiaqi Liu(The University of Tokyo)

Surface and subsurface hydrologic models (SSHM) simulate the relevant components of the water cycle that affect surface water and groundwater. Such models thus constitute important tools to support water resources management. For example, model predictions are used to manage increased water use, water pollution, droughts and floods.

Nevertheless, significant challenges are inherent to the development and application of SSHMs. One critical issue is the limited amount of data to inform model parameters. Moreover, automated calibration and a comprehensive uncertainty analysis of large-scale SSHMs are rarely carried out because of their high computational cost. In addition, there is a large uncertainty associated with the conceptualization of the relevant processes and the parametrization of subsurface heterogeneity, which can undermine the reliability of the predictions made.

For this session we seek presentations that focus on numerical simulations tools for water resources management and present solutions for pressing scientific challenges such as model calibration, uncertainty analysis or the conceptualization of the surface and subsurface and the relevant processes. Presentations that showcase examples where numerical modelling tools are employed for water resource management at emergency situations (e.g. earthquakes, tsunamis, droughts or stormfloods) are also encouraged.

[AHW31-01] Numerical analysis of the hyporheic flow in a gravel aquifer subjected to an extraction scheme using multiple radial collector wells

*Sue Tse Jhong[1], Jun Ying Huang[2], Chih Tse Wang[2], Tai Sheng Liou[3] (1.National Chung Cheng University Institute of applied geophysics and environmental science, 2.Stantec Consulting Services Inc., Taiwan Branch, 3.Department of Earth and Environmental Sciences, National Chung Cheng University)

[AHW31-02] Study on utilization of groundwater under emergency situations caused by natural disasters: A modeling approach in the Kanto Plain, Japan.

*Fukazawa Souki[1], Kazuhiro TADA[1], Hiroyuki TOSAKA[1], Yasuhiro TAWARA[1] (1.Geosphere Environmental Technology Corp.)

[AHW31-03] Simulating Two-Way Feedbacks between Surface-Water and Groundwater Management with the Surface Water Operations Process

*Scott E Boyce[1], Ian M. Ferguson[2] (1.U.S. Geological Survey, California Water Science Center, 2.U.S. Bureau of Reclamation)

[AHW31-04] **Predicting baseflow at the basin scale with an integrated surface and subsurface flow model**

*Rene Therrien[1], Hugo Delottier[1] (1.Laval University)

[AHW31-05] Metrics for Environmental Simulation in Decision Support

★Invited Papers

*John Doherty

Numerical analysis of the hyporheic flow in a gravel aquifer subjected to an extraction scheme using multiple radial collector wells

*Sue Tse Jhong[1], Jun Ying Huang[2], Chih Tse Wang[2], Tai Sheng Liou[3]

1. National Chung Cheng University Institute of applied geophysics and environmental science, 2. Stantec Consulting Services Inc., Taiwan Branch, 3. Department of Earth and Environmental Sciences, National Chung Cheng University

Clean water stored in a hyporheic zone can be directly used as a source of municipal water supply such that the cost of water treatment can be reduced. Another advantage of hyporheic water is its stable reserve even in dry seasons when the river water is depleted to a large extent. In the literature, however, no detailed numerical simulations of the response of a hyporheic zone corresponding to the extraction of water from radial collector wells have been published. In addition, the desaturation process during the extraction has not been rigorously considered. Therefore, this study aims to develop a numerical approach for investigating the physical processes in a hyporheic zone during the extraction period.
A river in northern Taiwan was selected to evaluate its feasibility of exploring additional water resources for municipal water supply. In general, the simulation domain needs to be selected from the reach that is free from contamination. For the selected river, hydrogeological characterization of its river basin is difficult but not impossible because not a single geological borehole is present in this area. Therefore, the simulation domain is characterized based on logging data form a borehole that is nearby the simulation domain.
Only the topmost unconfined aquifer is investigated in this study. Based on the existing logging data, this aquifer is conceptualized as five homogeneous but anisotropic sublayers of variably saturated gravel with only one thin layer representing the fine sand. The commercial software FEFLOW is used to simulate the three-dimensional steady-state hyporheic flow by solving the Richards equation combined with the van Genuchten model such that the desaturation process can be taken into account. Constant head boundary conditions are assumed at the western and eastern boundaries. No flux boundary condition is assumed elsewhere.
It was found that the direction of hyporheic flow is not normal to the river channel but parallel to it. Based on the presence of circulated sub-vertical exchange of groundwater in the vicinity of the fine sand layer, the hyporheic zone is defined as the unconfined aquifer between the river bed and the first layer with low hydraulic conductivity. In our model, three radial collector wells were located at the flood plain with high hydraulic conductivity. Simulation results have confirmed that water is extracted from the hyporheic zone but not from the river. Furthermore, the drawdown obtained by multiple collectors is significantly smaller than that obtained by a single point well.
In summary, a methodological approach has been developed. In particular, the detailed variation of hydraulic head and Darcy flux in the neighborhood of a radial collector well can be vividly revealed thanks to the mesh refinement and three-dimensional visualization capabilities provided by FEFLOW. Once a detailed hydrogeological conceptual model is available, this approach can be repeated to provide prediction results of higher precision to facilitate the decision making regarding the design of water resource exploitation.

Keywords: hyporheic flow, radial collector well, water resource, FEFLOW

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Study on utilization of groundwater under emergency situations caused by natural disasters: A modeling approach in the Kanto Plain, Japan.

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1. Geosphere Environmental Technology Corp.

Serious water shortage could occur after natural disasters, such as great earthquakes centered directly under big cities, extensive flooding induced by extreme rainfalls, and long-term droughts. In the aftermath of disasters, significant water demand would rapidly rise for the service at evacuation shelters and hospitals. In disaster preparedness plans of many local governments in Japan, groundwater is regarded as a good alternative water supply source under emergency situations. However, the potential of using groundwater under emergency situations cannot be verified without information from hydrogeological analysis. Also, it is necessary to carefully evaluate the risks of land subsidence caused by groundwater abstraction activities. This study aims to provide local governments with site specific guidance of safe groundwater usage under emergency situations by integrating information both from geosphere and human activity into up-to-date numerical models. In this presentation, we will introduce a case study of the Kanto Plain, Japan. The Kanto Plain covers a land area of around 40,000 km2, where multiple metropolitan areas and watersheds are surrounded by mountainous areas. Relevant information on climate, geology, land use, groundwater and river runoff observations, and records of groundwater pumping data, were collected. To evaluate surface/groundwater resources, we developed a 3D numerical model by using the simulator GETFLOWS that solves fully coupled surface/subsurface hydrological flows. The model was discretized into 39 million elements, including a 250 m ×250 m regular grid system based on 5 m DEM in the horizontal direction and around 50 layers based on the geological structure/facies distributions in the vertical direction. Information on vegetation and other land uses was assigned to the model surface. Calibrations were carried out against observed groundwater levels and river runoff data with a trial and error basis. Detailed simulations results and discussion will be introduced in this presentation.

Keywords: Groundwater utilization in emergency situations, 3D hydrogeological model of the Kanto Plain, surface/subsurface coupled simulation

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Simulating Two-Way Feedbacks between Surface-Water and Groundwater Management with the Surface Water Operations Process

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It is well established that groundwater pumping affects surface-water supplies by reducing groundwater discharge to streams or increasing seepage losses from stream channels. Conversely, surface-water management can affect groundwater supplies and use by altering the timing, location, and quantity of groundwater recharge and demand. Understanding these interactions between groundwater and surface-water supplies, management, and use is critical to conjunctive water management, flood protection, environmental requirements, and Flood-Managed Aquifer Recharge (FloodMAR). However, the majority modeling approaches used in water resources planning and management, focus on either the physical system (hydrologic processes) or the managed system (water operations), with simplified treatment of the other.

The Surface Water Operations Process (SWO) was developed by the US Geological Survey and the US Bureau of Reclamation to allow fully-coupled simulation of surface-water operations within MODFLOW One-Water Hydrologic Flow Model[1] (MF-OWHM). MF-OWHM is a MODFLOW-based conjunctive use simulation software that simulates groundwater flow, stream flow, and landscape usage and water demand. The first version of MF-OWHM[2] was selected by the World Bank Water Resource Software Review[3] as one of three recommended simulation programs for conjunctive use and management modeling. This presentation introduces the key features of SWO and a synthetic example problem that illustrates how MF-OWHM can be used for FloodMAR, an environmental flow requirement, reservoir deliveries for agricultural demand.

[1]Boyce, S.E., Hanson, R.T., Ferguson, I., Schmid, W., Henson, W., Reimann, T., Mehl, S.M., and Earll, M.M., 2020, One-Water Hydrologic Flow Model: A MODFLOW Based Conjunctive Use and Integrated Hydrologic Flow Model: U.S. Geological Survey Techniques and Methods 6-A60, 576 p

[2]Hanson, R.T., Boyce, S.E., Schmid, Wolfgang, Hughes, J.D., Mehl, S.M., Leake, S.A., Maddock, Thomas, III, and Niswonger, R.G., 2014, One-Water Hydrologic Flow Model (MODFLOW-OWHM): U.S. Geological Survey Techniques and Methods 6-A51, 120 p., https://dx.doi.org/10.3133/tm6A51.

[3]Borden, John Carter; Gaur, Anju; Singh, Chabungbam Rajagopal, 2016, Water resource software: application overview and review. Washington, D.C.: World Bank Group.

Keywords: Reservoir Operations, Conjunctive Use Managment, Numerical Modeling of Hydrological Processes, Reservoir, Streamflow, Groundwater Linkage, Groundwater-Surface water modeling

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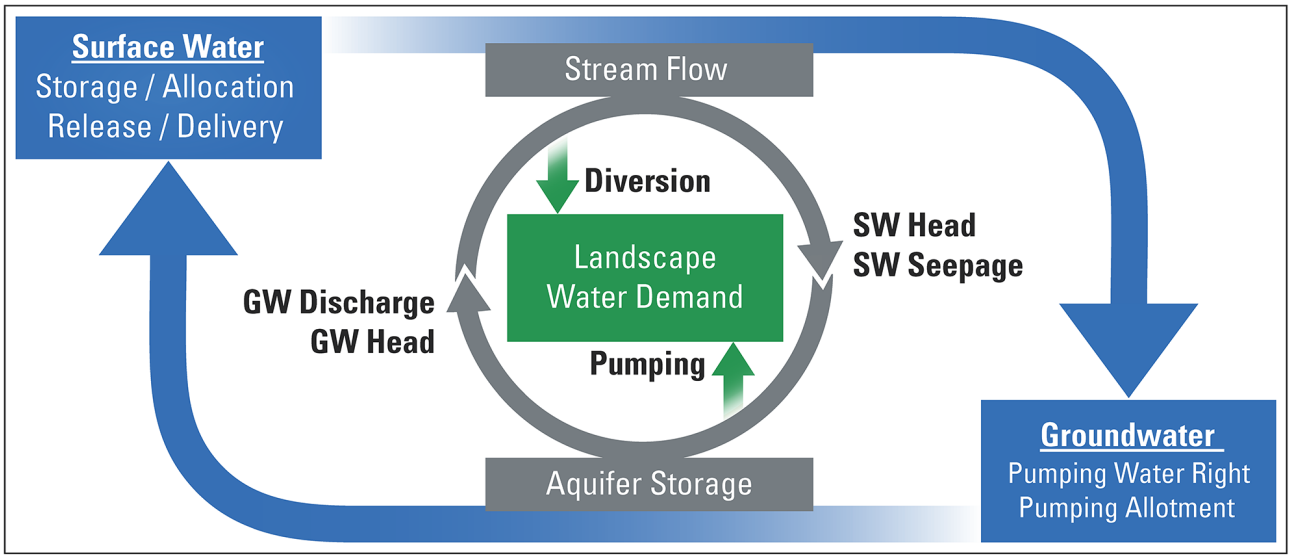

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Predicting baseflow at the basin scale with an integrated surface and subsurface flow model

*Rene Therrien[1], Hugo Delottier[1]

1. Laval University

The sustainable management of water resources under a changing climate is a major challenge of the 21th century. Basin-scale models are often preferred to investigate the potential effects of climate change on the terrestrial portion of the water cycle because they correspond to the scale of water policy decision. Potentially longer and more pronounced drier periods may increase the occurrence of low-flow periods, with reduced groundwater recharge and baseflow to streams and rivers. Integrated Surface and Subsurface Hydrological Models (ISSHMs) are well suited to investigate these low-flow events but their high computational cost can be a limiting factor to provide rigorous model calibration and uncertainty analysis at the basin scale.

We use here the integrated modeling platform HydroGeoSphere (HGS), which is an ISSHM that couples three-dimensional variably-saturated subsurface flow and two-dimensional surface water flow. HGS can also simulate snow accumulation, snowmelt, and evapotranspiration. The main input to the model is precipitation, which is then redistributed along the surface and in the subsurface by solving the governing flow equations. However, to reduce the simulation times, we have developed an additional module to externally compute the surficial components and generate spatially and temporally variable recharge. This recharge becomes the input function assigned to the integrated HGS model, instead of actual precipitations. Although we simplify the representation of groundwater recharge, we still simulate integrated surface and subsurface flow at the basin scale with HGS. This approach provides a computationally tractable integrated model at the basin scale where low flow processes are explicitly considered and generated in an integrated fashion, which is the main goal of the study.

We applied this model to a 36 900 km^2 basin in the Southern part of the province of Quebec, Canada. The basin includes the watersheds of eight main rivers, for which water availability issues related to reduced baseflow are increasing. A highly parameterized approach was chosen to introduce flexibility during calibration and allow consideration of sparse datasets within the basin. The model calibration follows a stepwise approach where the recharge model and the integrated HGS model are first calibrated independently with a gradient-based approach constrained by Tikhonov regularization and singular value decomposition. The recharge model is calibrated against snow accumulation and actual evapotranspiration for the whole basin and against mean baseflow and mean runoff for each monitored sub watershed. The integrated HGS model is calibrated against transient groundwater levels and baseflow. Using an ensemble generated from the posterior covariance matrix, the Iterative Ensemble Smoother approach is then applied to constrain the whole surface and subsurface model against all the available observations at a minimum computational cost. Thereafter, an ensemble of equally probable ISSHMs will be available to predict baseflow in a climate change context.

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Keywords: Integrated Hydrological Modeling, Basin Scale, Low Flow, Uncertainty Analysis

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Metrics for Environmental Simulation in Decision Support

*John Doherty

Our understanding of hydraulic processes allows us to develop complex numerical models that purport to simulate the details of water and solute movement in natural systems. We presume to know the partial differential equations that govern these processes. But do these equations apply at the scale at which environmental management must take place? Conversely, while we can measure the properties of the surface/subsurface at the small scale at which these equations apply, can we upscale these properties to the management scale?

While management of our environment will continue to rely on our awkward attempts to simulate natural processes, it should not rest on an assumption that we simulate these processes correctly. Rather, simulation should be viewed as one component of a more complex numerical enterprise. The premise of this enterprise must be that predictions of the future behaviour of managed natural systems (especially subsurface systems) are uncertain. Management therefore involves risks. However it may be possible to reduce the uncertainties of decision-critical predictions through assimilation of expert knowledge as it pertains to a particular site, and of historical measurements of system states and fluxes that have been made at that site. Model-based processing of all of this information may therefore reduce the risks associated with environmental management. Achievement of this outcome constitutes a return on the investments made in acquiring this information.

For numerical simulation to serve the decision-making process most effectively, its deployment must reflect its role in that process. This role is to provide receptacles for information that can reduce the uncertainties of decision-critical model predictions. In playing this role, it must be used in partnership with equally sophisticated numerical software that facilitates passage of information to the receptacles that it provides, and that can quantify the post-assimilation uncertainties of its predictions. Furthermore, design and deployment of numerical models must be tailored for use with this kind of software, at the same time as it must acknowledge the fact that a simulator must be run hundreds, maybe thousands, of times under the control of this software. This requires that a numerical simulator be numerically stable, and that its run times be reasonably short. Unfortunately, these requirements may hamper its ability to apply differential equations at the scale to which these equations apply. Errors incurred through loss of this ability may contribute to the uncertainties of some of its predictions. However these errors may be small compared to the reductions in predictive uncertainty that may be accrued through use of an appropriately-designed, fast running and numerically stable approximate simulator in conjunction with partnered data assimilation and uncertainty quantification software.
It is apparent that modelling for decision-support requires compromises. It also requires a mindset that understands the necessity for these compromises, and that can assess the costs and benefits of these compromises. More than this, it requires the development of a modelling culture that is united by common metrics for decision-support modelling against which the costs and benefits of different approaches can be assessed. While faithfulness to the differential equations that purportedly describe a natural system may be desirable and useful in some circumstances, this cannot be the metric which defines this new culture. It can only be the premise that the uncertainties of decision-critical model predictions be quantified, and that, through assimilation of pertinent data, these uncertainties be reduced to levels that allow stakeholders to know the risks associated with a particular choice of management action.

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Keywords: Uncertainty, Decision support, Modelling

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-HW Hydrology & Water Environment

[A-HW32] Material transportation and cycling in aquatic ecosystems; from headwaters to coastal areas

convener:Syuhei Ban(The University of Shiga Prefecture), Adina Paytan(University of California Santa Cruz), Takahiro Hosono(Faculty of Advanced Science and Technology, Kumamoto University), Morihiro Maeda(Okayama University)

This session aims to synthetize watershed sciences in order to understand dynamic processes in transportation and cycling of materials and nutrients in aquatic environments from headwaters to coastal areas. The session will integrate various inter-disciplinary researches including limnology, ground water hydrology, coastal oceanography, meteorology, pedology, sedimentology, forestry, agriculture, fishery, ecology, social science and so on. This session calls for ideas on new methods for understanding the watershed sciences, such as tracer and molecular techniques, hydrological modeling, paleontological approaches, and chemical analyses, in order to elucidate physical, chemical and biological mechanisms for shedding light on natural phenomena and their spatio-temporal variations in complex and dynamic aquatic systems under human and climate impacts. Both laboratory and field studies, social-scientific evaluation of ecosystem services and social-ecological systems will be also welcomed. Through this session, we would like to facilitate interdisciplinary collaboration among participants to create new knowledge on watershed sciences.

Introduction

[AHW32-01] **Geologic controls on source water drive baseflow generation and geochemistry across watershed scales**

★Invited Papers

*Adina Paytan[1], Christina Richardson[1], Margaret Zimmer[1], Joseph Fackrell[1] (1.University of California Santa Cruz)

[AHW32-02] The Processes Controlling Stream Water Chemistry at the Terrestrial-Aquatic Interface, Great Lakes Region, USA

*Fengjing Liu[1], Veronica Porter[1] (1.Michigan Technological University)

[AHW32-03] **Agriculture and brackish fishpond impact on the vulnerability of coastal groundwater in Southeast Asia**

*Anna Fadliah Rusydi[1,4], Shin-ichi Onodera[1], Mitsuyo Saito[2], Seiichiro Ioka[3], Rizka Maria[4] (1.Graduate School of Integrated Arts and Sciences, Hiroshima University, Japan, 2.Graduate School of Environmental and Life Sciences, Okayama University, Japan, 3.Institute of Regional Innovation, Hirosaki University, Japan, 4.Research Center for Geotechnology, Indonesian Institute of Sciences, Indonesia)

[AHW32-04] Permafrost distribution controls dFe concentrations in rivers, Russian Far East

*Yuto Tashiro[1], Muneoki Yoh[1], Takayuki Shiraiwa[2], Takeo Onishi[3] (1.Tokyo University of Agriculture and Technology, 2.Hokkaido University , 3.Gifu University)

[AHW32-05] **Identification of autotrophic denitrification anomaly in the fast flowing karst aquifer using $\delta^{15}N$, $\delta^{34}S$ and $\delta^{13}C$ tracers in the Ryukyu limestone aquifers, southern Okinawa, Japan**

*Oktanius Richard Hermawan[1], Takahiro Hosono[2], Jun Yasumoto[3], Masashi Nozaki[3] (1.Earth and Environmental Science, Graduate School of Science and Technology, Kumamoto University, 2.Faculty of Advanced Science and Technology, Kumamoto University, 3.Department of Regional Agriculture Engineering, University of the Ryukyu)

Discussion

Geologic controls on source water drive baseflow generation and geochemistry across watershed scales

*Adina Paytan[1], Christina Richardson[1], Margaret Zimmer[1], Joseph Fackrell[1]

1. University of California Santa Cruz

Baseflow sources were quantified for six sub-watersheds in a structurally complex watershed in coastal California using endmember mixing model analysis and examined with respect to potential spatial controls (e.g., topography, geology, land use, and soil characteristics). Both the shallow zone (e.g., shallow subsurface contributions) and deeper groundwater reservoirs were important for stream discharge during low flow periods, and the distribution of baseflow sources across subwatersheds was directly related to geologic indices. A binary classification of underlying bedrock permeability (e.g., permeable versus not permeable) best explained the changes in the proportions of shallow subsurface water and groundwater inputs in individual subwatersheds through the seasonal baseflow recession. Dissolved inorganic carbon (DIC), dissolved organic carbon (DOC), and specific UV absorbance at 254 nm ($SUVA_{254}$) were used to provide additional insight on endmember characteristics and their contributions to baseflow; stream DIC concentrations were broadly controlled by mixing of groundwater and shallow subsurface water endmembers with relatively static DIC concentrations, while stream DOC concentrations reflected both spatial and temporal changes in shallow subsurface water DOC endmember geochemistry. Results from this study show: (1) the importance of considering baseflow as a dynamic process with the potential to receive water from multiple sources, (2) the effect of geology on source geochemistry and flow contributions at the subwatershed scale during low flow conditions, and (3) the utility of using stream dissolved C concentrations for supplemental insight into geochemical variability in baseflow sources during low flow periods.

Keywords: Groundwater, Baseflow, Dissolved-Carbon

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The Processes Controlling Stream Water Chemistry at the Terrestrial-Aquatic Interface, Great Lakes Region, USA

*Fengjing Liu[1], Veronica Porter[1]

1. Michigan Technological University

The diagnostic tools of mixing models (DTMM) and concentration-discharge (C-Q) analysis were applied to understand the processes that control stream water chemistry at the terrestrial-aquatic interface in Great Lakes region, USA. Streamflow discharge and chemical data from 2005 to 2008 at eight sub-catchments (ranging in size from 0.5 to 168 km^2) were acquired from the US Geological Survey, including major ions, nutrients, and trace metals. The results of DTMM showed that specific conductance (SC), Ca^{2+}, Mg^{2+}, Na^+, HCO_3^-, Si, Al, As, Ba, and U in stream water behaved conservatively and their concentrations resulted from mixing of two end-members in eight catchments. Significant ($p < 0.01$, $n = 10$) C-Q power-law relationship occurred in all catchments for these conservative solutes above, further suggesting that the concentrations of these solutes in two end-members were relatively constant and their contributions to streamflow were persistent over time. Both DTMM and C-Q analysis indicated that K^+, Cl^-, SO_4^{2-}, DON, and Mn were conservative only in some catchments mostly at larger scales but NO_3^-, P, Cr, Co, Cu, Fe, Pb, Ni, Se, and Zn were strongly impacted by chemical equilibrium in stream water in all catchments. These analyses enable us not only to develop two end-member mixing models with constant but distinct chemical signatures in end-members for all catchments at various scales but also to help understand the fate of nutrients and trace metals in stream water.

Keywords: Stream water chemistry, Diagnostic tools of mixing models, Concentration-discharge analysis, End member mixing, Great Lakes Region

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Agriculture and brackish fishpond impact on the vulnerability of coastal groundwater in Southeast Asia

*Anna Fadliah Rusydi[1,4], Shin-ichi Onodera[1], Mitsuyo Saito[2], Seiichiro Ioka[3], Rizka Maria[4]

1. Graduate School of Integrated Arts and Sciences, Hiroshima University, Japan, 2. Graduate School of Environmental and Life Sciences, Okayama University, Japan, 3. Institute of Regional Innovation, Hirosaki University, Japan, 4. Research Center for Geotechnology, Indonesian Institute of Sciences, Indonesia

Brackish fishpond and agriculture are commonly found in the rural area of a developed country in Southeast Asia, such as Indonesia. Both activities are believed could leverage people's welfare. On the other hand, they are potentially increasing groundwater vulnerability. The use of fertilizer and low quality of irrigation water may become a risk to groundwater quality. Moreover, the intentional addition of seawater to brackish water pond is suspected will contribute to high groundwater salinity. We select Indramayu, which is located in the north part of West Java Indonesia, as our research area because this area is very important with the production of rice and brackish fish. As yet, in-depth research about groundwater vulnerability caused by those two activities is still limited. Through this research, we evaluate the potential risk of agriculture and brackish fishpond to groundwater quality. We collect 50 samples in two periods from the coastal groundwater (46) that representing all types of land-uses, and river (4). The samples from groundwater represent all types of land-uses in the area. Then, we analyze major elements, nutrients, water isotopes, and sulfate isotopes to evaluate the risk. The results of this study are very useful for maintaining groundwater sustainability in agricultural and brackish ponds of coastal areas.

Keywords: agriculture, brackish fishpond, coastal groundwater, vulnerability

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Permafrost distribution controls dFe concentrations in rivers, Russian Far East

*Yuto Tashiro[1], Muneoki Yoh[1], Takayuki Shiraiwa[2], Takeo Onishi[3]

1. Tokyo University of Agriculture and Technology, 2. Hokkaido University , 3. Gifu University

The Sea of Okhotsk is known as one of the world's richest marine ecosystems. This is because large amount of iron, an essential nutrient for the growth of phytoplankton, flows out of the wetlands in the Amur River basin and supports to high primary productivity in the Sea of Okhotsk (Amur Okhotsk Project 2005-2009). Interestingly, long-term observations of dissolved iron concentrations in the Amur River showed very high concentrations in the late 1990s which could not be explained by changes in wetland area. As this possible cause, Shamov et al., (2014) pointed out that the relatively higher temperature than usual in the 1990s may have caused deeper permafrost thawing and created reducing conditions in active layer, resulting to large amount of dissolved iron production. However, little research has been conducted on the generation of dissolved iron in active layer in the permafrost zone and on the runoff mechanism from soil to rivers. Therefore, we have been conducting the continuous investigation in the Tyrma River basin, where is equivalent to sporadic permafrost area, to clarify dissolved iron behavior from the soil to the river.

Our previous studies have shown that permafrost in the Tyrma exists under a wetland called `` Mari, " which is seen in gentle slope valleys (from riverside forests to slopes), and dissolved iron production occurred from August to September. In contrast, dissolved iron production was not seen in areas where permafrost does not exist. This suggests that the peat soils in the valley where permafrost exists plays an important role in the production of dissolved iron and its outflow to rivers.

In the present study, we attempted to clarify the correlation between the dissolved iron concentration in rivers and the permafrost distribution in river catchment by visualizing the permafrost distribution using satellite data. Visualization of the permafrost distribution in the Tyrma region was performed using QGIS. The method will be briefly described here. First, using the Landsat-8 satellite data, a normalized difference vegetation index (NDVI), a normalized difference soil index (NDSI), and a normalized difference water index (NDWI) were calculated. Then, these values were summarized for vegetation landscape types of wetland, forest, and grassland. As a result, these vegetations can be distinguished under the conditions of NDVI and NDSI. Based on these two values, the distribution of wetland “Mari” in the whole Tyrma region was extracted (Fig. 1 red area). Given that the results of our previous studies, the red area of Fig. 1 should be consistent with the permafrost distribution.

Moreover, we calculated these areas of permafrost in each catchment area of 24 rivers of various sizes (basin area 4.6 to 2847 km2) collected in 2019. The permafrost area / catchment area ratio and dissolved iron concentrations in the rivers showed a clear positive correlation (Fig. 2). This result indicates that the permafrost distribution created using GIS is highly reliable, and that the permafrost distribution is very effective to explain the variation in dissolved iron concentrations in the rivers. Until now, the correlation between the permafrost distribution and dissolved iron concentration has been discussed mainly by the wide differences depending on latitude (sporadic, discontinuous, and continuous permafrost area). Therefore, this is the first time to discover the correlation between the permafrost distributions and dissolved iron concentrations directly in the same region. Given that the predicted climate change, dissolved iron concentrations in river where the permafrost widely exists would be change due to deeper

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permafrost thawing.

Keywords: Permafrost, Remote sensing, Dissolve Iron, Wetland

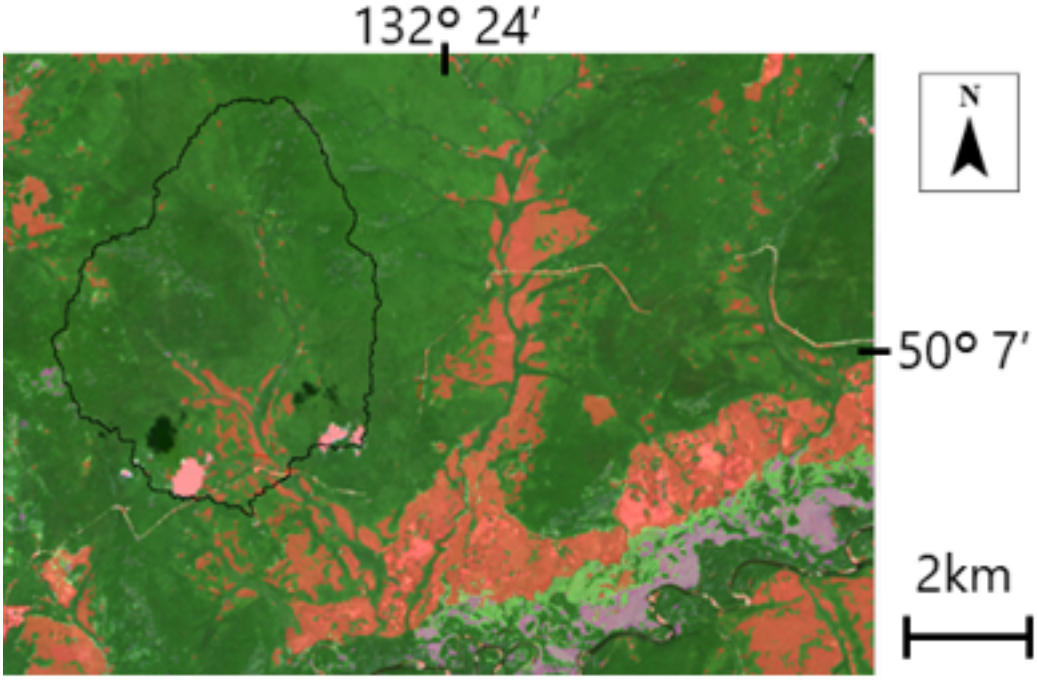

Fig.1 Permafrost distribution (Red area)

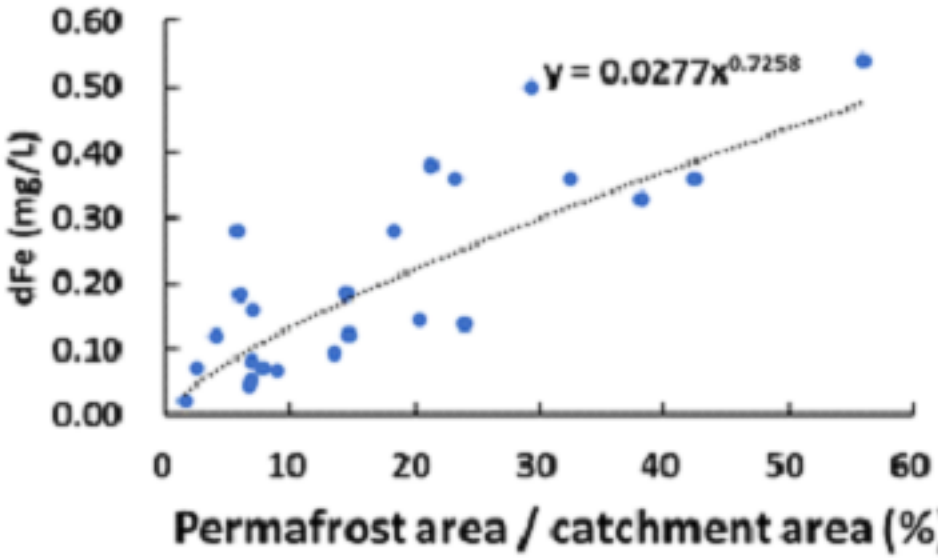

Fig.2 Positive correlation between permafrost arae / catchment area and dissolved iron concentration in each river

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Identification of autotrophic denitrification anomaly in the fast flowing karst aquifer using $\delta^{15}N$, $\delta^{34}S$ and $\delta^{13}C$ tracers in the Ryukyu limestone aquifers, southern Okinawa, Japan

*Oktanius Richard Hermawan[1], Takahiro Hosono[2], Jun Yasumoto[3], Masashi Nozaki[3]

1. Earth and Environmental Science, Graduate School of Science and Technology, Kumamoto University, 2. Faculty of Advanced Science and Technology, Kumamoto University, 3. Department of Regional Agriculture Engineering, University of the Ryukyu

Nitrate contamination issue in the karst aquifer has not been observed as details, although there are a lot of contaminated mantled karst areas because of human activities and extensive agricultural practices. The complex, random and fast flowing hydrogeological system become its own challenge in discussing groundwater pollution in the karst aquifer. This also happened in the southern part of Okinawa Island, Japan. The southern part of Okinawa Island is a sea shore area where Ryukyu limestone distributes. There was not enough surface water for agricultural and domestic use, then in 2005 to meet those demands, 2 geotechnical structures which are subsurface dams were established; Komesu and Giza Subsurface Dams. Nitrate concentration in the groundwater was relatively high, NO3-N concentration was more than 10 mg/L (20 of 69 observation sites). Nitrogen and sulfur isotope analysis presented the groundwater was contaminated by chemical fertilizers, with the value of $\delta^{15}N_{NO3}$ mostly around 6-14‰ and $\delta^{34}S_{SO4}$ approximately -2 to 5‰. Carbon isotopes identified that the major source of the carbon came from terrigenous soil which were released during C4 plant decompositions with value of $\delta^{13}C_{DIC}$ around -10 to -16‰. After a 4 year’s monitoring process, we found there was a decreasing concentration of NO_3-N along the seasonal pattern (with significant plummet ±8 mg/L) in some specific wells. This anomaly can be suspected as denitrification because it was followed by an increasing value of $\delta^{15}N_{NO3}$ to reach 50 ‰. Furthermore, multiple stable isotope analysis (N, C and S isotopes) suggests that autotrophic denitrification was the dominant type that occurred across the basin. This can be seen from the stable trend of $\delta^{13}C_{DIC}$ and was followed by a decrease in the value of $\delta^{34}S_{SO4}$, while $\delta^{15}N_{NO3}$ continued to increase, although this type of denitrification has rarely been identified in the karstic aquifer with relatively fast groundwater flow regime. There are two factors that can create stagnant conditions in the study area where denitrification reaction can preferentially proceed, in lithological gap generated due to geological structures and the existence of Komesu Subsurface Dam itself.

Keywords: Subsurface dam, Karst aquifer, Denitrification, Stable isotopes

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-HW Hydrology & Water Environment

[A-HW32] Material transportation and cycling in aquatic ecosystems; from headwaters to coastal areas

convener:Syuhei Ban(The University of Shiga Prefecture), Adina Paytan(University of California Santa Cruz), Takahiro Hosono(Faculty of Advanced Science and Technology, Kumamoto University), Morihiro Maeda(Okayama University)

This session aims to synthetize watershed sciences in order to understand dynamic processes in transportation and cycling of materials and nutrients in aquatic environments from headwaters to coastal areas. The session will integrate various inter-disciplinary researches including limnology, ground water hydrology, coastal oceanography, meteorology, pedology, sedimentology, forestry, agriculture, fishery, ecology, social science and so on. This session calls for ideas on new methods for understanding the watershed sciences, such as tracer and molecular techniques, hydrological modeling, paleontological approaches, and chemical analyses, in order to elucidate physical, chemical and biological mechanisms for shedding light on natural phenomena and their spatio-temporal variations in complex and dynamic aquatic systems under human and climate impacts. Both laboratory and field studies, social-scientific evaluation of ecosystem services and social-ecological systems will be also welcomed. Through this session, we would like to facilitate interdisciplinary collaboration among participants to create new knowledge on watershed sciences.

[AHW32-06] Methanotrophic food webs in tropical lakes

*Noboru Okuda[1], Milette U. Mendoza[9], Jaydan I. Aguilar[2], Karol Sophia Agape R. Padilla[2], Jonathan Carlo A. Briones[2], Rey Donne S. Papa[2], Masayuki Ito[3], Megumu Fujibayashi[4], Tzu-Hsuan Tu[5], Li-Hung Lin[5], Pei-Ling Wang[5], Yuki Kobayashi[6], Eleanor Austria[7], Fuh-Kwo Shiah[8] (1.Research Institute for Humanity and Nature, 2.University of Santo Tomas, 3. University of Hyogo, 4.Kyushu University, 5.National Taiwan University, 6.Yamaguchi University, 7.Adamson University, 8.Academia Sinica, 9.Ateneo de Manila University)

[AHW32-07] Did artificial re-oligotrophication induce a reduction of fish catch in Lake Biwa?

*Syuhei Ban[1], Xin Liu[1], Masahiro Maruo[1], Naoshige Goto[1], Ken'ichi Osaka[1], Shin-ichi Onodera[2], Mitsuyo Saito[3], Takuya Ishida[4], Noboru Okuda[4] (1.The University of Shiga Prefecture, 2.Hiroshima University, 3.Okayama University, 4.Research Institute for Humanity and Nature)

[AHW32-08] Phosphorus dynamics related to phytoplankton growth with newly sensitive measurement of orthophosphate and growth experiments in north basin of Lake Biwa

*Xin Liu[1], Rong Yi[1,2], Masahiro Maruo[1], Syuhei Ban[1] (1.The University of Shiga Prefecture, 2.Gannan Normal University)

[AHW32-09] Detection of Organophosphonates and Phosphite in Suspended Matter of P-limited Lakes

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[AHW32-10] Role of groundwater and river discharge on phosphorus supply into the lake

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Methanotrophic food webs in tropical lakes

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1. Introduction

Freshwater ecosystems are regarded as the primary source of atmospheric CH_4 which is 25-times more effective than CO_2 as a greenhouse gas. This estimation, however, could be biased because of limited knowledge on limno-physical and ecological processes of CH_4 cycling in tropical lakes. In tropical lakes which are meromictic, i.e., there is no mixing of surface and deep waters, CH_4 is stored in the deep anoxic waters, whereas its upward advection is hindered due to strong thermal stratification. To date, how much the CH_4 storage can contribute to the overall emission from the tropical lakes have been poorly understood for lack of intensive monitoring.

Since methane oxidizing bacteria (MOB) which assimilate dissolved CH_4 aerobically or anaerobically embed CH_4-derived carbon in consumer biomass through methanotrophic food webs (MFWs), they have great impacts on CH_4 cycling in lake ecosystems. Therefore, understanding of controlling mechanisms for the MFWs can also improve our estimation of CH_4 flux. Here we conduct monitoring survey for dynamics of CH_4, MOB and MFWs in tropical maar lakes of the Philippines.

2. Materials and Methods

We monthly monitored vertical profiles of physico-chemical environments in the Seven Lakes, which is a cluster of 7 volcanic crater lakes called ‘maar lakes’, located on the Luzon Island in the Philippines, from October 2016 to February 2019, using a CTD profiler. For the deepest three lakes (38, 62 and 156 m at depth for Yambo, Pandin and Calibato, respectively), we further measured dissolved CH_4 in 6-7 layers from surface to near-the-bottom waters. We also monitored vertical profiles of MOB and MFWs during the mixing season (February 2019), using NGS (Illumina Miseq), CARD-FISH and fatty acid analysis.

3. Results and Discussion

During the most of time, lakes experienced strong thermal stratification, except for the shallowest lake Palakpakin (7.7 m at depth) regarded as polymictic. During *Amihan*, which is Northeast Monsoon characterized by cool temperature and strong trade wind during months (December-March) shifting from wet to dry seasons, however, complete vertical mixing occurred in some lakes whose depth is 38 m or less. The correlation analysis for monthly data revealed that the thermal stratification was destructed with the decreasing air temperature rather than with the increasing wind speed, suggesting that temperature-driven advection is the primary limno-physical mechanism to cause vertical mixing in the tropical lakes.

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Three deepest lakes had high CH_4 concentrations in hypolimnion, ranging from 670 to 1172 μmol/L near the bottom at the end of the stratification period, which shows high potential for CH_4 storage in the deep tropical lakes. During the Amihan, however, the CH_4 storage almost disappeared in Yambo due to the vertical mixing.

In these three lakes, MOB communities were composed mainly of three types, Type I and II, and NC10, while the NGS analysis revealed that a novel taxon, Methylacidiphilaceae, dominated in an epilimnion. Despite the high CH_4 concentrations and the presence of MOB, contribution of CH_4-derived carbon to zooplankton was low in these lakes, compared to that in non-tropical lakes, suggesting that MFWs do not function as carbon recycling so much in the tropical lake ecosystems.

To quantitatively estimate atmospheric CH_4 emission during the mixing event, more intensive monitoring and incubation experiment are needed to measure advection flux of stored CH_4 and CH_4 oxidation rate for the MOB.

Keywords: Methane, Methane oxidizing bacteria, Tropical lake, Meromictic lake, Methanotrophic food web

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Did artificial re-oligotrophication induce a reduction of fish catch in Lake Biwa?

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Recently, decreasing of fish catch has been know in various freshwater and coastal systems in Japan. Artificially lowering nutrient loading, especially phosphorus, by emission regulation is recently considered to be one of the most plausible reasons for the decrease, despite a lot of potential reasons for the decrease, e.g. deteriorating spawning and nursery grounds due to reclamation in shallow coasts and losses of weed beds, and overfishing, proposed. Positive correlation between phosphorus loading and fish catch has been shown in a couple of coastal areas, Harima-nada and Osaka Bay, but few quantitative analyses, e.g. taking ecological transfer efficiency into consideration, have been done before. In Lake Biwa, fish catch also declined after 1990, and positively correlated with total phosphorus (TP) during the last 4 decades, but no quantitative analysis has been done until now.

In our on-going project, we are trying to clarify this relationship through determining zooplankton production and phosphorus dynamics using state-of-the-art techniques, i.e. nano-molar measurements of ortho-phosphate and phosphate oxygen isotope ratio. Until recently, nobody knew true concentrations of ortho-phosphate in oligo- and mesotrophic lakes, such as Lake Biwa, due to under the detection limit of soluble reactive phosphorus measured by traditional molybdenum-blue method. Our new method for measuring ortho-phosphate with nano-molar level using an ion-chromatography allowed us to truly determine dynamics of phosphorus in Lake Biwa, which will be proposed by our collaborators in this session. Apart from this, we have an evidence on regulating zooplankton biomass with fish predation during the last 4 decades. This strong top-down effect on zooplankton implies that bottom-up control on fish production may be unreasonable explanation for recent decline of fish catch in the lake. I’ d like to introduce the story that climatic and anthropogenic effects on zooplankton in this lake could be masked by fish predation.

We analyzed net zooplankton samples collected by Shiga Prefectural Fisheries Experiment Station for the last 4 decades from 1971 to 2010. Size-structure and biomass in crustacean zooplankton were determined and compared with catch per unit effort (CPUE) of dominant zooplanktivorous fish, Ayu (*Plecoglossus altivelis altivelis*). Generalized linear model (GLM) was conducted to clarify which factors, temperature, food abundance (TP) and fish predation (Ayu CPUE), affected on zooplankton community structure and biomass.

Annual mean water temperature above 20 m increased by 0.94°C during the study period. TP as food proxy increased until 1974, and then decreased until 1985, but being stable after that. Ayu CPUE increased up to 6.42 k-tons/net/y until 1987, but declined to 1.04 k-tons/net/y to 2005. Five zooplankton taxa, *Eodiaptomus japonicus*, Cyclopoida spp., *Daphnia* spp., *Bosmina longirostris* and *Diaphanosoma orientalis*, were always dominant throughout the study period. Annual mean total crustacean biomass varied from 0.3 to 3.6 g dry weight/m^2, slightly decreasing until 1993 but increasing thereafter. GLMs showed that annual mean body sizes were affected by temperature and Ayu CPUE while annual mean biomass was affected by TP and Ayu CPUE. There were no effects during high TP period

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until 1985, but only Ayu CPUE affected both traits during stable TP period after 1986. These results suggested that both crustacean biomass and body size structure might be strongly affected by fish predation, that effects of eutrophication and global warming would be masked by this top-down effect, and consequently that variation of crustacean biomass could not explain decreasing fish catch in the lake.

Keywords: re-oligotrophication, fish catch, zooplankton biomass, phosphorus dynamics, top-down control, Lake Biwa

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Phosphorus dynamics related to phytoplankton growth with newly sensitive measurement of orthophosphate and growth experiments in north basin of Lake Biwa

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Orthophosphate (PO_4-P) is a common growth-limiting factor for primary production in lakes. Quantification of PO_4-P concentrations in epilimnion of meso- and oligotrophic lakes were rarely reported because the concentrations were under the detection limit (60 nM) using traditional spectrophotometrical method. In this study, we measured PO_4-P concentrations with sensitive method using an ion chromatography with a detection limit of 5 nM, determined seasonal and vertical distributions of PO_4-P during 2018 and 2019 with other environmental factors in north basin of Lake Biwa, to clarify phosphorus (P) dynamics for phytoplankton growth in this mesotrophic lake.

Field investigations were conducted from Apr to Dec in 2018 and Mar to Dec in 2019 at station K4 (50 m deep). P-enrichment experiments were conducted at each sampling occasion, to determine threshold concentration of phosphate for phytoplankton growth. Lake water including phytoplankton assemblage collected from epilimnion (0-20 m) was enriched with 1 μM of PO_4-P (+P) and incubated together with untreated one as control for 2 days under ambient light and temperature conditions. To evaluate effect of potentially nutrient-rich bottom water, the filtered bottom water was combined with untreated epilimnion water including phytoplankton at 1:1 of volume (+B) and incubated at the same conditions as the +P treatment and control. Phytoplankton growth rate (g) was calculated by equation of $g=\ln(C_t/C_0)/2$, where C_0 and C_t are chlorophyll *a* (chl. *a*) concentrations at start and end of the experiment, respectively.

In epilimnion, water temperature showed similar seasonal variation between the two years; Strict thermocline was developed in 10-20 m from Jun to Sep; Annual mean was 17.6 ºC in 2018, and 1.8 ºC higher than that in 2019. Phytoplankton biomass showed bimodal temporal distribution in both years, though annual mean concentrations of chl. *a* were higher in 2018 compared to those in 2019.

In 2018, mean PO_4-P concentrations in epilimnion were <20 nM from Apr to Jun, increased from Jul, and >30 nM from Aug to Dec. In 2019, they were higher than those in 2018, ca. 40 nM from Mar to Jul, but decreased to <20 nM after Aug until Dec. Subsurface maxima of 60-70 nM were observed around 10 m from May to Jun and 10-20 m in Jul 2019, while they were always <50 nM throughout the year in 2018. PO_4-P concentrations increased below 30 m with depth; high concentrations up to 200 nM were observed near the bottom in both years. Concentrations of >150 nM were frequently observed from Sep to Dec 2018, whereas it was just in Aug during 2019. Total P, dissolved organic P and particulate P exhibited similar distributions between the two years. Seasonal and vertical distributions of nitrogen forms were almost the same between the two years; ammonia concentrations increased in 10-20 m from May to Jul, whereas nitrate concentrations decreased in epilimnion after Jun while increased in hypolimnion.

Phytoplankton growth in epilimnion was mostly limited by PO_4-P because the g in control always lower than those in +P and +B treatments. In 2018, the highest g in control was obtained in Sep probably due to high nutrient loading caused by typhoon. Since no obvious perturbations in 2019, the g in both +P and control treatments increased after Jun, reached to the maximum in Aug, and decreased toward winter

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depending on seasonally progressing temperature.

Different spatio-temporal distributions in PO_4-P between the two years might be caused by both abiotic and biotic factors, and subsurface maxima indicate possible transportation of nutrients from the littoral slope with internal wave, suggesting horizontal transportation of nutrients from littoral sediment may play an important role as nutrient source for pelagic phytoplankton production. P-enrichment experiments showed that <50 nM of PO_4-P was P-limited conditions for phytoplankton, and 15 nM of PO_4-P might be critical concentration for in situ phytoplankton growth.

Keywords: phosphorus, nutrient dynamics, phytoplankton production, P-limitation, nutritional horizontal transportation, freshwater lake

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Detection of Organophosphonates and Phosphite in Suspended Matter of P-limited Lakes

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Introduction

Bacteria possibly utilize phosphite and organophosphonates as P resources in freshwater lakes. At the subsurface layer of Lake Saiko (P-limited lake: Yamanashi, Japan), maximum methane concentration is observed under stratified condition in summer. This subsurface methane maximum (SMM) is considered to be formed by metabolism of methylphosphonate (MPn) by cyanobacterium *Synecococcus* to ingest phosphorus [Khatun et al., 2019]. In Lake Fukami-Ike (Nagano, Japan), a eutrophic lake, methane maximum layer is also formed in the epilimnion during summer stratification, probably because of the same reason as in Lake Saiko. However, there is no report concerning the detection of MPn and 2-hydroxyethylphosphonate (2-HEP), which is the precursor of MPn, while phosphite (iP(+3)) was detected in the water of some eutrophic lakes and rivers. We developed simultaneous determination methods to detect organophosphonates and iP(+3) in water and particulate matters in by ion chromatography.

Methods

Analytical condition for the determination of MPn in water was already established by ion chromatography with high volume injection [Tsuji et al., 2019; Maruo et al., 2016]. By optimizing elution condition, we applied this method to separate MPn, 2-HEP and iP(+3), with the detection limits of these analytes at the order of some nmol L^{-1}. This method was applied to the analysis of water sampled at the north basin of Lake Biwa (Shiga, Japan), inflowing rivers at the northeast part of the watershed, spring waters and treated waste water, in Nov. - Dec. of 2017 and 2018. Water samples of Lake Saiko were collected in Jul., 2018 and Aug., 2019 at the center of the lake (Max. depth 70 m). Water samples of Lake Fukami-Ike were obtained in Dec., 2019 (max. depth 7.5 m).

Sampled waters were immediately filtered with capsule filter (pore size 0.2/0.8 micrometer: Acropak 200). Particulate matters were collected on track etched membrane filters (pore size 0.2 micrometer: Nuclepore) from approx. 1.5 - 2.0 L of water. Tthe filters were heated at 60 ℃ in pure water for 1 hour to extract organophosphonates and iP(+3) from the particulates.

Results and Discussion

Dissolved MPn was detected from the waters of anoxic spring (2.9 nmol L^{-1}) and River Amano near the

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spring (2.3 nmol L^{-1}) (Maibara, Shiga, Japan), though no MPn and iP(+3) were detected from any other waters sampled in Lake Biwa and its watershed. Only iP(+3) was detected from the water samples of Lake Fukami-Ike.

During the analysis of extracted solution from particulate matters, MPn (0.08 nmol L^{-1}) and iP(+3) (0.06 nmol L^{-1}) were detected from the samples of anoxic spring. From the samples of Lake Biwa, iP(+3) was detected (0.38 nmol L^{-1}), while MPn (0.03 nmol L^{-1}) and iP(+3) (2.7 nmol L^{-1}) were detected from the sample of Lake Saiko obtained at 12.5 m in depth. In Lake Fukami-Ike, 2-HEP was also detected at the depth of 2.5 m and 7.5 m (close to the lake bottom), including MPn (2.5 m), and iP(+3) (2.5 m, 7.5 m).

Dissolved organophosphonates and iP(+3) were merely detected in the freshwaters, but MPn and 2-HEP were detected from particulate matters of these lake waters. Microorganisms in lake water (cf. cyanobacteria) might produce these phosphorous (+3) compounds in their bodies during their metabolic cycles of phosphorus. Methane might be excluded to the water during these processes.

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Keywords: P-limited Lakes, suspended matter, organiphosphonates

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Role of groundwater and river discharge on phosphorus supply into the lake

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We have confirmed groundwater discharge and nutrient flux into Biwa Lake in the eastern area and Yasu river catchment. In this presentation, we would like to examine to compare and quantify the role of groundwater and river discharge on phosphorus supply in the lake, based on our previous researches.

Phosphorus discharge via Yasu river into the lake has been estimated to be 25t to 37t by using SWAT model. The main source was agricultural land and human waste. In addition, water budget in the river catchment at the most downstream and flowing discharge monitoring site indicated around 40 % in river runoff of the precipitation. On the other hand, groundwater discharge into the lake was estimated to be 10 % in deep and 10 to 20% in shallow of the precipitation, respectively.

The phosphorus content of sediment was maximum in the depth of around 20m in the alluvial plain. The confined groundwater with the depth of 20m has higher pressure than the lake water level and the higher concentration than shallow groundwater and river water. Finally, we estimated larger phosphorus discharge via groundwater as compared with that via rivers.

Keywords: phosphorus, river, groundwater

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-HW Hydrology & Water Environment

[A-HW32] Material transportation and cycling in aquatic ecosystems; from headwaters to coastal areas

convener:Syuhei Ban(The University of Shiga Prefecture), Adina Paytan(University of California Santa Cruz), Takahiro Hosono(Faculty of Advanced Science and Technology, Kumamoto University), Morihiro Maeda(Okayama University)

This session aims to synthetize watershed sciences in order to understand dynamic processes in transportation and cycling of materials and nutrients in aquatic environments from headwaters to coastal areas. The session will integrate various inter-disciplinary researches including limnology, ground water hydrology, coastal oceanography, meteorology, pedology, sedimentology, forestry, agriculture, fishery, ecology, social science and so on. This session calls for ideas on new methods for understanding the watershed sciences, such as tracer and molecular techniques, hydrological modeling, paleontological approaches, and chemical analyses, in order to elucidate physical, chemical and biological mechanisms for shedding light on natural phenomena and their spatio-temporal variations in complex and dynamic aquatic systems under human and climate impacts. Both laboratory and field studies, social-scientific evaluation of ecosystem services and social-ecological systems will be also welcomed. Through this session, we would like to facilitate interdisciplinary collaboration among participants to create new knowledge on watershed sciences.

[AHW32-12] Coffee-waste biochar and nano-biochar applications to reduce nitrous oxide and carbon dioxide emissions from agricultural soils

*Morihiro Maeda[1], Thuong Thi Thu Nguyen[1], Chiyu Nakano[1], Yuta Nishina[1] (1.Okayama University)

[AHW32-13] **Suppression of phosphorous release from sediment in agricultural drainages flowing into Lake Kojima by using biochar-amended sediment microbial fuel cells**

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[AHW32-14] Assessment of hydrological processes and sediment yield in Dakbla catchment, Kon Tum province, Vietnam.

*Tram Ngoc Quynh Vo[1], Hiroaki Somura[1] (1.Okayama University)

[AHW32-15] Acidic fresh submarine groundwater discharge around mud diapirs in southwestern Taiwan

*Hon-Kit Lui[1], Chen-Tung Arthur Chen[1], Wei-Ping Hou[2], Rae Chang[1] (1.Department of Oceanography, National Sun Yat-sen University, Kaohsiung 80424, Taiwan, 2.Taiwan Ocean Research Institute, National Applied Research Laboratories, Kaohsiung 80143,Taiwan.)

[AHW32-16] Spatio-temporal dynamics of submarine groundwater discharge (SGD) on an intertidal beach scale, temperate coastal area

*Mitsuyo Saito[1], Shin-ichi Onodera[2], Shingo Nozaki[2], Yusuke Tomozawa[2] (1.Okayama University, 2.Hiroshima University)

[AHW32-17] **Impact of terrestrial nutrients in groundwater on coral reefs via submarine groundwater discharge around Yoron Island of the Southwest Islands, Japan**

*Shinji Nakaya[1], Sho Nagata[1], Masashi Toyota[1], Jun Yasumoto[2], Tetsuya Shintani[3], Takashi Nakamura[4] (1.Department of Water Environment and Civil Engineering, Faculty of Engineering, Shinshu University, 2.Department of Regional Agriculture Engineering, University of the Rykuyus, Japan, 3.Department of Civil and Environmental Engineering, Tokyo Metropolitan University, 4.Biology Program, Faculty of Science, University of the Ryukyus)

Coffee-waste biochar and nano-biochar applications to reduce nitrous oxide and carbon dioxide emissions from agricultural soils

*Morihiro Maeda[1], Thuong Thi Thu Nguyen[1], Chiyu Nakano[1], Yuta Nishina[1]

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Denitrification is one of important pathways responsible for nitrous oxide (N_2O) emissions from soil. Biochar can decrease N_2O emissions because it acts as an electron shuttle that would enhance the denitrification processes. It also provides favorable conditions for denitrifers by increasing soil pH and water retention capacity. However, research on effects of biochar with different particle sizes on N_2O emissions is currently limited. The objective of the study was to determine effects of biochar and nano-biochar applications on N_2O and CO_2 emissions in the denitrification processes with reference to surface structures of the biochar materials, soil pH, electrical conductivity (EC), mineral nitrogen, and soil type.

Topsoil soil samples, collected from a paddy field in Ushimado, Okayama (TC 14.7 g kg^{-1}, CN ratio 10.2) and a greenhouse at Kochi University (TC 62.6 g kg^{-1}, CN ratio 16.0), Japan, were air-dried and 2-mm sieved for the following experiment. Soil NO_3^--N contents were 3.5 and 373 mg N kg^{-1} for Ushimado (U) and Kochi (K) soils, respectively and it increased in subsamples of U soil to 400 mg N kg^{-1} (U400) to eliminate the effect of initial NO_3^--N content. Coffee grounds waste was pyrolyzed for biochar at 600°C for 1 hour and that mixed with $Fe(NO_3)_3 \cdot 9H_2O$ for nano-biochar at 900°C for 1 hour. Values of pH and EC (1:10) were 10.0 and 0.4 dS m^{-1} for biochar and 10.1 and 2.8 dS m^{-1} for nano-biochar. Five grams of air-dried soil amended with or without 5% biochar materials were adjusted to 100% water holding capacity and anaerobically incubated at 25°C for 4 days in 125-mL glass bottles in triplicate. Concentrations of N_2O and CO_2 in the headspace of bottles were analyzed with gas chromatograph (GC-8A, Shimazu, Japan) equipped with an electron capture detector (ECD) and a thermal conductivity detector (TCD), respectively.

Fluxes of N_2O were generally the largest from K soil, followed by U400 and U soils. The lowest N_2O emissions in U soil occurred due to much lower initial NO_3^--N content. Cumulative N_2O emissions decreased in K and U400 soils amended with biochar and nano-biochar. These are probably due to the electron shuttle effect and pH increase by application of these biochar materials. Moreover, nano-biochar reduced more cumulative N_2O emissions than biochar, which can be explained by Fe added in nano-biochar production and a larger specific surface area of nano-biochar (325 m^2 g^{-1}) than that of biochar (1.7 m^2 g^{-1}). Trends of NO_3-N content decreases in each soil were similar among treatments with and without biochar materials, indicating the last reduction process of N_2O to N_2 in denitrification was more enhanced by application of nano-biochar. Emissions of CO_2 decreased in K and U400 soils amended with biochar and nano-biochar, which is generally more distinct in the soils amended with nano-biochar than with biochar. Nano-biochar with a larger specific surface area would have absorbed more CO_2 than biochar. Nitrogen mineralization in soils amended with nano-biochar was lower than with biochar, which is indicated by more increases in NH_4^+-N content in nano-biochar amended soils.

Applications of biochar and nano-biochar reduced N_2O and CO_2 emissions from different two agricultural soils when NO_3-N contents were as high as 400 mg kg^{-1}. Nano-biochar reduced N_2O emissions more than biochar did. This is because nano-biochar had a larger specific surface area and increased more soil pH than biochar. Further research is needed to investigate effects of biochar and nano-biochar on soils with

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different microbial and chemical properties before applying them to a real field condition.

Keywords: biochar, nitrous oxide, carbon dioxide

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Suppression of phosphorous release from sediment in agricultural drainages flowing into Lake Kojima by using biochar-amended sediment microbial fuel cells

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Polluted sediment in watersheds tends to act as an internal source of phosphorous due to metabolism of iron reducing bacteria (IRB) under depleted dissolved oxygen concentrations at benthic layer, despite the mitigating measures taken to control external P loadings. Iron bound P repositories releases P into overlying water bodies when iron hydroxides in sediment are dissolved by anaerobic digestion, causing enhancement of trophic states in surface waters. Sediment Microbial Fuel Cell (SMFC) is an electrochemical system that produces bioelectricity using the electrons released by electroactive microorganisms while improving P immobilization of sediment. Biochar has found as an electron shuttle and electron acceptor which promotes the mass transportation in freshwater sediments and support microbial redox transformations. Recently, the fishery industry and agricultural activities in Kojima lake are substantially affected due to degraded surface water quality. As a result of recent remedial measures though N and COD concentrations are reducing, P concentration is recorded as twice of the water quality standards. Agricultural drainages are the prime P donors of Lake Kojima. Although a number of studies have been conducted on microbial fuel cells, the effectiveness of SMFCs in irrigated water is not sufficiently addressed. Thus, initiation of SMFCs in agricultural drainages and investigating on biochar and nano-biochar amendment in SMFCs will denote a novel platform to maintain the water quality within the thresholds.

Sediment samples (130g were used in each cell) were collected from agricultural drainage which flows into Kurashiki river (N= 34.5, E = 133.9). pH, electrical conductivity (1:10) and the moisture content of the sediment were measured to identify the raw sediment characteristics. Four laboratory scale dual chambered SMFC models were constructed using fiber glass cylindrical columns (dia. =45mm, height =440mm). Wooden (Cedar) biochar and nano biochar samples were prepared and sediment was mixed with 2% of biochar and nano biochar. Biochar was produced by pyrolyzing the wood chips at 800°C for 1 hour and nano-biochar was produced by pyrolyzing the wood chip at 800^0C for 1 hour after treating in a $Fe(NO_3)_3 \cdot 9H_2O$ solution. Pure water was used as overlying water and the brim was covered with a silicon plug. Cathode chamber was executed with 100 ml of 0.2 mol KCl filled glass beaker and connected with a salt bridge. Carbon rods (10cm long and 5mm dia. with 3cm, 3cm carbon cloth) were used as electrodes while platinum electrode was used as the reference electrode. External circuit consist of 1000Ω resistor and titanium wires was used to connect the electrodes. The experiment was conducted in a 25^0C dark room for 7 days. Data acquisition system was used to record the generating current and voltage. Physicochemical characteristics of sediment and biochar were determined after the SMFC operation to evaluate the alteration of sediment and microbial characteristics. Eh measurements were measured and nutrient analysis was conducted for both sediment and overlying water using Auto-analyzer.

Nano biochar circuit showed the highest current density while biochar circuit shows the second best bioelectricity production. The lowest voltage was observed in the control treatment. This is probably due to the enhanced iron mobility and low internal resistivity resulted due to the biochar amelioration. High graphite compound of nanobiochar improves the electrical conductivity. Highest effectiveness of PO_4^{3-}

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suppression is recorded in nanobiochar while biochar and control systems fall to second and third. This results can be explained with the high adsorption capability of nanobiochar due to high specific surface area compared to biochar and added Fe(III) during the nano biochar production may enhance the metal bound P adsorption. High redox potential at the anode of nanobiochar and biochar treatments proves the enhancing oxidative condition of sediment layer.

This study suggests that the power productivity and P adsorption can be intensify in freshwater sediments of agricultural drainages by the nanobiochar amelioration in SMFCs. High graphite compound and high specific surface area of nanobiochar demonstrate its suitability as an amendment in freshwater SMFCs for a sustainable aquatic ecosystem management. However, the results may depend upon the properties of raw materials used to produce nanobiochar and biochar.

Keywords: Sediment microbial fuel cell (SMFC), Nano biochar, Phosphorus adsorption, Kojima lake, Bio-electricity, Biochar

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Assessment of hydrological processes and sediment yield in Dakbla catchment, Kon Tum province, Vietnam.

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The Dakbla catchment, a sub-basin of Se San river basin, is located in the Central Highland of Vietnam with an area of about 3,507 km^2, the length of the main river is 152 km. As it belongs to the tropical monsoon climate, there are two distinct seasons including rainy season (May - October) and dry season (November - April). The average annual temperature is about 20 - 25°C and the total annual rainfall is 1,500 - 3,000mm. The meteorological and hydrological monitoring system has not been invested and developed. Moreover, the economy in the study area depends heavily on cultivation activities with the main crops such as rubber and coffee grown on basalt soil. During rainy season, intensive rainfall has damaged farmlands and accelerated soil erosion from the areas. Thus, soil fertility in farmlands and crop productivity have been reducing. Therefore, simulating the flow and sediment yield are extremely important as the first step to understand an impact of land degradation in the catchment against local economy, based on the historical time series.

At present, there are many critical issues for water resource management ranging from hydrological variability, environmental degradation, erosion, and conflicts over the use of water for different purposes. So far, many studies have assessed water discharge in Dakbla catchment but still lack of data on sediment and water quality. In this study, SWAT model, a physically based semi-distributed hydrological model, was selected to assess hydrology and water quality in an agricultural catchment. The results showed that model was calibrated and validated for the period 2000 - 2005 and 2006 - 2011, respectively, using the observed water discharge data at Kon Tum station. Statistical evaluations including R^2 (coefficient of determination) and NSI (Nash–Sutcliffe index) indicated good performance of the model in simulating water discharge on monthly time step during the calibration and validation period. The calibration result of water discharge at Kon Tum station from 2000 to 2005 was good with $R^2 = 0.78$ and NSI = 0.77. Similar to the calibration period, water discharge was simulated well with $R^2 = 0.82$ and NSI = 0.80 during the validation period (2006 - 2011). Focusing on sediment yield, the results were $R^2 = 0.70$, NSI =0.70 in calibration period, and $R^2 = 0.58$, NSI = 0.50 in validation period, respectively. As next step, it is very important to assess local farming activities and to analyze its influence for sediment discharges from agricultural fields.

Keywords: Water discharge, Soil loss, Agricultural fields, Central Highland of Vietnam

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Acidic fresh submarine groundwater discharge around mud diapirs in southwestern Taiwan

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Submarine groundwater discharge (SGD) is an important source of nutrients in many coastal regions, yet little information is available on its carbonate chemistry and the controlling factors. Our SGD samples collected around the coast of southwestern Taiwan contain relatively high total alkalinity (TA) and dissolved inorganic carbon (DIC) concentrations, but low in salinity, dissolved oxygen, pH and the saturation state of calcium carbonate (Ω_{ara}). Of note is that these high-carbon but low-pH SGD samples are largely located in the coasts with mud diapir outcrops, such as in the coasts of Liuqiu Island, Nanwan Bay, and Chaishan Mountain. The Ω_{ara}, however, is far below saturation, adversely affecting the marine lives with their skeletons or shells made of calcium carbonate (e.g. coral, shellfish). Meanwhile, seawater near submarine volcanoes with depths 370m and 520m off southwestern Taiwan also contain relatively low pH. Data from the Liuqiu Island suggest that the acidic properties of the SGD are a result due to the physical mixing between seawater and high TA and DIC but low pH and Ω_{ara} fresh groundwater. Such a result is consistent with our data that some lake waters located nearby the mud diapir regions have distinctly high TA but low pH and Ω_{ara} values, and the reason deserves further investigation.

Keywords: submarine groundwater discharge, SGD, pH, saturation state of calcium carbonate, mud diapirs

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Spatio-temporal dynamics of submarine groundwater discharge (SGD) on an intertidal beach scale, temperate coastal area

*Mitsuyo Saito[1], Shin-ichi Onodera[2], Shingo Nozaki[2], Yusuke Tomozawa[2]

1. Okayama University, 2. Hiroshima University

Submarine groundwater discharge (SGD) is defined as subsurface water flow from the seabed to the coastal sea and ocean. Because groundwater often contains higher nutrients than river water, SGD delivers comparatively large quantities of nutrients to coastal ecosystems. However, there are few studies to examine the detailed dynamics of SGD including spatial heterogeneity, seasonal variation and tide-induced variation. In the present research, we aimed to examine the spatio-temporal dynamics of SGD on an intertidal beach scale in a temperate coastal island.

The study area is located on Ikuchijima Island in Seto Inland Sea, southern Japan. The regional climate is mild, with an annual mean precipitation of 1,100 mm and temperature of 15.6 ˚C. The whole island is characterized by steep slopes and is widely covered by citrus farms with more than 40% of the island. The previous researches confirmed that SGD can rival or even exceed surface runoff in this island. The target beach is located in the southern area of the island characterized by steep backland topography. Main bottom material of the beach is sand, however, the western part is covered by coarse gravels. We installed piezometers and measured water pressure, water temperature (WT), electric conductivity (EC), and radon (^{222}Rn) concentration in pore water on several times from 2018 to 2019. Time-series variation in WT and ^{222}Rn in seawater were monitored in December 2019. Before the field campaign in July 2018, the study area had an extreme rainfall event. Large spatial variation in hydraulic potential, water temperature, EC and ^{222}Rn concentration in pore water were confirmed in the beach. Significant low EC and high ^{222}Rn concentration were confirmed in the western part of the beach.

*This work is supported by JSPS Grant-in-Aid for Scientific Research (A) (25241028, PI: Shin-ichi ONODERA) and Grant-in-Aid for Scientific Research (B) (18H03411, PI: Mitsuyo Saito).

Keywords: Submarine groundwater discharge, Intertidal zone, Spatio-temporal dynamics

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Impact of terrestrial nutrients in groundwater on coral reefs via submarine groundwater discharge around Yoron Island of the Southwest Islands, Japan

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Anthropogenic activities often have significant environmental impact. On tropical to subtropical islands without rivers, terrestrial nutrients from agricultural activity and waste water are transported from land to ocean via submarine groundwater discharge (SGD). It has been reported phosphorus inhibits skeletal development of corals in laboratory experiments. In general, nitrogen transported from land breeds algae. In Yoron Island, phosphorus and nitrogen concentrations in SGD from Ryukyu limestone-aquifer at east coast were 2.3 mg/L and 3.5 mg/L, respectively. Corals in shallow lagoon have not recovered since mass-scale coral bleaching caused by seawater temperature rise in 1998. However, the causal relationship between terrestrial nutrients in SGD and delay in coral recovery is unknown.

We investigated the effect of nutrients in groundwater on coral reefs via SGD around the Yoron Island of the Southwest Islands, Japan, from numerical simulation in spread of submarine groundwater due to tidal current in coral reef lagoon leading to the open sea. Results are summarized:

1. Submarine groundwater spreads to north part of coral reef lagoon in surface and bottom, reaches the reef habitat, and tend to stay blocked by the outer reef structure.
2. Strong spread zone of submarine groundwater is coincident with low coverage zone of corals, suggesting that terrestrial anthropogenic activities are affecting marine corals via SGD.

Keywords: submarine groundwater discharge, coral, Yoron Island, numerical simulation

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-HW Hydrology & Water Environment

[A-HW32] Material transportation and cycling in aquatic ecosystems; from headwaters to coastal areas

convener:Syuhei Ban(The University of Shiga Prefecture), Adina Paytan(University of California Santa Cruz), Takahiro Hosono(Faculty of Advanced Science and Technology, Kumamoto University), Morihiro Maeda(Okayama University)

This session aims to synthetize watershed sciences in order to understand dynamic processes in transportation and cycling of materials and nutrients in aquatic environments from headwaters to coastal areas. The session will integrate various inter-disciplinary researches including limnology, ground water hydrology, coastal oceanography, meteorology, pedology, sedimentology, forestry, agriculture, fishery, ecology, social science and so on. This session calls for ideas on new methods for understanding the watershed sciences, such as tracer and molecular techniques, hydrological modeling, paleontological approaches, and chemical analyses, in order to elucidate physical, chemical and biological mechanisms for shedding light on natural phenomena and their spatio-temporal variations in complex and dynamic aquatic systems under human and climate impacts. Both laboratory and field studies, social-scientific evaluation of ecosystem services and social-ecological systems will be also welcomed. Through this session, we would like to facilitate interdisciplinary collaboration among participants to create new knowledge on watershed sciences.

[AHW32-18] Evaluation of the long-term impact of forest growth and change on water and sediment yield in forested watershed of Kikuchi river using SWAT model

*Yuko Nagano[1], Soichiro Fujii[1], Masahiko Kanamori[1], Maki Kinoshita[2], Masatoshi Yamazaki[3], Yuta Shimizu[4], Shin-ichi Onodera[5] (1.Japan Forest Technology Association, 2.Field Partners, 3.PASCO Corporation, 4.Western Region Agricultural Research Center, National Agriculture and Food Research Organization, 5.Graduate School of Integrated and Arts Sciences, Hiroshima University)

[AHW32-19] Estimation of Change in Groundwater Recharge by Urbanization in a Granitic Mountain Catchment, Using SWAT Model

*Sharon Bih Kimbi[1], Kunyang Wang[1], Shin-ichi Onodera[1], Yusuke Tomozawa[1], Shingo Nozaki[1], Anna Fadliah Rusydi[1] (1.Graduate School of Integrate Arts and Sciences, Hiroshima University)

[AHW32-20] Understanding of Subsurface Flow Systems: Role of Environmental Tracers in Model Calibration

*A T M Sakiur Rahman[1], Takahiro Hosono[1], Yasuhiro Tawara[2], Dennis Boateng[1], Jun Shimada[1] (1.Department of Earth and Environmental Science, Kumamoto University, Japan, 2.Geosphere Environmental Technology Corporation, NCO Kanda, Awajicho, Chiyoda-ku, Tokyo 101-0063, Japan)

[AHW32-21] Impact of Urban Functional Area Subdivision on Simulation of Flash Flood in Hydrological Model

*Kunyang Wang[1], Shin-ichi Onodera[1], Shuxue Qu[2], Yuta Shimizu[3], Mitsuyo Saito[4] (1.Graduate School of Integrated Arts and Science, Hiroshima University, 2.College of Resources, Environment and Tourism, Capital Normal University, 3. National Agriculture and Food Research Organization, 4.Faculty of Environmental Science and Technology, Okayama University)

Discussion

Discussion

Evaluation of the long-term impact of forest growth and change on water and sediment yield in forested watershed of Kikuchi river using SWAT model

*Yuko Nagano[1], Soichiro Fujii[1], Masahiko Kanamori[1], Maki Kinoshita[2], Masatoshi Yamazaki[3], Yuta Shimizu[4], Shin-ichi Onodera[5]

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The Kikuchi River is the third largest river (996 km^2) flowing into the Ariake Sea lying on the island of Kyū shū in Japan, following the Chikugo River and Midori River.

Eutrophication has become a problem in the Ariake Sea in recent years, and the influence of inflowing rivers has been attracting attention. As more than half of the Kikuchi River basin is forested, and it is assumed that forests have a significant impacts on water balance of the basin, it would be meaningful to elucidate the water cycle process of the Kikuchi River basin.

In recent years, the role of forests as green infrastructures has been particularly attracting attention. Those include such functions as water recharge, runoff and erosion control, and water quality improvement, and it is expected that taking advantages of those functions will lead to improvements in the marine environment in the Ariake Sea.

Although many studies examine the impact of land use on hydrological responses in a watershed using a distributed hydrological model, few analyzes have focused on the long term impacts of land cover/land use change, especially of forest growth within the same site, on the hydrological responses.

The purpose of this study is to quantitatively evaluate the long-term impacts of forest growth and change on forest functions such as water recharge and control of sediment yield in Kikuchi River basin using the Soil and Water Assessment Tool (SWAT), a physically based semi-distributed hydrologic model.

Land use and climate data were prepared for two time points, 2010s and 1970s, to see the impact of forest growth over the last 40 years. Forests, one of the land-use types, were subdivided into four types according to tree type (coniferous and hardwood) and growth stage (early, young, and mature). The same data was used for soil and topography between the two time points, assuming that there was no change for those data.

For the model calibration and validation, we also collect data for daily streamflow from 2005 to 2016 for the 2010s model and from 1976 to 1977 for the 1970s model. Data for sediment yield is available only for 2010s. Calibration and validation for daily streamflow and sediment yield is conducted basically for 2010s model using SWAT-CUP until satisfactory results are obtained. Model performance is evaluated using statistical indicators such as Nash-Sutcliffe model efficiency (NSE), percentage bias (PBIAS), root mean square error and measured standard deviation (RSR).

Once the optimal parameters are adjusted, those parameters are applied to 1970s model to see whether

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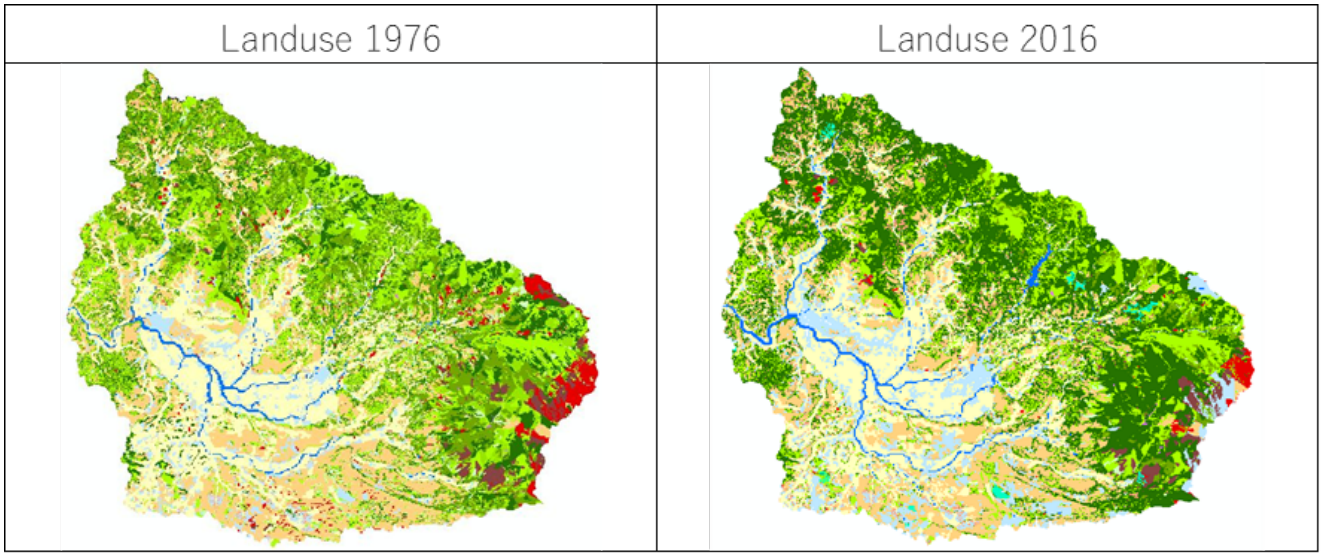
key hydrological parameters and/or processes exist or not by verifying the difference in parameter behavior between two models, which can provide useful information for developing strategies for sustainable forest and water management, not only for the Kikuchi river basin but also for similar mountainous forest watersheds.

Keywords: SWAT model, Hydrologic and Sediment Transport Modeling, Forest watersheds, Ariake Sea, Long-term valiavility



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Estimation of Change in Groundwater Recharge by Urbanization in a Granitic Mountain Catchment, Using SWAT Model

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River discharge is controlled by various functions, not only by different natural water cycles affected by topography, climate and land use but also by water used for domestic, agricultural and industrial purposes. Therefore, it is essential to confirm long-term variations of streamflow quantity and quality in their catchment in order to conserve and properly manage their watersheds. Increasing population growth with rapid changes of other aspects such as social and economy within the city of higashihiroshima has led to an increasing demand of settlement and agricultural area. Such changes in land use pattern has a profound impact on groundwater recharge. Higashi-Hiroshima city has the largest rice production of amongst 86 cities, towns and villages in the chugoku region. To understand the hydrological and biogeochemical processes occurring within the Kurose river catchment occurring, the Soil and Water Assessment Tool (SWAT) was used for water budget and groundwater recharge modelling to predict the impact of land management practice on water, and agricultural chemical yield with varying soils, land use, and management condition over an extended time frame (2006-2018). Meanwhile SWAT-CUP SUFI12 was used for model calibration and validation. The outputs of this current project will be information on the relationship between land use as a dynamic parameter in the catchment area and the output presented by hydrograph. The simulation model will be used as a basis for Integrated Watershed Management System.

Keywords: groundwater recharge, SWAT model, mountain catchment

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Understanding of Subsurface Flow Systems: Role of Environmental Tracers in Model Calibration

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Integrated watershed modeling techniques are being applied to examine the surface and subsurface interactions in recent years. Generally, modeling approaches heavily rely on the best fit of the hydrograph which alone cannot describe entire catchment water dynamics. For holistic understanding of hydrological processes, it is necessary to incorporate and simultaneously simulate tracers which can provide important inferences about water ages, flow paths and origin. Hence, this study incorporated multiple tracers like tritium (^{3}H), Krypton-85 (^{85}Kr), and groundwater temperature in model calibrations and seamlessly simulated tracers coupled with surface and subsurface flows using a fully distributed physically based modeling approach (*i.e.,* GETFLOWS) for detailed characterizations of Kumamoto water regimes in southern Japan. The first model developed using the regular hydrometric parameters could not characterize isotopic compositions and groundwater temperature, though it showed acceptable model performance for simulating surface water and groundwater hydrographs for several observation stations located in the area. The second model calibrated by integrating tracers with regular parameters well characterized hydrographs of surface water, groundwater as well as isotopic compositions and groundwater temperature. Hence, tracer-aided model was used for simulating groundwater storage, flow paths and groundwater age which showed a close agreement with estimation of water ages using isotopic approaches in previous studies. The findings of the novel approach proposed in this study prove the potential in the use of multiple tracers for details visualizations of subsurface water dynamics and findings can be used for local water resources management and planning.

Keywords: Fully coupled tracer aided model, Multiple tracer simulation, Groundwater age, Uncertain boundary correction

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Impact of Urban Functional Area Subdivision on Simulation of Flash Flood in Hydrological Model

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Flash flood is one of the most common natural disasters, floods and other water-related disasters account for 70 per cent of all deaths related to natural disasters. Due to the short time of flash flooding, higher time accuracy is required for simulation. Soil and Water Assessment Tools (SWAT) is very widely used in watershed research. Boithias et al. simulated flash floods at SWAT model hourly time-step in Mediterranean river coastal basin and proved that the SWAT model appears to be a reliable modelling tool to predict discharge over long periods of time in large flash-flood-prone basins.

For flood simulation and prediction, it is important to know the flood risk area, especially in densely populated urban areas. But sometimes it was limited by land use and land cover information. Traditional land use classify method could not reflect detail hydrologic property discrepancy clearly. For example, commercial blocks with high building density and impervious percentages and university campuses with high greenery are both classified as "urban" in the land use classification system. But in fact, there are large differences in its hydrological process.

POI means “Point of information”, a kind of big data. Urban POI can effectively describe the division of functional areas within a city. Use POI to refine land classification and give POI hydrological attributes. So as to improve the accuracy of land use information. Yamato River Basin has experienced 13 flash floods in the last 20 years, especially in recent years, almost each year one-time flash flood. The flood caused the streamflow in the river channel to be too large, the water level was too high, and there was a risk of flooding the surrounding area. The SWAT model is a commonly used watershed hydrological model. SWAT can simulate runoff in hours, which is very important for simulating the corresponding flood.

This study extracts 15 types of POI including parks, schools, medical facilities, post offices, city streets, cultural facilities, passenger facilities, and industrial land, etc., use remote sensing methods to statistically calculate their surface characteristics. Selected SWAT model to compare the difference between the daily simulation and the hourly simulation under the traditional land use map and the POI-enhanced land use map, search the weak areas in urban area. In the results of the SWAT model, the POI enhanced map can display richer urban hydrological process information, and the simulation of river runoff has higher accuracy.

Keywords: POI, big data, SWAT, hourly simulation, urban flooding

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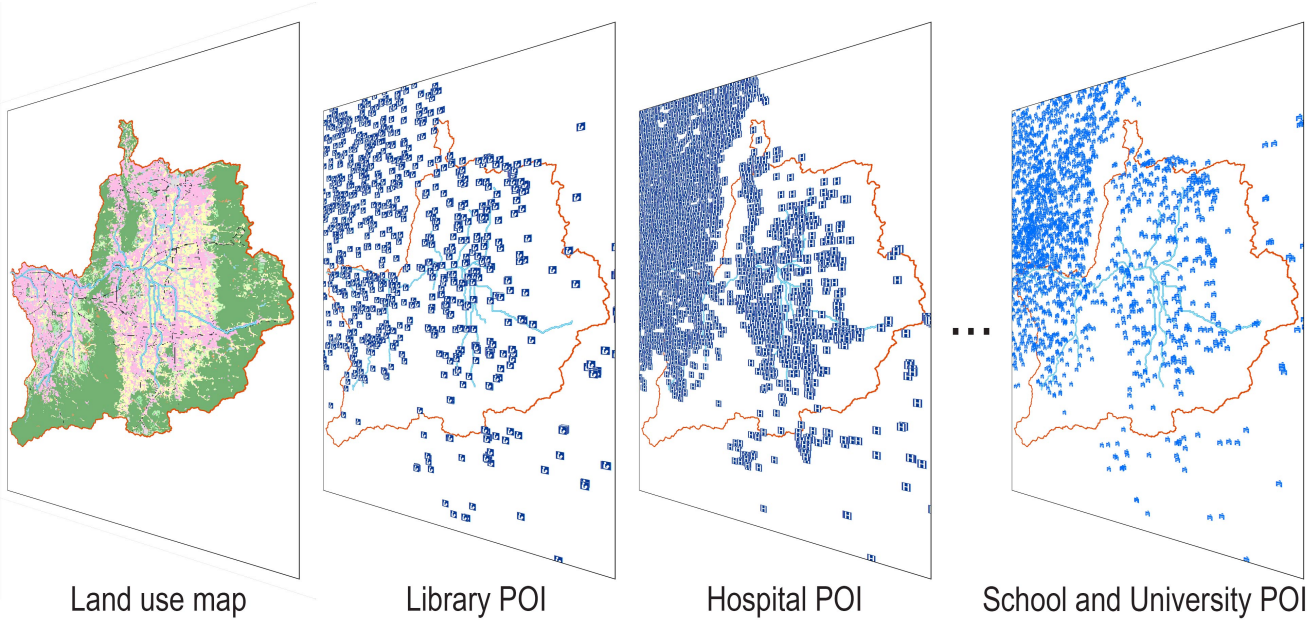

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-HW Hydrology & Water Environment

[A-HW33] Prediction of water and sediment dynamics from small to large scales

convener:Yoshiyuki Yokoo(Fukushima University), Yuko Asano(The University of Tokyo)

After the IAHS decade of PUB, challenges have been continued for understanding internal processes and developing models for elevating the predictability of hydrological response for watershed with multiple scales. Simultaneously, changes in the precipitation patterns and intensity as well as increases in associated sediment disasters due to global climate changes brought us challenges for developing tight linkages between water and sediment dynamics in the areas of observation and modeling approaches. For tacking the issues, we have conducted studies for comprehending scale dependency of processes for water and sediment movement from small to large watersheds and explored process representation of numerical models coupled to field-based evidences. Based on these studies, we proposed (1) classification for the behaviors of water and sediment movement from small and large watersheds depending on internal processes, (2) internal hydrologic and geomorphic processes can be included in models. Further discussion needs to be extended for applicability of the approaches.
This session aims to explore updated and current studies for scale dependencies and process representation of hydrologic and geomorphic processes in multiple watersheds. We welcome for topics related to hydrology, geomorphology, and biogeochemistry in small and large watersheds for both field and modeling approaches. Patterns and variability for water and sediment movements within watersheds are also included in the topics.
In this session, we will extend discussion for next step of field and modeling studies toward integrating hydrologic and geomorphologic processes in various landscapes and achieving prediction of ungauged basin in the areas of water and sediment dynamics. Finding through this session may advance our ability for hydrological predictions in any ungauged basins from small to large spatial scales toward sustainable water resources and sediment management.

[AHW33-01] Effect of spatial scales on runoff / sediment transport in mountain catchments

*Yuko Asano[1], Taro Uchida[2], Takashi Gomi[3], Shigeru Mizugaki[4], Marino Hiraoka[5], Masanori Katsuyama[6], Satoshi Niwa[7], Yoshiyuki Yokoo[8] (1.The University of Tokyo, 2.Tsukuba University, 3.Tokyo University of Agriculture and Technology, 4.Civil Engineering Research Institute for cold region, Public Works Research Institute, 5.Public Works Research Institute , 6.Kyoto Prefectural University, 7.Japan Conservation Engineers & Co., Ltd., 8.Fukushima University)

[AHW33-03] Contrasting patterns in the decrease of spatial variability with increasing catchment area between stream discharge and water chemistry

★Invited Papers

*Tomohiro Egusa[1], Tomo'omi Kumagai[1,2], Tomoki Oda[1], Takashi Gomi[3], Nobuhito Ohte[4] (1.The University of Tokyo, 2.Nagoya University , 3.Tokyo University of Agriculture and Technology, 4.Kyoto University)

[AHW33-04] Effects of small-scale vertical unsaturated flow on the exponent of a runoff-storage power-law relationship in catchment storm runoff models

*Makoto Tani[1], Yuki Matsushi[2], Takahiro Sayama[2], Roy C Sidle[3], Nagahiro Kojima[4] (1.University of Human Environments, 2.Disaster Prevention Research Institute, Kyoto University, 3.University of Central Asia, 4.Lake Biwa Environmental Research Institute)

[AHW33-05] Towards improving predictivity of runoff and sediment transport for mountainous catchments through measurement of spatial patterns of hydrological behaviors

*Taro Uchida[1], Yuko Asano[2], Shigeru Mizugaki[3], Yoshiyuki Yokoo[4], Marino Hiraoka[5], Takashi Gomi[6], Satoshi Niwa[7], Masanori Katsuyama[8] (1.University of Tsukuba, 2.University of Tokyo, 3.Civil Engineering Research Institute for cold region, Public Works Research Institute, 4.Fukushima University, 5.Public Works Research Institute, 6.Tokyo University of Agriculture and Technology , 7.Japan Conservation Engineers & Co., Ltd. , 8.Kyoto Prefectural University)

Effect of spatial scales on runoff / sediment transport in mountain catchments

*Yuko Asano[1], Taro Uchida[2], Takashi Gomi[3], Shigeru Mizugaki[4], Marino Hiraoka[5], Masanori Katsuyama[6], Satoshi Niwa[7], Yoshiyuki Yokoo[8]

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Examining the patterns of spatial variability of runoff and sediment transport should be the key to understand hydrologic and geomorphic processes in watersheds and improve the process-based representation of numerical models. Therefore (1) we reviewed the relations between drainage areas and various properties of runoff and sediment transport comprehensively, particularly addressing spatial-scale dependence and spatial heterogeneity. (2) We summarized and elucidated the processes controlling scale dependence and spatial heterogeneity based on the observed results from selected intensively studied sites. (3) We reviewed and analyzed the treatment of spatial scales in numerical models of runoff and sediment transport, to elucidate current problems and to identify avenues for future research.

(1) Some properties on water and sediment transport showed increase and/or decrease pattern relative to the catchment area, although other properties showed no distinctive relation to catchment areas, partly because of a lack of measured data. Most earlier studies specifically examined either spatial-scale dependence or spatial heterogeneity. Properties such as peak specific discharge showing clear spatial-scale dependence should be controlled by mechanisms that change with the spatial scale. Properties such as base flow specific discharge showed spatial heterogeneity, which suggested that mechanisms controlling base flow did not change much with the spatial scale for the measured ranges of catchment areas but heterogeneous properties of landscapes exerted strong effects.

(2) We selected well studied Fudoji and Kiryu (Shiga), Tanzawa (Kanagawa) and Saru watersheds (Hokkaido) for analysis. For baseflow generation, various ratio of contribution from weathered bedrock layer to soil layer derive spatial heterogeneity in small catchments and this variation tapered with increased catchment area due to the mixing of several flow components. Sediment transport also varied spatially depending on the catchment characteristics. Variation tapered with increased catchment area. For some catchment, sediment transport decreased with catchment area due to the increased storage components and decreased ratios of sediment source areas to the total catchment area for larger drainage areas. While for other catchment, sediment yields increased in larger catchment, due to landscape legacies of sediment supply, storage, and transport.

(3)We examined following questions. (a) Which spatial scale is used in existing modeling and how was it decided? (b) What spatial information was used? (c) Do the governing equations differ with spatial scale? Results show that (a) the smallest spatial scale in distributed models was determined by the spatial resolution of spatially distributed information used in modeling, although lumped models were applicable at any scale. (b) Physical parameters used in modeling were not based on field-based information, except elevation, land use and vegetation cover. (c) Results demonstrated that the governing equations differ depending on locations within the watershed (i.e., hillslopes and channels) that present different processes for runoff and sediment transport. Nevertheless, no report of the relevant literature described the changes in governing equations with the changes in spatial scales. We also reviewed modeling studies

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that focused on how we should treat the spatial scale. For runoff models, they had reported minimum and the maximum spatial scales for lumping runoff mechanisms and the relative importance of spatial data used as input parameters. While we were unable to find similar studies for sediment transport models. The effect of spatial scales on runoff / sediment transport and processes behind that pattern have been demonstrated to some extent. However, many of the numerical models have not been sufficiently considered these information, yet.

Keywords: spatial scale dependence, spatial heterogeneity, water discharge, sediment discharge, numerical model, spatially distributed information

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Contrasting patterns in the decrease of spatial variability with increasing catchment area between stream discharge and water chemistry

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Understanding the relationships between spatial variability in hydrological and biogeochemical processes and spatial scale is required to obtain information about the spatial representativeness and potential of extrapolation of these processes and to improve our ability of predictions in poorly gauged or ungauged basins (PUB). One major approach was to determine the Representative Elementary Area (REA), which was defied as the minimum area where spatial variability in small catchments became sufficiently small to be ignored. Despite the large number of studies available, only a few have examined how spatial variability in stream discharge and water chemistry decreases with increasing catchment area, and how the size of REA is determined. Therefore, our purpose was to obtain a better understanding of how the spatial variability of stream discharge and water chemistry decreases with increasing catchment area in small headwater catchments. For this purpose the following questions were addressed.

1) How does the rate of decrease in spatial variability with increasing catchment area differ among catchments and for stream discharge and water chemistry?

2) What type of spatial structure causes different rates of decrease in spatial variability with increasing catchment area?

We observed stream discharge and water chemistry in multiple points within three forested headwater catchments and investigated differences in this decrease of variability with increasing catchment area among catchments, and among specific discharge (Q_s) and water chemistry parameters. We quantified the slope of the decrease in the variability with increasing catchment area as the rate of decrease in the standard deviation and coefficient of variation (δ_{SD} and δ_{CV}, respectively), both of which are −0.5 for the simple mixing of random variables (random mixing). Then, we defined two indices to evaluate the spatial structure of the parameters. One was “relative difference”, which referred to the ratio (in percentage) of the parameters' mean values between low- and high-order streams. The other was “D_{200}”, which indicated the dissimilarity of parameter values within sub-catchments.

All δ_{SD} and δ_{CV} values of Q_s were less than −0.5, while those of most water chemistry values were greater than −0.5, indicating that with increased catchment area the spatial variability of Q_s decreased more steeply than for random mixing, while for water chemistry they decreased less steeply. δ_{SD} and δ_{CV} had positive linear relationships with the relative difference and negative linear relationships with D_{200}. It suggested that differences in δ_{SD} or δ_{CV} for Q_s and water chemistry can be explained by the different spatial structures, where dissimilar values of Q_s and similar values of water chemistry, respectively, are located close together in space. Differences in δ_{SD} and δ_{CV} according to Q_s and water chemistry should significantly affect the determination of representative elementary area (REA), and therefore need to be considered when predicting REA from spatial variability of low-order streams.

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Keywords: Spatial variability , Stream discharge , Stream water chemistry, Catchment area

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Effects of small-scale vertical unsaturated flow on the exponent of a runoff-storage power-law relationship in catchment storm runoff models

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Numerical experiments on vertical unsaturated flow using the Richards equation were conducted to examine the physical basis of why storm runoff responses from mountainous catchments in tectonically active regions can be simulated by simple runoff models with a runoff-storage power-law relationship. An interdependent relationship between the total storage of a soil column and the outflow rate from the bottom in the recession stage obtained experimentally was approximated by a power-law equation derived from relationships between total storage and constant outflow under steady-state conditions. The exponent of the power-law equation approaches a maximum of unity as the column length decreases, and it approaches the minimum value obtained from the intrinsic relationship between soil hydraulic conductivity and volumetric water content as the column length increases. This result strongly suggests that vertical unsaturated flow at the smallest scale may play an important physical role in the production of storm runoff responses at the catchment scale.

Keywords: Vertical unsaturated flow, Runoff-storage power-law relationship, Storm runoff response, Scale dependencies of hydrologic processes

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Towards improving predictivity of runoff and sediment transport for mountainous catchments through measurement of spatial patterns of hydrological behaviors

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n the last several decades, hydrologist have been argued spatial variability and scale dependencies of runoff and sediment transport for mountainous catchments. In this paper, we discussed issues and approaches for connecting findings of field-based observations and numerical hydrological modeling for improving predictability of runoff and sediment discharge transport for mountainous catchments. We proposed a method for identifying dominant processes of water and sediment movement as well as site- or catchment-specific conditions (e.g., topography, soil, and vegetation) for controlling specific processes using spatial patterns of runoff and sediment discharge in a given catchment. In our method, processes controlling runoff and sediment discharge simply classified into three based on mass balance such as (1) sum of inflow amount from upstream tributaries, (2) advection in a given channel segment, (3) storage change within a channel segment. We considered that if the first type of processes is dominated, the spatial patterns of runoff should be described as central limit theorem. While, second and/or third types of processes are dominated, the spatial pattern should be different from the previous one. This indicated that the observed data of spatial variability and spatial scale dependencies is essential to improve the predictivity of a numerical hydrological models through clarifying dominant processes and site-conditions.

Keywords: Characteristics of catchments, Catchment areas and water/sediment movement, umerical model

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-HW Hydrology & Water Environment

[A-HW33] Prediction of water and sediment dynamics from small to large scales

convener:Yoshiyuki Yokoo(Fukushima University), Yuko Asano(The University of Tokyo)

[AHW33-06] Linking micro scale hillslope properties and a meso scale constitutive equation used in rainfall-runoff modeling

★Invited Papers

*Yutaka Ichikawa[1] (1.Graduate School of Engineering, Kyoto University)

[AHW33-07] **Sediment Transport Modeling Beyond Normality: Estimation of Sediment Concentrations Accounting for Spatial Influence of Turbulence Coherent Structures**

★Invited Papers

*Christina Tsai[1], Kuang-Ting Wu[1] (1.National Taiwan University)

[AHW33-08] **Change in Sediment Yield Dynamics in Bhagirathi Basin (Large Watershed) with Climatic Variables Having One Outlet by Using SWAT Model and SUFI-2 Algorithm.**

*Jagriti jain[1], Deepak Khare[1] (1.Indian Institute of Technology, Roorkee)

[AHW33-09] Characteristics of Discharge and Tidal Asymmetry over Two Inlets Lagoon: A Case Study on Segara Anakan Lagoon, Central Java, Indonesia

*Faruq Khadami[1,2], Kiyoshi Kawanishi[1] (1.Department of Civil and Environmental Engineering, Hiroshima University, 2.Oceanography Study Group, Faculty of Earth Science and Technology, Institut Teknologi Bandung)

[AHW33-10] Understanding catchment processes and scale effect on catchment flows

*Chris Leong[1], Yoshiyuki Yokoo[1] (1.Fukushima University)

[AHW33-11] Applying a data-based rainfall-runoff modeling approach to interpret the mechanisms of decreasing spatial variability of subcatchment-specific discharge with increasing subcatchment area

*Yoshiyuki Yokoo[1], Takeshi Sakairi[1], Chris Leong[1] (1.Fukushima University)

Linking micro scale hillslope properties and a meso scale constitutive equation used in rainfall-runoff modeling

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A number of rainfall-runoff models have been developed in the field of hydraulic and hydrologic engineering, with a special emphasis on simulating temporal patterns of river discharge in order to meet practical demands such as discharge predictions. Conceptual rainfall-runoff models were initially developed, followed by physical-based models. The physical-based models have achieved a certain level of success, which was partly due to the rapid advancement of computers and the increasing availability of a variety of datasets. It is pointed out, however, that recent important findings based on field studies are not incorporated into rainfall-runoff models, especially used for engineering purposes. To examine the raised issue, this study conducted detailed simulations coupling surface flow, saturated-unsaturated flow and pipe flow for hillslope rainfall-runoff processes, and investigated the validity of a constitutive equation (depth-discharge relationship) used in a rainfall-runoff model. The results revealed that the constitutive equation was capable of describing the dynamics of water flows arising on a steep hillslope with relatively wet conditions.

Keywords: hillslope properties, constitutive equation, water flows, coupled model simulations

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Sediment Transport Modeling Beyond Normality: Estimation of Sediment Concentrations Accounting for Spatial Influence of Turbulence Coherent Structures

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1. National Taiwan University

Recent experiments have established that the sediment particle motion, especially for particles near the bed, may not follow the normal (Fickian) diffusion behavior. To modify the diffusion equation where the fluctuation velocity is based on the normal distribution, this study attempts to acquire some physical insight into the particle diffusion behavior by considering more details on turbulent coherent structures including the asymmetry of velocity fluctuations and spatial distributions of turbulent coherent structures. The uniform momentum zones (UMZ) are further identified and consequently the spatial locations of the edges that demarcate UMZs can be estimated. Once UMZs in the turbulent boundary layers can be characterized, the streamwise momentum deficit, and occurrences of ejection events and sweep events in the vicinity of UMZ edges under different Reynolds numbers can be simulated. The simulation results identify the contributions of these structures to suspended sediment transport, and show the time coherence of flow velocity may be essential for flow to carry sediment particles in suspension. The spatial influence of turbulent coherent structures on sediment particle trajectory can also be demonstrated.

Keywords: Turbulent Coherent Structures, Sediment Transport, Memory Effect, Spatial distribution of turbulent structures

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Change in Sediment Yield Dynamics in Bhagirathi Basin (Large Watershed) with Climatic Variables Having One Outlet by Using SWAT Model and SUFI-2 Algorithm.

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In the present study, an attempt has been made to assess the impact of the climatic change on sediment yield in a hilly region of India (north of Tehri Garhwal district, Uttarakhand) by using Soil Water and Assessment Tool (SWAT). The study was conducted to determine the sediment yield using SWAT model Bhagirathi Basin, north of Tehri Garhwal district. The SWAT model is simulated from the year 1980-1993 with a warm-up period of 3 years on an annual basis. The sediment data is calibrated and validated with SWAT- CUP 2012 using SUFI-2 algorithm having R^2= 0.43 and 0.54, NSE= -0.32 and -0.27 respectively. R^2 is set as the objective function for the analysis. From this study, it is found that the SWAT model has run perfectly well. From the result, it is conferred that the SWAT model does not cater to gully erosion, landslides and mass wasting, which are occurring in the region. There is also a lack of sites for the collection of data sample in a watershed of Tehri Garhwal as the sample collection is done at one outlet only. To determine the change in sediment yield dynamics with the climate, the climate sensitivity analysis is performed for the sediment yield in the study area with respect to perturbations in rainfall and temperature keeping other parameters constant. The change in sediment yield is decreasing when the rainfall is increasing and decreasing with the increase in rainfall. Maximum decreasing is seen when the smallest change in rainfall is observed with a value of 23.26 % when the rainfall is decreased by 5 % and the maximum increase is observed when the increase in rainfall is maximum with a value of 26.68 % when the rainfall is increased by 15%. The change in sediment yield is increasing when the temperature is increasing. The maximum increase in sediment yield is seen having a value of 42.10 % when the temperature is increased by 3^0C from the baseline temperature.

Keywords: Sediment Yield, SWAT model, Climate Sensitivity , Large Watershed, One Outlet

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Characteristics of Discharge and Tidal Asymmetry over Two Inlets Lagoon: A Case Study on Segara Anakan Lagoon, Central Java, Indonesia

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Segara Anakan Lagoon is a two-inlet lagoon with high sedimentation rate. Tides from the two inlets can be main factor that leads to the sedimentation pattern. A two-dimensional hydrodynamic model was used to investigate the tidal asymmetry and discharge in the inlets of the Segara Anakan Lagoon. The model results of water elevation and discharge were acceptable compared with the observation. The results show that the tidal wave propagates to the lagoon from both inlets and amasses in the central of lagoon. The type of tides in the Segara Anakan Lagoon is a mixed semi-diurnal tide which M2 component is dominant by having 0.5 m in amplitude. Analysis of the result of the water elevation model shows the tidal duration asymmetry in both inlets is flood dominance, while the tidal duration asymmetry around the amassing area is ebb dominance. Furthermore, the peak discharge asymmetry in both inlets is ebb dominance while the slack water asymmetry is ebb dominance. The slack water and peak discharge asymmetry indicates that the ebb flow in both inlets have shorter duration than the flood flow. However, the flood discharge is larger than the ebb discharge. The asymmetries of the tides duration and peak discharge may affect the sediment flux in both inlets and distribution of sediment in the lagoon.

Keywords: Tidal Assymetry, Discharge, Two Inlets Lagoon, Tidal Dynamics

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Understanding catchment processes and scale effect on catchment flows

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The shapes of flow duration curves of catchments are unique to their respective catchments and embedded within these shapes are important hydrological process occurring information within the catchment. This work seeks a process-based understanding of the flow duration curve of three different types of catchment flows, perennial, intermittent and ephemeral and its relational dependencies on scaling issues, in particular is the catchment size. First, the number of dominant processes within the catchments were identified and a tank model was built according to this number of dominant processes. Next, process-based equations that calculated return flows from in and out of the components of the tank model were derived from an initially used linear storage estimation method. The results showed that a combination of lower aridity, humid climate and large catchment size had more dominant processes occurring in it, in contrast to a catchment with a higher arid climate and small catchment size which has fewer dominant processes occurring in it. These combinations that affect the dominating occurring processes cause perennial and ephemeral flows within the catchments respectively. The results in this study contribute to the hydrological initiatives of process-based understanding of catchments in contribution towards predictions in ungauged basins.

Keywords: process-based, catchment size, flow duration curves, dominant processes, predictions in ungauged basins

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Applying a data-based rainfall-runoff modeling approach to interpret the mechanisms of decreasing spatial variability of subcatchment-specific discharge with increasing subcatchment area

*Yoshiyuki Yokoo[1], Takeshi Sakairi[1], Chris Leong[1]

1. Fukushima University

The weak law of large numbers can mathematically explain why there is a decrease in the spatial variability of river flows from subcatchments when travelling downstream, while catchment area increases. On the contrary, there is no process-based interpretation of this phenomena in today's catchment hydrology literature. The present study attempted to interpret the mechanisms of decreasing spatial variability of river flow with increasing catchment area in terms of a data-based rainfall-runoff modeling approach. First, we collected hydrological data from HJ Andrews Experimental Forest, Oregon, U.S.A. to plot the subcatchment specific discharge against subcatchment area. Second, we applied a data-based rainfall-runoff modeling approach to identify the unique rainfall-runoff processes for all the subcatchments in order to understand why the spatial variability of subcatchment-specific discharge decreases with increasing subcatchment area. The results showed that (1) the spatial variability of subcatchment-specific discharge is mostly explained by the spatial variability of faster processes in the subcatchments and (2) the decrease of spatial variability of faster processes in the subcatchments caused decreasing spatial variability of subcatchment-specific discharge with increasing subcatchment area. These results suggest that, among subcatchments, spatial variability of slower processes occur deep in the ground.

Keywords: rainfall-runoff mechanisms, spatial scale, uniqueness

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-HW Hydrology & Water Environment

[A-HW37] Interdisciplinary approach to support climate change adaptation measures in regional scale

convener:TEBAKARI TAICHI(Toyama Prefectural University), Yadu Pokhrel(Michigan State University), Masashi Kiguchi(University of Tokyo), Sompratana Ritphring(Kasetsart University)

[AHW37-01] ADAP-T for water-related adaptation to climate change and supporting its policy making

★Invited Papers

*Taikan Oki[1], Thanya Kiatiwat[2], Hiroaki Shirakawa[3], Weerakaset Suanpaga[2], Taichi Tebakari[4], Sompratana Ritphring[2], Masashi Kiguchi[5], Kyoko Matsumoto[5] (1.Institute for Future Initiatives, The University of Tokyo, 2.Faculty of Engineering, Kasetsart University, 3.Granduate School of Environmental Studies, Nagoya University, 4.Department of Civil and Environmental Engineering, Toyama Prefectural University, 5. Institute of Industrial Science, The University of Tokyo)

[AHW37-02] Land use and climate change impact assessments in humid tropics regions

*Eva Mia Siska Yamamoto[1], Takahiro Sayama[1], Kodai Yamamoto[2], Apip Apip[3] (1.Disaster Prevention Research Institute, Kyoto University, 2.Graduate School of Engineering, Kyoto University, 3.Indonesian Institute of Sciences)

[AHW37-03] Effects of ocean acidification on marine ecosystem services: use of natural analogues around volcanic CO_2 vents

*Shigeki Wada[1], Sylvain Agostini[1], Ben Paul Harvey[1], Koetsu Kon[1], Masanori Take[1] (1.University of Tsukuba)

[AHW37-04] Encouraging Climate Change Adapatation and Mitigation Measures Platform from Indonesia

*Komariah Komariah[1], Dwi Priyo Ariyanto[1], Sumani Sumani[1] (1.Sebelas Maret University, Indonesia)

[AHW37-05] Impact of Sea Level Rise on Tourism Carrying Capacity in Thailand

*Sompratana Ritphring[1], Pattrakorn Nidhinarangkoon[1], Keiko Udo[2] (1.Faculty of Engineering, Kasetsart University, 2. International Research Institute of Disaster Science,Tohoku University)

Discussion

ADAP-T for water-related adaptation to climate change and supporting its policy making

*Taikan Oki[1], Thanya Kiatiwat[2], Hiroaki Shirakawa[3], Weerakaset Suanpaga[2], Taichi Tebakari[4], Sompratana Ritphring[2], Masashi Kiguchi[5], Kyoko Matsumoto[5]

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The anthropogenic climate change is increasing water-related disaster risks such as flood and drought, in particular, because most of the adverse impacts of climate change is delivered to society through water. Mitigation efforts to reduce the greenhouse gas, e.g., CO2, emission and to reduce the speed of climate change are essentially important, and at the same time, adaptation measures to reduce the vulnerability and exposure of human lives and properties from risks exacerbated by climate change are also relevant. After the Paris Agreement of UNFCCC in 2015, all the member states are encouraged to set their National Adaptation Plan (NAP).

The formulation of “Thailand’s National Adaptation Plan” is being led by the Office of Natural Resources and Environmental Policy and Planning (ONEP) under Ministry of Natural Resources and Environment (MONRE) as a plan for the implementation of adaptation measures by each ministry and agency. For supporting the NAP formulation and development of climate change measures that contribute to a resilient and sustainable society, a new research project entitled "Advancing co-design of integrated strategies with adaptation to climate change in Thailand (ADAP-T)" with international collaboration between Thailand and Japan was proposed, approved, and implemented since 2016, supported by JICA for Thai side and JST for Japanese side under the framework of SATREPS. ADAP-T has three piers of research, namely i) Knowledgebase of climate change, ii) Adaptation measures to climate change, and iii) Co-designing adaptation measures. Disciplines relevant for the major sectors prone to climate change, such as riverine hydrology, forest hydrology, sediment erosion, coastal erosion, urban hydrology, and agricultural hydrology are collaborating under ADAP-T, and Kasetsart University, Thai Meteorological Department, Royal Irrigation Department, and ONEP are managing the ADAP-T project in Thailand with close communication with The University of Tokyo and member researchers.

These research results have been contributed to the formulation of NAP, which was compiled and published as ADAP-T Special Report 2018 “Scientific Report: Climate Change Effects and Adaptation Measures on Water related Sectors in Thailand” in April 2018. Moreover, these results are summarized and developed as a web-based adaptation simulator as a tool to assist policy makers considering policy priorities.

Keywords: Climate Change, Mitigation and Adaptation, SATREPS, Thailand, National Adaptation Plan

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Land use and climate change impact assessments in humid tropics regions

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Conversion of forests to other land uses due to economic activities is increasing more rapidly in developing countries particularly in humid tropics. These issues are often blamed as the cause of the water disasters such as floods and droughts. Raised concerns of the impact of rapid deforestation urges policy maker to create a regional planning which allow economic growth as well as forest protection. On the other hand, studies on climate change projects that the risks will be higher in the future. A number of research assessing the risks of water disasters due land use and climate change are increasing recently. This study will discuss on the further review on the wide application of empirical based hydrological models (which were developed in temperate regions) to assess land use and climate change impact in the humid tropic region. The land use impact studies using empirical models can give misleading results if it is not calibrated to represent the right dominant flow pathway in the basin. Finally, this study suggests that the model selection, particularly for the land use impact studies, should not be solely selected based on good fit to observed hydrograph but should also represent the right dominant flow pathway in the basin.

Furthermore, this study also will discuss a preliminary results of dynamic link between the increasing water related hazard risks such as floods and forest fires due to land use and climate change and the land use change distribution at spatial scale and vice versa.

The study took the Batanghari River Basin (42,960 km2) in Sumatera, Indonesia as a study area. The whole river basin is categorized as humid tropics, with basin average annual rainfall of 2,021 mm and average temperature ranging from 22 ºC to 26.8 ºC. Prior studies show that soil layer in the basin ranging from 1,100 to 4,500 mm with high hydraulic conductivity up to 320 mm/h. Half of forest area in the basin was mainly converted agriculture between 1990 and 2015.

Keywords: Runoff generation, Land use change, Climate change, Land use model

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Effects of ocean acidification on marine ecosystem services: use of natural analogues around volcanic CO_2 vents

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Anthropogenic CO_2 is being drawn down into the ocean surface, and a subsequent shift in carbonate chemistry has been predicted. In the near future, increases of hydrogen ion (decline of pH) and aqueous CO_2, and decrease of carbonate ions of seawater termed as ocean acidification (OA) will have a significant effect on marine ecosystems. While laboratory experiments have shown various impacts of OA on organisms, analysis at the species-level is sometimes incommensurable with responses at the ecosystem level. Area around volcanic CO_2 vents have been considered as a natural analogue of OA, because the conditions with higher CO_2 concentration would represent the environment found under OA. Our research team previously discovered natural CO_2 vents off the coast of Shikine Island in the Izu Archpelago in 2014. Intensive investigation of biota along the CO_2 gradient demonstrated a drastic shift in species composition (e.g., disappearance of calcifying organisms and dominance of turf algae).

About 500-600 people are living in Shikine Island. Their lifestyle is strongly dependent on marine ecosystems, because fishery and tourism such as recreational diving are major sources of income. Therefore, it is possible to assess the relationship between the ecosystem under OA and social activity on Shikine Island, and carry out an evaluation of the effect of OA on ecosystem services in Shikine Island. This will provide demonstrative information showing the impact that OA will have on human lives. In our project, the supporting, regulating, provisioning and cultural services are evaluated based on the monetary value attributed to biodiversity, carbon sequestration, fishery, and recreational diving, respectively.

Investigations of biota along CO_2 gradient have shown that the abundance of coral and canopy-forming macroalgae declines under high CO_2, and that low-profile and turf algae will become more dominant. Since large organisms such as coral and canopy-forming macroalgae provide habitat complexity for micro-benthos, and so species diversity under high CO_2 is lowered. Carbon sequestration has been anticipated to increase due to OA, because marine plants would be subjected to CO_2 limitation at present ocean conditions. However, surveys along the CO_2 gradient showed no significant increase in photosynthesis regardless of the change in CO_2 concentrations. The value of the high CO_2 area as fishing ground is low based on our questionnaire for fisherman, for which their responses highlighted that the abundance of fish seems to be low in the high CO_2 area. Recreational diving is one of the other important incomes for Shikine Island, and coral and tropical fish are important targets that tourists wish to see. The analysis of seascape component using photo taken by recreational diver showed that the number of photos of coral and fish declined in high CO_2 area. Our investigation regarding ecosystem services in Shikine Island showed that OA is likely to reduce ecosystem services within the coastal area.

Keywords: Ocean acidification, Shikine Island, Ecosystem services

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Encouraging Climate Change Adapatation and Mitigation Measures Platform from Indonesia

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Climate change is a global problem promoted by global warming. It leads to uncertain climatic conditions such as floods, droughts, landslides, high waves, and sea level rise are increasingly common with increasing intensity, resulting in casualties and economic and ecological losses. Adaptation and mitigation are two complementary strategies for responding to climate change. Adaptation is the process of adjusting to the actual and expected climate and its effects to reduce or avoid harm or exploit profitable opportunities. Mitigation is the process of reducing emissions or improving greenhouse gas sinks (GHGs), thereby limiting climate change in the future. Both adaptation and mitigation can reduce and manage the risk of climate change impacts. However, adaptation and mitigation can also create other risks, as well as their benefits. The strategic response to climate change involves consideration of climate-related risks along with additional risks and benefits of adaptation and mitigation measures.

The climate change problems should be addressed with local-based management. We provide a platform to discuss the strategies of local adaptation and mitigation actions, called as International Conference on Climate Change. It accommodates the new related inspiration about how to minimize the climate change on local-based approach. This conference provides access to valuable information. This is an excellent international forum for sharing knowledge and research results in theoretical and practical aspects of climate change mitigation and adaptation .

Keywords: climate change, adaptation measures, mitigation, discussion platform, global warming

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Impact of Sea Level Rise on Tourism Carrying Capacity in Thailand

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Sea level rise due to climate change affects beaches, which produce high recreational value in the economy. The tourism carrying capacity (TCC) assessment is one of the tools to determine the management capacity of a beach. Pattaya beach represents the character of a well-known beach in Thailand, while Chalatat beach represents the character of domestic tourism at beaches in Thailand. This study detected the shoreline position from Google Earth images with tidal correction to evaluate beach areas. The Bruun rule was used for shoreline projection. TCC was calculated by using the beach area, correction factors, and management capacity. The results find that the current effective carrying capacity is approximately 200,000 for Pattaya beach and 49,000 for Chalatat beach. Although the Chalatat beach areas are larger than Pattaya, the effective carrying capacity of Pattaya beach is more extensive than the effective carrying capacity of Chalatat beach for all situations because TCC is affected by beach areas, correction factors, and management capacity. Because the beach areas experience the effect of sea-level rise, protection against future beach loss should be considered for coastal management.

Keywords: climate change, sea level rise, tidal correction, Bruun rule, tourism carrying capacity

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-HW Hydrology & Water Environment

[A-HW37] Interdisciplinary approach to support climate change adaptation measures in regional scale

convener:TEBAKARI TAICHI(Toyama Prefectural University), Yadu Pokhrel(Michigan State University), Masashi Kiguchi(University of Tokyo), Sompratana Ritphring(Kasetsart University)

In Japan, the impact of climate change has already become apparent and may become even more serious in the future. For example, there are the following specific damages; crop damage such as mandarin orange edema and white immature grains of rice, health hazards such as the northward distribution of Aedes albopictus and heat stroke patients, meteorological disasters such as increased torrential rain and increased number of strong typhoons, and coral bleaching Ecosystem.
The climate change adaptation law, which was enacted in 2018, clarified the legal position of adaptation measures in Japan, and is a legal for the national, local governments, businesses and citizens to cooperate and cooperate to promote adaptation measures. Based on this law, the Climate Change Adaptation Information Platform (A-PLAT) was established to develop and provide tools to support information provision and adaptation actions, and to collect, organize and provide best practices. AP-PLAT and T -Overseas development such as -PLAT is also progressing. Overseas expansion such as AP-PLAT and T-PLAT are also progressing.
In each research field, it is necessary to promote effective adaptation measures based on reliable and detailed information, and measures based on scientific knowledge of future impacts and strengthening of adaptation in the region are urgently needed.
This proposed session would like to invite presentations on the latest achievements in interdisciplinary fields such as hydrology, agriculture, forestry, weather, and climate that support specific climate change adaptation measures, as well as on the development of new research.

[AHW37-06] The GEWEX Regional Hydroclimate Projects in High Mountainous Terrains: Barriers that Bridge

★Invited Papers

*Petrus J van Oevelen[1] (1.Universities Space Research Association Columbia)

[AHW37-07] Transportation in the UK’s Third Climate Change Risk Assessment

*David John Jaroszweski[1] (1.University of Birmingham)

[AHW37-08] Analysis for impacts of urban flood on traffic flow in Bangkok

*Shinichiro NAKAMURA[1], Napaporn Piamsa-nga[2], Sanit Wongsa[3], Varameth Vichiensan[2] (1.Nagoya University, 2.Kasetsart University, 3.King Mongkut's University of Technology Thonburi)

[AHW37-09] Validaion of land surface model considering groundwater level change

*Daiya Shiojiri[1], Kenji Tanaka[2], Shigenobu Tanaka[2] (1.Graduate School of Engineering, Kyoto Univ., 2.Disaster Prevention Research Institute, Kyoto Univ.)

[AHW37-10] Climate Change Impacts on Groundwater Recharge in the Yom and Nan River basins, Northern Thailand

*Chaiwat Ekkawatpanit[1], Chanchai Petpongpan[1], Duangrudee Kositgittiwong[1], Naota Hanasaki[2] (1.King Mongkut s University of Technology Thonburi, 2.National Institute for Environmental Studies, Tsukuba, Japan)

[AHW37-11] **Shallow Groundwater Plays as a Key of Water Supply Management for Crop Land during Severe Drought Crisis Situation in Thailand**

*Desell Suanburi[1], Koshi Yoshida[2], Weerakaset Suanpaga[1], Naruekamon Janjirawuttikul[3] (1.Kasetsart University, 2.Ibaraki University, 3.Land Development Department)

The GEWEX Regional Hydroclimate Projects in High Mountainous Terrains: Barriers that Bridge

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1. Universities Space Research Association Columbia

The Global Energy and Water EXchanges Project (GEWEX) of the World Climate Research Programme focuses on in particular process understanding of how water and energy manifest themselves in the earth system. To address the science at a more regional level the Regional Hydroclimate Projects (RHPs) provide a unique opportunity to bring better the scientific community and rally around those issues that are specific and relevant to the region. High mountainous regions of the world provide a unique challenge both in terms of observations as well as modeling. At the same time these regions are of crucial importance to our water resources and the live stream to the major part of the global population. Better understanding of the processes in these regions under climate and environmental change is of the essence to provide for sustainable solutions. These mountainous regions act not only as physical barriers but also link communities as they provide the (water) resources they depend upon. At the same time these regions are also more vulnerable rand strongly impacted by climate change. The GEWEX Regional Hydroclimate Projects in the various mountain regions of the world can help bridge the knowledge gap and expertise and as such translate global environmental change to local change and impacts.

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Transportation in the UK’s Third Climate Change Risk Assessment

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1. University of Birmingham

This paper presents the ongoing work of the United Kingdom’s Third Climate Change Risk Assessment (CCRA). Specifically, it focuses on the work on transportation within the Infrastructure Chapter. Under the 2008 Climate Change Act, the government is required to provide Parliament with a comprehensive assessment of the risks that climate change poses to the UK every 5 years. The 3rd risk assessment, CCRA3, is due to be laid before Parliament by January 2022.

Work on the CCRA3 began in late 2018, and is in the process of collating evidence from the scientific and stakeholder communities on changes in the magnitude of key risks within the areas of natural environment, infrastructure, people and the built environment, and business and industry. The infrastructure component of the most recent CCRA [1] identified several risks directly and indirectly related to transport (e.g. risks to transport, digital and energy infrastructure from extreme heat; risks of cascading failures from interdependent infrastructure networks). The urgency for adaptation work for these risks was assessed using a three step process [2] centred on the questions: 1) What is the current and future level of risk/ opportunity? 2) To what extent is the risk/ opportunity going to be managed, taking into account government commitments and autonomous adaptation? 3) Are there benefits to further action in the next five years, over and above what is already planned? The results of this process set were a key input into the second National Adaptation Programme [3], covering the period 2018-2023.

This paper seeks to present the current work being undertaken to update the urgency assessment for the risks directly and indirectly related to transportation, and will also outline a number of supporting research projects in the areas of interacting risks, flooding, socio-economic scenarios and behavioural change. Discussion will be made on the differences in approach between this programme and the impact and adaptation assessment programmes of other countries including the United States, the Netherlands and Japan.

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Analysis for impacts of urban flood on traffic flow in Bangkok

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Traffic is an important economic and social activities in urban area, and its congestion tends to be a bottleneck for their activities and economic developments, especially in developing countries. Heavy rainfall and urban flood are factors which generate or enhance the traffic congestions in urban area. Bangkok, our target city, has been under a rapid economic growth in last decades and the traffic congestion have been one of important and urgent social issue through the increasing population and economic activities. In addition, it’ s expected that climate change will increase heavy rainfall in Thailand and the insufficient drainage system may heighten the flood damages via traffic congestion. Under the circumstances, an evaluation for damages of heavy rainfall on the economic activities and for effectiveness of adaptation measures are urgently required.

This study aims to analyze the impacts of urban flood on the traffic flow in Bangkok with connecting an urban flood model (iRIC) and a traffic model (traffic assignment user's equilibrium model (TRANSCAD)) . In addition, we evaluated the effectiveness of adaptation measures to reduce the impacts of urban flood on traffic by applying the connected model to several adaptation scenarios. The results show that several main roads in Bangkok are under vulnerable situations for urban floods and installing additional pumping stations will dramatically reduce the traffic congestion in several main roads.

Keywords: Urban flood, Traffic, Bangkok

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Validaion of land surface model considering groundwater level change

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Kotsuki et al. (2012) developed a global water cycle model in-land to simulate the sustainability of water resources, but groundwater resources are not considered. This study aims to improve land surface model SiBUC, which is main component of the model developed by Kotsuki et al., to simulate groundwater level.

Soil layer consists of three parts (surface layer, root zone and recharge zone) in original model, and another groundwater layer is added at the bottom of soil layer in this study. Soil water content in all layers is simulated based on Richards' equation, and water exchange between the layers is calculated using Darcy's low. In the groundwater layer, saturated and unsaturated zone coexist and water exchange from third to fourth layer is calculated between the center of third layer and unsaturated zone in fourth layer. As for the relationship between soil physical properties, Clapp and Hornberger (1978) is used. Matric potential in unsaturated zone is assumed to change linearly (Takasao et al., 1997). By solving this assumption and Clapp and Hornberger’ s equation, groundwater level is determined depending on soil water content. Base flow is represented as gravitational drainage from fourth layer. Original SiBUC simulates water balance only in vertical direction, but this model can consider horizontal soil water movement using methods developed by Tanaka et al. (1997) and Takasao et al. (1997).

This model is validated using groundwater level data obtained at some observation wells. At a well near river, groundwater recharge from river water is considered by determining slope which is necessary to calculate base flow based on the difference between groundwater level and nearest river water level.

Keywords: land surface model, groundwater

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Climate Change Impacts on Groundwater Recharge in the Yom and Nan River basins, Northern Thailand

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Climate change is real and is now an international problem. It has a broad and spatially distributed impact on multiple sectors. The number of extreme weather events has surged and there have been many natural disasters because of the level of CO_2 concentration and uncertainty in weather circulation, influencing the change of the hydrologic cycle. It is generally known that surface water and groundwater affect an occurrence of several natural disasters directly such as floods and droughts. In the Yom and Nan River basins, flood and drought have occurred frequently because of the climate change impact and non-systematic management in the conjunctive use of both sources of water. Therefore, this study aims to assess the climate change impact on surface water and groundwater of the Yom and Nan River basins, located in the Northern Thailand. The surface water and groundwater regimes are generated by a fully coupled SWAT-MODFLOW model. Besides, Nash–Sutcliffe model Efficiency (NSE) and Root Mean Square Error (RMSE) are applied to investigate the efficiency of the model. For analyzing the future scenarios, the output of Global Climate Models (GCMs) from Coupled Model Intercomparison Project Phase 5 (CMIP5) is applied with consideration on the Representative Concentration Pathway (RCP) 2.6 and 8.5 to mainly focus on the difference between minimum and maximum of Green House Gas (GHG) emissions scenarios. The consequences of climate change impacts on hydro-meteorology are complicated. These impacts are uncertain and difficult to predict. Therefore, understanding how potential climate change effects alter the distribution and availability of hydro-meteorological variables at a regional or basin scale is crucial and necessary to frame resilient measures to provide and formulate better water resource management adaptations. The amount of surface water and groundwater during the reference (1981–2005) and near future (2021–2045) periods are compared to investigate their change influenced by climate change. The results show that the air temperature and rainfall in the near future are not different from the present period under scenario RCP 2.6. The annual water yield and percolation during 1981–2005 (reference period) and 2021–2045 (near future period) was compared with amount of water demand, reported by the Department of Water Resources. The water demand of the Yom and Nan river basins, amounting to 3575 and 4638 MCM per year, it can be considered that there are 11 water shortage years and two years that needed percolated water for the water supply in the Yom river basin. In the Nan river basin, there is neither a water shortage year nor a year which needed percolated water. This might be an influence of water management operated by the Sirikit dam. This produces an amount of surface water and groundwater between both periods that is much similar. However, the air temperature and rainfall tend to show a rising trend under scenario RCP 8.5, affecting the amount of runoff and groundwater significantly. Furthermore, the change of the amount of water from both sources directly impacts water availability, when evaluating the water demand for consumption, industry, and agriculture. These results are very useful and can be applied as primary information for sustainable water management in the near future.

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Shallow Groundwater Plays as a Key of Water Supply Management for Crop Land during Severe Drought Crisis Situation in Thailand

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1. Kasetsart University, 2. Ibaraki University, 3. Land Development Department

Drought phenomenon is found in many regions of Thailand affected since over 30’ s decade and become worse in 2020 due to the effect of climate change in 2019 lessening rainfall. Groundwater should be most beneficial of water supply for agriculture utility. Shallow groundwater (SGW) found as a significant role of water resources for appropriated agriculture crop during dry season and useful for farmer to manual drilling and manage effectively by themselves to support planting process with low cost investment. SGW can be constrained by EM and resistivity measurement at the high terrace zone (or margin) of Chao Phraya basin or sedimentation zone such as Dan Chang - Nong Ya Sai region of Suphanburi province, (SGW found as old channel sand deposit zone of large alluvial fan deposit area) mainly indicate as mono crop i.e. sugar cane and Southern part of Chainat province (SGW obtained from weathered rock sediment) found as integrate agriculture crop i.e. sugar cane, paddy field and cassava including Bo Phloi district of Kanchanaburi province (SGW is found in erosion channel within thick sediment deposit basin) Combination of various crops may to select appropriate crop. 2D resistivity technique was successfully located SGW in many different geohydrology area such as Manorom district, Northern part of Chainat province (SGW obtained deep sand deposit layer > 14 m deep) for second rice crop, Sai Ngam district, Kamphaeng Phet Province (SGW found in sand deposit zone) may helpful for second rice crop. SGW are also found in Northestern area (need to separate from salinity water) where found as combination crop including vegetable. High potential of SGW was found in deep sediments at the Eastern region where present as fruit orchard plating. SGW can be treated as sustainable use with artificial infiltration (known as groundwater bank) technique which storage surface water into subsurface sand/gravel layer during raining season then higher potential of shallow groundwater may support as sufficient agriculture planting

Keywords: Shallow groundwater, Agriculture Land, Drought crisis

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CC Cryospheric Sciences & Cold District Environment

[A-CC38] Ice cores and paleoenvironmental modeling

convener:Ayako Abe-Ouchi(Atmosphere and Ocean Research Institute, The University of Tokyo), Ryu Uemura(Nagoya University), Kenji Kawamura(National Institute of Polar Research, Research Organization of Information and Systems), Nozomu Takeuchi(Chiba University)

Analyses of ice cores from polar and mountain regions have contributed to the reconstruction and understanding of the past environmental changes on timescales from years to several hundred thousand years. In this session, we welcome paleoenvironmental studies using ice cores and paleoclimatic modeling. Studies on reconstruction methods, recording processes and new paleoenvironmental proxies, technical aspects of paleo-modeling are also welcomed. Studies with marine sediment cores, terrestrial sediment cores and tree-rings on similar timescales are also important and welcomed, in order to discuss past environmental changes from multidisciplinary viewpoints.

[ACC38-01] Variations in nitrate stable isotopes in ice cores from two glaciers in central Asia

*Nozomu Takeuchi[1], Nobuhito Ohte[2], Koji Fujita[3] (1.Chiba University, 2.Kyoto University, 3.Nagoya University)

[ACC38-02] **Reconstructions of past microbial flora from ice core samples on Gregoriev Glacier, Kyrgyz Tienshan**

*Segawa Takahiro[1], Ryo Matsuzaki[2], Ayumi Akiyoshi[3], Takahiro Yonezawa[4], Hiroshi Mori[5], Nozomu Takeuchi[6] (1.University of Yamanashi, 2.National Institute for Environmental Studies, 3.National Institute of Polar Research, 4.Tokyo University of Agriculture, 5.National Institute of Genetics, 6.Chiba University)

[ACC38-03] Collaborative studies for locating the oldest ice near Dome Fuji, Antarctica

*Kenji Kawamura[1,2,3], Ayako Abe-Ouchi[4,1], Shuji Fujita[1,2], Prasad Gogineni[5], David Braaten[6], Jean-Charle Gallet[7], Kumiko Goto-Azuma[1,2], Ralf Greve[8], Elisabeth Isaksson[7], Brice van Liefferinge[7], Kenichi Matsuoka[7], Hideaki Motoyama[1,2], Fumio Nakazawa[1,2], Takashi Obase[4], Hiroshi Ohno[9], Ikumi Oyabu[1], John Paden[6], Fernando Rodriguez-Morales[6], Fuyuki SAITO[3], Ryan A. Taylor[5], Shun Tsutaki[1], Members of Third Dome Fuji Project Promotion Committee (1.National Institute of Polar Research, Research Organization of Information and Systems, 2.Graduate University for Advanced Studies, SOKENDAI, 3.Japan Agency for Marine-Earth Science and Technology (JAMSTEC), 4.University of Tokyo, 5.University of Alabama, 6.University of Kansas, 7.Norwegian Polar Institute, 8.Hokkaido University, 9.Kitami Insittute of Technology)

[ACC38-04] Mapping near-surface layers with UWB microwave radar and optimized processing of sounder data to enhance deep layers

★Invited Papers

Sivaprasad Gogineni[1], *Ryan Andrew Taylor[1], Shriniwas Kolpuke[1], Jordan Larson[1], Linfeng Li[1], Charles O'Neill[1], Ryan Thomas[1], Shashank Wattal[1], Jie-Bang Yan[1], David Braaten[2], Ayako Abe-Ouchi[3], Shuji Fujita[4], Kenji Kawamura[4], Shun Tsutaki[4], Brice van Liefferinge[5], Kenichi Matsuoka[5] (1.University of Alabama, 2.University of Kansas, 3.University of Tokyo, 4.National Institute of Polar Research, 5.Norwegian Polar Institute)

[ACC38-05] Features of the ice sheet radio-echoes from deep internal layers and ice/bed boundaries observed with radars of the Japanese Antarctic Research Expedition: a summary

★Invited Papers

*Shuji Fujita[1,2], Kenji Kawamura[1,2,3], Ayako Abe-Ouchi[1,4], Kotaro FUKUI[5], Kenichi Matsuoka[6] (1.National Institute of Polar Research, Research Organization of Information and Systems(ROIS), 2.The Graduate University for Advanced Studies (SOKENDAI), 3.Japan Agency for Marine-Earth Science and Technology (JAMSTEC), 4.Atmosphere and Ocean Research Institute, The University of Tokyo, 5.Tateyama Caldera Sabo Museum, Japan, 6.Norwegian Polar Institute)

Variations in nitrate stable isotopes in ice cores from two glaciers in central Asia

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1. Chiba University, 2. Kyoto University, 3. Nagoya University

Nitrogen and oxygen stable isotopes of nitrate in ice cores from two alpine glaciers of different geographical locations in central Asia were analyzed. One ice core was drilled in 2002 on Dunde Ice Cap located in Qilian Mountains in China (DUC), another was drilled in 2007 on Grigoriev Ice Cap located in Tienshan Mountains in Kyrgyz Republic (GGC). Variations in the stable isotopes for approximately 150 years from the mid-19th Century to the present were compared between the two cores. The concentrations of nitrate in the two ice cores showed no remarkable trend in the last 150 years and no significant difference between the two ice cores. However, the nitrogen stable isotopes of nitrate showed the distinctive variations between the two ice cores. The isotope of both cores generally decreased in the last 150 years, the values of nitrogen isotope differed particularly in 19C and mid 20C, and the timing of decrease was earlier in GGC than in DUC. These different features suggest that nitrate was supplied on the glaciers from each local source. The oxygen stable isotopes of nitrate were similar values and almost constant in both cores, but they showed declines in 1940s to 60s in GGC and 1980s in DUC. The declines of the oxygen isotopes is likely to show microbial growth on the glacier surface during the periods.

Keywords: ice core, nitrate stable isotope, central asia

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Reconstructions of past microbial flora from ice core samples on Gregoriev Glacier, Kyrgyz Tienshan

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Ancient DNA has been obtained from many kinds of substrates. Ice cores, permafrost, as well as subfossil and recent skeletal remains stored in museums are potentially accessible for DNA analysis. Ancient DNA analyses are helpful in clarifying the phylogenetic relationships among organisms with branching dates (time-tree). Analyses of extinct ice cores have often been used in reconstructing past environments. However, the DNA in these samples is often highly degraded and fragmented, and therefore in order to analyze the small amount of DNA preserved in these samples, an effective technique to extract total DNA, shotgun sequencing from ancient DNA extracts, and bioinformatics and molecular evolution analysis from large-scale sequence data set are required. Ice cores drilled from glaciers can provide a means of direct analysis of microbes in the past. The species composition of microorganisms in the ice core could reflect the environmental condition at that time.

Several recent studies have focused on the effect of glacier microorganisms such as snow algae and bacteria on the melting of glacial ice. Despite the ecological importance in glacial environments, little is known about microbial evolutionary dynamics, because of the lack of knowledge regarding past microbial information. We report the results of microbial community structure and their evolution by molecular DNA analysis collected from the ice core samples collected on Gregoriev Glacier, Kyrgyz Tienshan. We successfully reconstruct the microbial community in the ice core samples. We also present detailed pictures of snow algal distribution patterns on glaciers over the Arctic, Antarctic, and Asian high mountains, using the sequences of the nuclear rDNA internal transcribed spacer 2 (ITS2) region. Our results enhance understanding of the enigmatic time scale of snow algal microevolution, which has the potential to elucidate environmental responses of them to the drastic climatic change events of the Quaternary.

Keywords: ice core, microorganism, ancient DNA

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Collaborative studies for locating the oldest ice near Dome Fuji, Antarctica

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1. National Institute of Polar Research, Research Organization of Information and Systems, 2. Graduate University for Advanced Studies, SOKENDAI, 3. Japan Agency for Marine-Earth Science and Technology (JAMSTEC), 4. University of Tokyo, 5. University of Alabama, 6. University of Kansas, 7. Norwegian Polar Institute, 8. Hokkaido University, 9. Kitami Insittute of Technology

International Partnerships in Ice Core Sciences (IPICS) sets a priority project "Oldest Ice Core," which states the importance of drilling multiple ice cores in Antarctica to cover more than one million years. Previous studies have indicated that such old ice may exist in the Antarctic interior.

This presentation introduces ongoing, international collaborative studies for locating the oldest ice near Dome Fuji. In 2016, an international workshop was held to plan collaboration between Japan, U.S. and Norway for a ground-based site survey in the Dome Fuji area, as well as its collaboration with German airborne survey (as a Beyond EPICA activity). In 2016/17 austral summer, the airborne radar survey was conducted by Alfred Wegener Institute, and the data was kindly shared with the Japan-US-Norway for selecting areas for the ground-based survey. In the 2017/18 summer, 59th Japanese Antarctic Research Expedition (JARE) conducted a suite of glaciological studies, including a ground-based radar survey in three areas around Dome Fuji with 5-km line spacing, and three shallow ice corings (40 to 152 m depth). The survey areas were determined based on discussion among international colleagues.

Based on the radar data of AWI and JARE 59, one-dimensional ice-sheet modelings started independently in Japan and Norway to interpret the respective radar data and to estimate the age of ice near the bed. The outcomes of the radar data and modeling results were used to narrow down the target areas for the Japan-US-Norway international survey using higher-performance U.S. ice radars together with the JARE radars with improved antennas. The international survey was in the 2018/19 summer, including the ground-based radar survey in the south of Dome Fuji, one shallow coring, firn air sampling, and surface mass balance and flow observations.

From the series of data and models, the following outcomes and investigations will at least be necessary to locate the oldest ice around Dome Fuji.

-- creating most detailed bedrock map (from radar data)
-- full processing of radar data to resolve internal layers within ice near the bedrock
-- layer tracking and their age estimation (combining deep radar data, Dome Fuji ice core and 1-D model)
-- spatial distribution of surface mass balance (from shallow-depth radar data)
-- 1-D ice flow modeling (both forward and inversion)
-- 3-D ice flow modeling (for the possibility of dome migration and effect of horizontal flow to deepest layers)

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The discussion of the oldest ice will place particular importance on the full examinations of deepest layers in the U.S. radar data after advanced processing, with the aid of ice-sheet modeling and the past Dome Fuji ice cores to inform us on the age and flow in the studied area.

Essential criteria for including a location in further consideration as the oldest ice site may be the following (note this list itself is the subject of discussion).

-- lack of obvious or suspected basal melting
-- no indication of flow disturbance (folding) or refrozen ice
-- smooth visible layers near the bed (within a hundred meters or so)
-- relatively old age near bedrock (from layer tracking)
-- old age from 1-D modeling
-- small effect of horizontal flow (in case of dome migration) from 3-D model
-- relatively low accumulation rate

For reference, after locating the oldest ice site hopefully by late 2020, the next steps will be to transport materials and fuel, establish the drilling station, and to prepare for the deep drilling by the end of 2021/22 summer season. The actual deep drilling near Dome Fuji is proposed by the Third Dome Fuji Project Promotion Committee and JARE to start in the 2022/23 austral summer and continue for a few years to reach the bedrock.

Keywords: Oldest Ice Core, Dome Fuji, Ice radar, IPICS, Shallow core, Surface mass balance

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Mapping near-surface layers with UWB microwave radar and optimized processing of sounder data to enhance deep layers

Sivaprasad Gogineni[1], *Ryan Andrew Taylor[1], Shriniwas Kolpuke[1], Jordan Larson[1], Linfeng Li[1], Charles O'Neill[1], Ryan Thomas[1], Shashank Wattal[1], Jie-Bang Yan[1], David Braaten[2], Ayako Abe-Ouchi[3], Shuji Fujita[4], Kenji Kawamura[4], Shun Tsutaki[4], Brice van Liefferinge[5], Kenichi Matsuoka[5]

1. University of Alabama, 2. University of Kansas, 3. University of Tokyo, 4. National Institute of Polar Research, 5. Norwegian Polar Institute

The University of Alabama Remote Sensing Center developed an ultra-wideband radar operating over the frequency range of 2-8 GHz. We designed the radar for surface-based operation and mapping of near-surface internal layers. The radar was operated as a part of the Japan-Norway expedition to Antarctica during the 2018 field season. The radar was mounted on the side of a tracked vehicle and data were collected over a large area near Dome Fuji as part of the experiment. We processed data collected to generate radar echograms and results show layers to a depth of over 15 m.

We have also been involved in the design and development of high-sensitivity radars to map internal layers in the bottom ten percent of the ice. This involved the design and simulation of the radar and antenna array with sufficient gain to map layers close to the bed. We also developed a quick-look and a real-time processor optimized to bring out layers near the bed.

In this paper, we will discuss the design considerations for the UWB microwave radar to map near-surface internal layers and show sample results from the 2018 field campaign. We will present the design and simulation of UWB radar sounders for mapping layers near the bed. We will also discuss the design considerations for a radar signal processor to bring out layers near the bed and show sample results obtained with our processor from data collected as a part of the Japan-Norway expedition.

Keywords: RF & Microwave, FM-CW radar, Radar signal processing

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Features of the ice sheet radio-echoes from deep internal layers and ice/bed boundaries observed with radars of the Japanese Antarctic Research Expedition: a summary

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For deep ice coring projects in polar ice sheets, it is essential to collect glaciological information from within the ice sheet, before locating exact drilling site. Integrity of the climate signals with well-layered condition of the ice sheet is a prerequisite. In addition, we should know various physical conditions such as temperature, presence/absence of basal melting. Since 1980’s, the 2nd highest dome in Antarctica, namely, Dome Fuji is one of areas where the Japanese Antarctic Research Expedition (JARE) had its focus on the glaciological investigations. So far, JARE have collected several shallow (100~200-m-long) ice cores as well as two very deep cores known as 2503-m-long DF1 ice core and 3035-m-long DF2 ice core. The latter core covers back in time ~720 k-years. Scientists in the Dome Fuji Ice Coring project have their next scope to drill the 3rd very deep ice core covering age more that 1 million years, to better understand climate systems and climatic history.

Ground-based radar sounding has been a powerful method to collect information from deep within the ice sheet. The Dome Fuji Ice Coring project started ground-based radar sounding near Dome Fuji already in 1980’s using a VHF pulse-modulated radar operating with a frequency of 179 MHz. Since then, ground-based radar surveys were repeated in 8 austral summer and/or winter seasons, in 1993/1994, 1997/1998, 2000/2001, 2006/2007, 2007/2008, 2012/2013, 2017/2018 and 2018/2019. A brief history is as follows. Mountainous topography beneath the ice sheet was already found at ~40 km south of Dome Fuji in the survey of 1993/1994. In the 1997/1998 season, the survey team made a 150-km-long trip to the south and they discovered that significant layered scattering of the electromagnetic waves within the deepest few hundred meters above the subglacial mountains at approximately 45-65 km south from the Dome Fuji. They identified that the subglacial mountain area could be a candidate location for future deep ice coring. In the 2012/2013 season, further survey was done at a location centering a site which we called as New Dome Fuji (77.801 ºS in latitude, 39.040 ºE in longitude, 3761 m in elevation and 2157 m in ice thickness). In the 2017/2018 season, the team made a radar survey with high gain antennas along about 2,990 km, with major spacing of the lines 5 km, covering total area of 20,000 km^2. In the 2018/2019 season, the team investigated along 2,700 km in an area of about 1,000 km^2. The latest spacing between survey lines varied between 0.5 km and 0.25 km. In this 2018/2019 season, we also made a collaborative international survey with University of Alabama, University of Kansas and Norwegian Polar Institute (See, for example, presentation by Tsutaki and others in this session). Overall, efforts over more than 30 years made the NDF area with very high-density coverage of the radar measurements.

In this talk, we will first talk about historical aspects, how the observations have proceeded with what kinds of radars. And then, we will explain how we have extracted ice thickness and features of internal layers, from the data of the Japanese pulse-modulated radars. Finally, we will discuss how we will cooperate with (i) the team-efforts with the state-of-the-art radars developed by University of Alabama and University of Kansas, and (ii) team-efforts of the ice sheet modelling.

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Keywords: Antarctica, ice core, Dome Fuji, bed topography, radar

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CC Cryospheric Sciences & Cold District Environment

[A-CC38] Ice cores and paleoenvironmental modeling

convener:Ayako Abe-Ouchi(Atmosphere and Ocean Research Institute, The University of Tokyo), Ryu Uemura(Nagoya University), Kenji Kawamura(National Institute of Polar Research, Research Organization of Information and Systems), Nozomu Takeuchi(Chiba University)

Analyses of ice cores from polar and mountain regions have contributed to the reconstruction and understanding of the past environmental changes on timescales from years to several hundred thousand years. In this session, we welcome paleoenvironmental studies using ice cores and paleoclimatic modeling. Studies on reconstruction methods, recording processes and new paleoenvironmental proxies, technical aspects of paleo-modeling are also welcomed. Studies with marine sediment cores, terrestrial sediment cores and tree-rings on similar timescales are also important and welcomed, in order to discuss past environmental changes from multidisciplinary viewpoints.

[ACC38-06] Fine-Resolution Radar Measurements for Ice-Core Drilling Site identification Near Dome-Fuji

★Invited Papers

*Fernando Rodriguez Morales[1,2], David Braaten[1,2], John Paden[1,2], Prasad Gogineni, Ryan Taylor, Ayako Abe-Ouchi, Shuji Fujita, Kenji Kawamura, Shun Tsutaki, Brice Van Liefferinge, Kenichi Matsuoka (1.University of Kansas, 2.Center for Remote Sensing of Ice Sheets)

[ACC38-07] A basal topographic map in the Dome Fuji area, East Antarctica, constructed from a ground-based radar survey

★Invited Papers

*Shun Tsutaki[1], Shuji Fujita[1,2], Kenji Kawamura[1,2,3], Prasad Gogineni[4], Ayako Abe-Ouchi[5,1], David Braaten[6], Jean-Charles Gallet[7], Elisabeth Isaksson[7], Brice van Liefferinge[7], Kenichi Matsuoka[7], Charles O'Neil[4], John Paden[6], Fernando Rodriguez-Morales[6], Ryan Taylor[4], Jie-Bang Yan[4], Kumiko Goto-Azuma[1,2], Ralf Greve[8], Stephen Hudson[7], Jack Kohler[7], Shriniwas Kolpuke[4], Linfeng Li[4], Geir Moholdt[7], Hideaki Motoyama[1,2], Takashi Obase[5], Fuyuki SAITO[3], Kotaro FUKUI[9] (1.National Institute of Polar Research, 2.The Graduate University for Advanced Studies, 3.Japan Agency for Marine-Earth Science and Technology, 4.The University of Alabama, 5.The University of Tokyo, 6.The University of Kansas, 7.Norwegian Polar Institute, 8.Hokkaido University, 9.Tateyama Caldera Sabo Museum)

[ACC38-08] Searching potential sites of million year-old ice by modelling ice sheet age near New Dome Fuji region

*Ayako Abe-Ouchi[1], Takashi Obase[1], Kenji Kawamura[2], Shuji Fujita[2], Fuyuki SAITO[3], Shun Tsutaki[2], Prasad Gogineni[4], David Braaten[5], Fernando Rodriguez-Morales[5], John Paden[5], Kenichi Matsuoka[6], Hideaki Motoyama[2], Ralf Greve[7], Brice van Liefferinge[6], Ryan Taylor[4] (1.Atmosphere and Ocean Research Institute, The University of Tokyo, 2.NIPR, 3.JAMSTEC, 4.The University of Alabama, 5.University of Kansas, 6.Norwegian Polar Institute, 7.Institute of Low Temperature Science, Hokkaido University)

[ACC38-09] Antarctic warmth in the last interglacial driven by Northern insolation and deglaciation

*Takashi Obase[1], Ayako Abe-Ouchi[1,2], Fuyuki SAITO[3] (1.Atmosphere and Ocean Research Institute, the University of Tokyo, 2.National Institute of Polar Research, 3.Japan Agency for Marine-Earth Science and Technology)

Fine-Resolution Radar Measurements for Ice-Core Drilling Site identification Near Dome-Fuji

*Fernando Rodriguez Morales[1,2], David Braaten[1,2], John Paden[1,2], Prasad Gogineni, Ryan Taylor, Ayako Abe-Ouchi, Shuji Fujita, Kenji Kawamura, Shun Tsutaki, Brice Van Liefferinge, Kenichi Matsuoka

1. University of Kansas, 2. Center for Remote Sensing of Ice Sheets

As a part of a multi-national collaboration between the USA, Japan and Norway, we developed a mobile, high-performance radar system for fine-resolution measurements of ice thickness and imaging of the englacial and basal structure of the East Antarctic Ice sheet. We operated the radar near Dome Fuji during the 2018/2019 Austral Summer campaign. We performed surface-based measurements over 2,000 line-km to aid with the identification of potential drill sites for the recovery of ice samples more than 1 to 1.5 million years (1 Ma to 1.5 Ma) old in this area. In this contribution, we will present an overview of the radar system and field operations; and show the most recent radar images obtained after synthetic aperture radar (SAR) processing, precision geo-location, and systematic corrections applied to the radar data.

Keywords: Oldest Ice , Radio Echo Sounding

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A basal topographic map in the Dome Fuji area, East Antarctica, constructed from a ground-based radar survey

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1. National Institute of Polar Research, 2. The Graduate University for Advanced Studies, 3. Japan Agency for Marine-Earth Science and Technology, 4. The University of Alabama, 5. The University of Tokyo, 6. The University of Kansas, 7. Norwegian Polar Institute, 8. Hokkaido University, 9. Tateyama Caldera Sabo Museum

Knowledge gained from ice core studies is crucial to understand the past and present climate and to predict the impacts of future climate changes. The International Partnership for Ice Core Sciences (IPICS) identified that drilling deep ice cores extending back in time to 1.5 million years (Ma) is crucial to better understand the change of the periodicity of the glacial cycles from 40 thousand years (ka) to the current 100 ka during the mid-Pleistocene transition (0.9–1.2 Ma). However, continuous ice core records extending beyond 1 Ma have not been retrieved from the Antarctic ice sheet. The Dome Fuji area in East Antarctica is one of the candidate areas where we may be able to find very old ice near the bottom of the ice sheet. The Japanese Antarctic Research Expedition (JARE) has conducted deep ice corings at Dome Fuji twice in the past decades. They recovered ice cores covering ages up to about 720 ka BP. Sufficient knowledge of the basal topography is crucial to find suitable candidates based on numerical ice sheet experiments. The JARE have accumulated radar sounding data in this area since 1984 (JARE 26). In order to reveal the more detailed basal topography to find candidate site of very old ice in the Dome Fuji area, a ground-based radar survey was conducted over an area of 20,000 km^2 with a line spacing of 5 km during JARE 59 (2017–2018 Antarctic summer). Based on results of these surveys, we conducted a more detailed radar survey at Dome Fuji in the 2018–2019 season as a collaboration between The University of Alabama, The University of Kansas, National Institute of Polar Research under Research Organization of Information and Systems (Japan), Norwegian Polar Institute and The University of Tokyo. we used two different radar systems for the data collection. A wideband VHF radar ice sounder developed by CReSIS, University of Kansas, and a conventional pulse-modulated VHF radar with high gain antennas from JARE. An ultrawideband microwave radar developed by the University of Alabama was used to survey shallow part of internal layers to investigate surface mass balance in the area. We investigated a distance of 2,700 km in an area of about 1,000 km^2. The final spacing between the survey lines varied between 0.5 km and 0.25 km. We analyze the JARE and CReSIS radar data to construct an improved map of the basal topography in the Dome Fuji area to foster the identification of a suitable drilling site in the region.

Keywords: Antarctica, Bed topography, ice sheet

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Searching potential sites of million year-old ice by modelling ice sheet age near New Dome Fuji region

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1. Atmosphere and Ocean Research Institute, The University of Tokyo, 2. NIPR, 3. JAMSTEC, 4. The University of Alabama, 5. University of Kansas, 6. Norwegian Polar Institute, 7. Institute of Low Temperature Science, Hokkaido University

Finding a good site of drilling a new Antarctic ice core to cover more than one million years is crucial for our understanding of the climate system in our international community (IPICS). Previous ice flow modeling studies indicate that such old ice may exist in inland areas of the Antarctic continent, where horizontal ice flow is slow, the ice is thick, accumulation rate is low, basal temperature is well below the pressure melting point (Pattyn 2010; Fischer et al. 2013). Japanese drilling near Dome Fuji did not reach one million years because of the basal melt at the bottom of 3000m thick ice sheet. In the previous Dome Fuji drilling, modelling effort for interpreting high resolution radar measurement was missing. Here we combine the analysis of field data taken mainly by 59th and 60th Japanese Antarctic Research Expedition (JARE 59 and 60, 2017-2019) and ice flow modelling as the essential parts of the site selection activities. We estimate the temperature and age of ice, and age resolution of the ice near the bed at a dome of the ice sheet under various conditions. In the one-dimensional ice flow-thermodynamic model used in the study, the vertical velocity of the ice is parameterized with empirical functions and the coefficients were tuned to simulate and reproduce the Dome Fuji profile for both temperature and age. We show the influence of parameters (ice thickness, accumulation rate, geothermal heat flux, profile of vertical velocity of the ice) on the age of ice especially in the lowest few hundred meters. The one-dimensional model is applied along the transects of JARE 59, 60 surveys with both Japanese and American CReSIS ground radar system, using the estimated bed topography, ice thickness and simplified pattern of surface mass balance and geothermal heat flux. The calculated distribution of the age of ice are compared with internal layers of the ice (isochrone) derived from ground radar surveys for some typical cases in the region. We will focus especially on the comparison between model and CReSIS radar measurement and discuss the possibility of existence of old ice.

Keywords: Ice core , ice sheet modelling, paleo climate

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Antarctic warmth in the last interglacial driven by Northern insolation and deglaciation

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The global mean sea level in the last interglacial (LIG, about 130,000 to 115,000 years before present) was very likely higher than the present level, driven mainly by mass loss of the West Antarctic Ice Sheet (WAIS). Some studies have shown that this mass loss may have been caused by the warmer temperature over the Southern Ocean in the LIG compared with the present interglacial, suggested based on Antarctic ice cores and marine sediments. However, the ultimate cause of this warming, which is indispensable to understand future mass loss of the Antarctic ice sheet, has not been explained nor modelled. Here, based on transient simulations of the last deglaciation using a fully coupled ocean–atmosphere model, we show that faster (by a factor of 1.5) melting of the Northern Hemisphere ice sheets and the associated meltwater during the middle stage of the deglaciation could have produced the reconstructed Antarctic warmth. This study suggests that slightly smaller orbital eccentricity in our current interglacial than in the LIG has prevented the Antarctic ice sheet from passing the tipping point of large mass loss at present.

Keywords: deglaciation, ice sheet

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-GE Geological & Soil Environment

[A-GE40] Subsurface Mass Transport and Environmental Assessment

convener:Hirotaka Saito(Department of Ecoregion Science, Tokyo University of Agriculture and Technology), Shoichiro Hamamoto(Department of Biological and Environmental Engineering, The University of Tokyo), Yuki Kojima(Department of Civil Engineering, Gifu University), Yasushi Mori(Graduate School of Environmental and Life Science, Okayama University)

This session covers the topics on fluid flow and mass transport in geological media. Subjects related to laboratory testing, subsurface characterization, theoretical analysis and numerical modeling will be discussed. Presentations on geo-pollution, remediation, geological disposal of hazardous wastes, mass transport in vadose zone, and environmental assessment are especially encouraged.

[AGE40-01] Impacts of Si on Se(IV) immobilization on ferrihydrite: An *in-situ* ATR-IR spectroscopic investigation

*Paul Clarence Magdael Francisco[1], Yukio Tachi[1] (1.Japan Atomic Energy Agency)

[AGE40-02] Reaction and alteration of mudstone with cement pore fluids

*Keith Bateman[1], Yuki Amano[1], Yukio Tachi[1] (1.Japan Atomic Energy Agency)

[AGE40-03] Measurement and analysis of real-world pore micromodel for multiphase flow displacement

*Chun-Wei Peng[1] (1.Taiwan National Chiao Tung University)

[AGE40-04] Assessment of Soil Quality as Affected by Topography and Farming Practices in the Rice Terraces in Ifugao, the Philippines

★Invited Papers

*Tomoyo Kurozumi[1], Yasushi Mori[1], Hiroaki Somura[1], Milagros Ong How[2], Pearl Basilio Sanchez[3] (1.Graduate School of Environmental and Life Science, Okayama University,, 2.Universal Harvester Incorporated, 3.University of the Philippines Los Banos)

[AGE40-05] Effect of surface and weather conditions on subsurface water flow and heat transport

*Shintaro Kubota[1], Mito Nishioka[1], Yuki Kojima[2], Megumi Yamashita[1], Hirotaka Saito[1] (1.Graduate School of Agriculture, Tokyo University of Agriculture and Technology, 2.Department of Civil Engineering, Gifu University)

[AGE40-06] Effect of soil type on estimating infiltration front depth using time-lapse array antenna GPR data: A numerical study

*Koki Oikawa[1], Seiichiro Kuroda[2], Hirotaka Saito[1] (1.Tokyo University of Agriculture and Technology, 2.NARO Institute for Rural Engineering)

Impacts of Si on Se(IV) immobilization on ferrihydrite: An *in-situ* ATR-IR spectroscopic investigation

*Paul Clarence Magdael Francisco[1], Yukio Tachi[1]

1. Japan Atomic Energy Agency

The long-lived radionuclide Se-79 is one of the key radionuclides of interest in radioactive waste disposal. Its release from radioactive waste repositories and into groundwater presents serious environmental concerns due to its chemical and radiologic toxicity. Under partly oxidizing conditions typical of shallow repositories, Se exists in the form of highly mobile Se(IV); its migration may be potentially mitigated via interaction with iron minerals [1] present in the components of the repository such as steel overpack, clay buffer, host rock and the overlying soils. At the same time, Si derived from clay alteration and the host rock may potentially compete with Se(IV) for sorption sites on iron mineral surfaces. It is, however, unclear whether Si modifies Se(IV) sorption mechanisms, inhibits Se(IV) sorption or promotes Se(IV) desorption. Understanding the mechanisms underlying competitive processes have implications in modeling the behavior of Se(IV) in actual disposal repositories. Thus, this work aims to clarify the impacts of Si on the mechanisms, degree and stability of Se(IV) sorption on iron oxides.

This work focuses on ferrihydrite, a poorly crystalline ferric hydroxide that is common oxidation product of Fe(II) and is a ubiquitous component of rocks and soils. In order to obtain direct information on sorption mechanisms at the solid-fluid interface, sorption was monitored in a flow-through setup using *in situ* attenuated total reflectance infrared (ATR-IR) spectroscopy. A ferrihydrite film was deposited on a diamond ATR element and Si and Se(IV) solutions at pH 7 to 11 were flowed on the surface. The absorbance of the Se—O and Si—O stretching bands, which provide information on sorbate geometry, was then monitored over time. Generally, Se(IV) sorption was more pronounced at pH 7 and 9 than at pH 11, with the IR spectra exhibiting prominent bands consistent with a bidentate sorption mechanism. In experiments wherein Si was initially adsorbed on ferrihydrite, the absorbance of the Se—O stretching bands increases at a slower rate and attains a lower value than in the absence of Si. This observations suggest that Si inhibits the sorption of Se(IV) on ferrihydrite, likely by blocking sorption sites. In experiments wherein Se(IV) was pre-adsorbed prior to the introduction of Si, the Se—O stretching bands exhibited a decrease in absorbance, indicating desorption. This suggests that Si displaces Se(IV) on sorption sites. Finally, competitive sorption experiments wherein Si and Se(IV) were introduced at the same time were conducted. The results show that while both Si and Se(IV) are adsorbed, Se(IV) sorption proceeded at slower rates than Si, indicating that Si has a greater affinity for surface sites on ferrihydrite than Se(IV).

To summarize, the results show that Si strongly influences the interaction of Se(IV) with ferrihydrite. Given that Si is preferentially adsorbed on ferrihydrite, it inhibits Se(IV) sorption and promotes its remobilization. In the context of the radioactive waste disposal, a key implication of these findings is that in Si-rich environments such as in repositories backfilled with clay, the mobility of Se(IV) is likely to be enhanced. This behavior must be taken into account in safety assessments of radioactive disposal repositories. The approach and results reported in this study also provide a basis to investigate the competition between other species relevant to radioactive waste disposal.

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[1] Francisco et al. (2018) *Environ. Sci. Technol.* 52, 4817 –4826.

Keywords: Ferrihydrite, Selenite [Se(IV)], Silica, Competitive sorption, ATR-Infrared Spectroscopy

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Reaction and alteration of mudstone with cement pore fluids

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1. Japan Atomic Energy Agency

The construction of a repository for geological disposal of nuclear waste will include the use of cement-based materials. Following closure, groundwater will saturate the repository and the use of cement will result in the development of a highly alkaline porewater, pH >12.5 in the case of Ordinary Portland cement (OPC). The alkaline fluid will migrate and react with the host rock, affecting the long-term performance of the repository altering the physical and chemical properties, including radionuclide behaviour. Understanding these changes forms the basis for modelling the long-term evolution of the repository. This study focused on the alteration due to OPC-type leachates on mudstone, a potential candidate host rock in Japan. It was anticipated that firstly, clay minerals would react with the high pH fluids and that silicate minerals would provide longer term buffering; this study was aimed at determining the specific nature and extent of these reactions.

A series of batch (to provide long-term equilibrium data) and flow experiments (to provide spatial and temporal data) were conducted inside a N_2 atmosphere glove box, with Horonobe mudstone, and simplified OPC leachates. These represented a ‘young’, with high pH and high levels of Na and K, and a later, ‘evolved’ leachate (portlandite saturated) corresponding to the early stages (100’s to 10,000’s y) in the evolution of cement porewater. Fluid analysis was by Inductively Coupled Plasma Mass Spectrometry and Ion Chromatography, and determination of pH, and E_h. Solids were examined by scanning electron microscopy (SEM).

Batch experiments were conducted at durations of up to 56 days, at lab temperature, ≈25˚C. The pH of the reacted fluids decreased compared to the initial values, pH≈13.4 to 8.5 and pH≈12.5 to 7, for the ‘young’ and ‘evolved’ fluids respectively. This was reflected in the fluid chemistry with large decreases in [K] observed, compared to the ‘young’ fluid. In the ‘evolved’ fluid experiments, [Ca] decreased and [Na] increased over time. Si showed initial gains, consistent with clay/silicate dissolution, which then decreased over time. The changes in Ca and Si were reflected in the observation of secondary CSH phases with differing Ca:Si ratios. Changes in cations may be due to ion exchange with the clay minerals present. This behaviour is consistent with reaction of the clay minerals, though evidence for this from mineralogical analysis of reacted solids was inconclusive, due to the nature of the mudstone.

Flow experiments using packed columns, were conducted using the ‘young’ fluid, at ≈25˚C, flow rates ≈0.5 ml/h. Si levels showed an initial increase then a reduction, whereas [Ca] dropped immediately to around half value of the starting fluid and then remained constant. Na levels remained close to the ‘young’ fluid throughout, but K showed an initial decrease followed be a recovery to close to the initial levels, this may reflect early ion exchange reactions with sites becoming occupied over the first 400 h of flow. As with the batch experiments, the changes in Ca and Si were due to the formation of secondary CSH phases. Examination of the saturation indices (SI) of selected minerals for the reacted fluids showed CSH to be saturated, and clay minerals to be under saturated suggesting continued dissolution.

In all experiments, S levels increased and although the Horonobe mudstone contains minor pyrite, oxidation of which was the likely source of the S, no attempt was made to control redox so this may simply reflect the initial oxidising experimental conditions.

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In summary, the reaction of the mudstone with OPC type fluids demonstrated that long term, its chemical buffering capacity, leading to a reduction in the pH of the leached fluid, dissolution of primary minerals and subsequent precipitation of CSH phases with differing Ca:Si. This behaviour is consistent with previous similar studies, with Ca and Si concentrations being controlled by CSH phase precipitation.

Keywords: Geochemistry, cement, alkaline , geological disposal , mudstone

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Measurement and analysis of real-world pore micromodel for multiphase flow displacement

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1. Taiwan National Chiao Tung University

In this study, a pipe flow pressure measuring machine was used to measure the pressure of the PDMS micro-model made of the actual pore image injected by the pump. The residual amount in the micromodel is estimated from the numerical value of the pressure change, and whether the residual amount is the same as that of the previous micromodel.

Keywords: porous media, pipe flow pressure

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Assessment of Soil Quality as Affected by Topography and Farming Practices in the Rice Terraces in Ifugao, the Philippines

*Tomoyo Kurozumi[1], Yasushi Mori[1], Hiroaki Somura[1], Milagros Ong How[2], Pearl Basilio Sanchez[3]

1. Graduate School of Environmental and Life Science, Okayama University,, 2. Universal Harvester Incorporated, 3. University of the Philippines Los Banos

In the Rice Terraces of the Philippine Cordilleras, there have been serious issues such as watershed destruction and low productivity. However, few studies discussed the soil environment at present, nevertheless, it would contribute to making farming more sustainable. Therefore, the soil quality, mainly focusing on the soil chemical properties, was assessed in this study. Soil analysis and interviews using questionnaires and group discussions were done. Soil samples were collected considering different topography such as elevation and farming practices. The soil was collected from each elevation at first. Even at the same elevation, the other soil samples were also collected from the fields which are unique in its topography and farming practices in order to identify the effects of mentioned unique points on soil quality. Results showed that topography and farming practices affected the soil quality of the field. Soil acidity was observed in some fields and it caused cation leaching from the topsoil. Organic matter (OM), Total Nitrogen (TN), and Available Phosphorous (AP) increased as elevation decreased, which indicated that they were transferred from the upper. In addition, fields just below the village have high OM and AP. This may be due to domestic wastewater. TN and Available Potassium (AK) were generally smaller than target values in the whole area. From the interview, it was also found that farmers have little awareness of soil environment. Based on the findings, some proper farming and land management were proposed such as how to improve soil quality as well as soil physical conservation.

Keywords: rice terraces, Cordilleras, soil quality, soil environment, organic matter

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Effect of surface and weather conditions on subsurface water flow and heat transport

*Shintaro Kubota[1], Mito Nishioka[1], Yuki Kojima[2], Megumi Yamashita[1], Hirotaka Saito[1]

1. Graduate School of Agriculture, Tokyo University of Agriculture and Technology, 2. Department of Civil Engineering, Gifu University

Nowadays, advanced technologies, such as drip irrigation systems, allows one to improve water use efficiency in farmland. However, evaporation from soil surface is still one of the main factors of water loss especially in water limited arid or semi-arid areas. To further improve water use efficiency, it is important to understand the effect of external factors, such as surface condition, on water, both liquid and vapor, flow and heat transport in the soil. The main objective of this study is therefore to experimentally investigate the effect of surface condition on soil water and thermal regimes. In this study, we have conducted field monitoring experiments at a experimental field of Tokyo University of Agriculture and Technology, where artificial ridges, aligned either east-west or north-south, of about 5-m long were created. In addition to soil moisture sensors and thermo-couples, several heat pulse probes were also installed to monitor changes in soil water content, temperature, and water vapor fluxes. Incoming and outgoing thermal radiations as well as sky cloudiness were also monitored.

Standard metrological data, such as precipitation, air temperature, humidity, and wind speed, have been collected from a nearby Japan Meteorological Agency weather station. Preliminary data show that daily and seasonal changes of soil water content and temperature clearly depend on the direction of the ridge aligned and weather condition. For example, soil temperature near the surface of the slope facing west slowly increases compared to that near the surface of the slope facing east on a sunny day, while such effect is less on a cloudy day. We will further summarize and analyze the effect of surface and weather conditions on soil water and temperature regimes.

Keywords: Water Transport, Heat Transport

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Effect of soil type on estimating infiltration front depth using time-lapse array antenna GPR data: A numerical study

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1. Tokyo University of Agriculture and Technology, 2. NARO Institute for Rural Engineering

As an array antenna ground penetrating radar (GPR) system electrically switches any antenna combinations sequentially in milliseconds, multi-offset gather data, such as common mid-point (CMP) data, can be acquired almost seamlessly. The array antenna GPR system has been used to track the infiltration front and estimate its depth during the field infiltration experiment (*Iwasaki et al.*, 2016) by collecting time-lapse CMP data. Electromagnetic (EM) wave velocities were then obtained to estimate the infiltration front depths. Our previous study showed that the GPR estimated infiltration front depths agreed reasonably well with independently measured infiltration front depths. It is however still not well understood where the EM wave was actually reflected at the infiltration front because the soil water content changes gradually from the transmission zone toward the infiltration front. This shape depends upon the soil type. Because of recent technological advancement, there are a number of simulation tools available for both water flow and EM wave propagation in soils.

The main objective of this study was to investigate numerically the effect of the soil type on estimating the infiltration front depth using array antenna GPR data. While HYDRUS (2D/3D) (*Simunek et al.*, 2018) was used for simulating water flow in variably-saturated soils, gprMax (*Warren*, 2016) was used to simulate propagation of pulse EM wave in such soils by assigning dielectric constant and electrical conductivity correspond to simulated soil water content within the simulation domain. Sandy loam and silt loam, hydraulic properties of which were obtained from the database of HYDRUS (2D/3D), were compared in this study. The simulation time was set to 6 hours for sandy loam and to 40 hours for silt loam so that the position of the infiltration front reached at around 1 m deep. EM wave propagation was simulated at a given elapsed time to obtain CMP data. Then, the HYDRUS simulated infiltration front depth and the GPR obtained infiltration front depth were compared.

Results showed that GPR estimated reflection point was shallower than the simulated infiltration front for silt loam due to the gradual change in the volumetric water content near the infiltration front compared to sandy loam. The dielectric constant estimated from the EM wave velocity was then used to compute the average volumetric water content of the transmission zone to compute cumulative infiltration. When the infiltration progressed sufficiently long enough, the flux was assumed to asymptotic to the hydraulic conductivity. Based on the computed cumulative infiltration, the hydraulic conductivity was estimated. As a result, the accuracy of sandy loam was higher than that of silt loam.

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Keywords: array antenna ground penetrating radar (GPR), velocity analysis, infiltration

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-GE Geological & Soil Environment

[A-GE41] Energy-Environment-Water Nexus and Sustainable Development

convener:Ming Zhang(Institute for Geo-Resources and Environment, Geological Survey of Japan, AIST), Yonghong Hao(Tianjin Normal University), Jet-Chau Wen(National Yunlin University of Science and Technology), Ken Kawamoto(Graduate School of Science and Engineering, Saitama University)

This session provides a broad platform for discussion and presentation of fundamental and up-to-date scientific results related to clean energy production, environmental remediation and restoration, waste management, water cycle, monitoring of water quality, management of water resources and interconnections among them for sustainable development. Presentations on the topics associated with social science that enhance public awareness, stakeholder empowerment and involvement, and policy decisions regarding the management of water, energy and the environment are also encouraged.

Introduction

[AGE41-01] Impacts of the aquifer depletion on ground surface temperature in north China plain

★Invited Papers

*You-Kuan Zhang[1] (1.Southern University of Science and Technology)

[AGE41-02] **Investigate Sustainable Development for Micro-hydropower Generation of Water-food-energy Nexus of Irrigated Agriculture**

*Jen-Chieh Shih[1], Sheng-Hsin Hsieh [2], Ming-Der Hong [2], Hong-Ru Lin [3], Jyun-Lin Chen[4], Shao-Yang Huang [4], Jet-Chau Wen [4,5] (1. Graduate School of Safety Health and Environmental Engineering, National Yunlin University of Science and Technology., 2.Department of Irrigation and Engineering, Council of Agriculture, Executive Yuan., 3.Graduate School of Engineering Science and Technology, National Yunlin University of Science and Technology., 4.Research Center for Soil and Water Resources and Natural Disaster Prevention (SWAN), National Yunlin University of Science and Technology., 5.Department and Graduate School of Safety Health and Environmental Engineering, National Yunlin University of Science and Technology.)

[AGE41-03] ANALYSIS OF PORE STRUCTURAL PARAMETERS WITH MICROFOCUS X-RAY COMPUTED TOMOGRAPHY AND GAS TRANSPORT MEASURMENTS

★Invited Papers

*Arjun Baniya[1], Akihiro Matsuno[1], Takeshi Saito[1], Ken Kawamoto[1] (1.Graduate School of Science and Engineering, Saitama University, Japan)

[AGE41-04] Using ship’s device-produced drinking water to achieve a ballast free management

*Kun-Tu Lu[1], Hon-Kit Lui[2], Chen-Tung Arthur Chen[2], Li-Lian Liu[2] (1.Department of Marine Environment and Engineering, National Sun Yat-sen University, Kaohsiung 80424, Taiwan., 2.Department of Oceanography, National Sun Yat-sen University, Kaohsiung 80424, Taiwan.)

[AGE41-05] Possible Pathways and Microorganisms Associated with Biodegradation of Chlorinated Ethanes

*Ming Zhang[1], Miho Yoshikawa[1] (1.Institute for Geo-Resources and Environment, Geological Survey of Japan, AIST)

Discussion

Impacts of the aquifer depletion on ground surface temperature in north China plain

*You-Kuan Zhang[1]

1. Southern University of Science and Technology

It has been observed that the ground surface temperature (GST) in north China plain (NCP) has kept raising since 1970s. At the same time the depth to water table (DWT) has been increasing due to groundwater (GW) over-pumping during the same time period in the same region. Are these two events coincidences or related? In this study a coupled ParFlow.CLM model representing subsurface and land-surface processes was built to answer this question and investigate the impacts of GW pumping and irrigation on the GST in NCP. The model was validated using the water and energy fluxes reported and from the JRA-55 reanalysis. Results of numerical experiments show the subsurface acts as a buffer to temporal variations in heat fluxes at the land-surface, but long-term pumping can gradually weaken this buffer, resulting in increases in the spatio-temporal variability of GST, as exemplified by hotter summers and colder winters. Considering that changes of water table depth (WTD) significantly affect land surface heat fluxes when WTD ranges roughly between 0.01–10 m, the water table decline of 0.5 m/year simulated by the model due to pumping disturb GST for about 20 years from the pre-pumping WTD in the NCP, before the WTD exceeds 10 m. The variations of GST are expected to be faster initially and gradually slow down due to the nonlinear behaviors of GST with WTD. The findings from this study in the NCP may also have implications for other regions with GW depletion.

Keywords: Ground surface temperature , Groundwater over-pumping, North China plain, Intergrated hydrological modeling, ParFlow.CLM

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Investigate Sustainable Development for Micro-hydropower Generation of Water-food-energy Nexus of Irrigated Agriculture

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Micro-hydropower is necessary renewable energy to provide baseload, and it has the advantages of sustainable development and reduction of greenhouse gas emissions. There is an interrelationship between irrigation water and energy from micro-hydropower with the development of micro-hydropower in agricultural irrigation systems; furthermore, it will affect the effectiveness of micro-hydropower, which is set up in agricultural irrigation systems. In a previous study, Li et al. (2019) developed a model called the AWEFSM (Agricultural Water-Energy-Food Sustainable Management) model. The model can be used to estimate the water demand from the different types of crops and the yield. However, the study did not analyze the correlation between the water requirement of crops and renewable energy. Therefore, the purpose of this study is to use the AWEFSM model to investigate the relationship between irrigation water, electricity generated by micro-hydropower, and irrigation area in the agricultural irrigation system.

The Taiwanese orographic condition is rugged and abundant with water resources. In recent years, the development of micro-hydropower has been emphasized. Especially the Zhuoshui River watershed, which has a large watershed area and a well-developed agricultural irrigation system. Hence, the study builds a micro-hydropower generation system in Linnei channel and the south connecting channel of the Zhuoshuixi river watershed in the middle of Taiwan, and collect channel background information, irrigated area, crop species and yield, and electricity production by micro-hydropower. Use the AWEFSM model to investigate the interrelation between the generated energy and irrigation water after setting up micro-hydropower in water-energy-food nexus.

Keywords: Micro-hydropower, Water-energy-food Nexus, Irrigation Channel

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ANALYSIS OF PORE STRUCTURAL PARAMETERS WITH MICROFOCUS X-RAY COMPUTED TOMOGRAPHY AND GAS TRANSPORT MEASURMENTS

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Understanding of gas transport in porous media has wide applications, particularly in contaminates transport at polluted sites, emission of greenhouse gases from solid waste landfill site and decomposition process of waste layer. Gas transport are controlled through the pore structure parameters (i.e. pore size distribution, porosity, pore connectivity and tortuosity). Nowadays micro-focus X-ray computed tomography (MFXCT) has been proven to be a valuable non-destructive tool for the direct visualization and better understand soil pore geometry. However, there have been few studies on visualization and quantification of soil pore network and soil pore networks linked to indirect pore parameters for gas flow based on measured gas diffusion coefficient and air permeability. The study aimed to identify the effect of moisture content on pore structural parameters based on MFXCT analysis and compare the MFXCT derived parameters to indirectly-estimated parameters from soil gas diffusion coefficient and air permeability such as pore tortuosity-connectivity factor (X_G) and equivalent pore diameter (d_G) for gas flow. Undisturbed and repacked samples taken from a solid waste landfill site located in Saitama prefecture Japan was used in this study. For repacked soil samples, particle size (d<2mm) with field water content were used with different dry bulk densities by hand compaction. A hanging water suction method and pressure plate apparatus were used for maintaining the different moisture content inside the soil sample. Finally, all the samples were prepared in air dry conditions (AD) at the constant room temperature of 20°C and relative humidity of 60%. Soil samples were scanned by MFXCT system with different scanning resolutions of 12, 30 and 50 μm/voxels. Then, 3-dimensional models were reconstructed with different regions of interest (ROI) of 50, 100, 200 and 300 voxels. Finally, soil pore-structural parameters such as effective pore diameter (d_{MFXCT}), pore coordination number (C_{MFXCT}), and pore tortuosity (T_{MFXCT}) were analyzed. Results showed with increasing ROI, the pore structure parameters of both undisturbed and repacked samples showed less variation. Moisture content affected clearly pore structural parameters, T_{MFXCT} and C_{MFXCT} decreased with increasing soil air filled porosity, however, measured d_{MFXCT} were independent on the moisture content. The pore connectivity-tortuosity factors derived from MFXCT were well correlated with the indirect connectivity tortuosities from measured soil gas diffusion. However, it was observed that there were some variations between effective pore diameters from MFXCT and equivalent pore diameters for gas flow estimated by gas transport parameters depending on scanning resolutions (ranging from 1:4 to 2:1 for SR =12 μm/voxels and 1:1.5 to 5:1 for SR = 30 μm/voxels).

Keywords: Micro-focus X-ray computed tomography (MFXCT), Pore structural parameters, Gas transport parameters

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Using ship’s device-produced drinking water to achieve a ballast free management

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The ballast system is essential for the safe operation of a ship. However, the discharge of about five billion tons of seawater ballast water around the world annually, which is loaded with organisms from other parts of the ocean, has already caused serious environmental impacts worldwide, such as the invasion of alien marine species, bacteria, or viruses. The discharge of ballast water is adversely affecting marine ecosystems of the global oceans and human’s health. The International Maritime Organization developed and adopted the “International Convention for the Control and Management of Ships' Ballast Water and Sediments (also known as the Ballast Water Management Convention or BWM Convention)” in 2004. Now all ships are required to have a ballast water record book and to carry out ballast water management procedures to a given standard. This study proposes a ballast free approach that, when the dedicated ballast tanks of a ship are changed to drinking water tanks, the storage of drinking water produced by on-site desalination (such as through distillation, reverse osmosis, or a combination of both) can be used to compensate the stability change by weight loss due to fuel consumption. Using a 60 m length and 2,057 tonnes ocean-going salvage tugboat, the “Salvage Titan”, as an example, we show that a simple merchantable distilled water maker, which consumes less than 26.6 kg of diesel oil daily, is sufficient to meet the need. Using our proposed method, two ships, Salvage Champion (65m length, 1,830 tonnes) and Salvage Ace (65m length, 1,714 toones), were certificated by the American Bureau of Shipping, stating that two ships contained no ballast water tank and shall not subject to the BMW Convention. Since that on-site produced drinking water is environmental harmless and our proposed method is easy and economical to install, ships with similar existing seawater ballast systems can be modified with our proposed method to meet the needs of BWM Convention and to avoid the environmental impacts caused by the use of traditional seawater ballast system.

Keywords: ballast, drinking water, distilled water, International Maritime Organization, BWM Convention, ballast free

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Possible Pathways and Microorganisms Associated with Biodegradation of Chlorinated Ethanes

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Chlorinated ethanes, represented by 1,1,1-trichloroethane and 1,2-dichloroethane etc., are the toxic, volatile organic compounds (VOCs) that are specified as contaminants by the Japanese Soil Contamination Countermeasures Act. Due to the number of the sites contaminated with chlorinated ethanes are much less than that of the sites contaminated with chlorinated ethenes represented by tetrachloroethene (PCE), trichloroethene (TCE) and their biodegradation products such as cis-1,2-dichloroethene and vinyl chloride, the studies and information on degradation of chlorinated ethanes are very limited in Japan compared with those on chlorinated ethanes.

Based on systematic literature surveys, we summarize possible pathways and microorganisms that can be involved in biodegradation of chlorinated ethanes, especially under anaerobic conditions because such conditions generally exist in the deep subsurface environment. Besides the biotic degradations, abiotic degradations were also investigated for complementarity. A variety of mechanisms such as hydrolysis, dehydrohalogenation, reductive dichlorination and co-metabolism can be involved in degradation of 1,1,1-trichloroethane, and reductive dichlorination, anaerobic oxidation and catabolic reaction can be involved in degradation of 1,2-dichloroethane. Degradation rates can be affected by many factors including the contaminant itself and temperature. The rates may vary over several orders of magnitude under different conditions and/or in different sites. To predict the time required for a bioremediation of a specific contaminated site, detailed investigations on chemical, biological and hydrogeological conditions are fundamentally necessary.

Keywords: Chlorinated Ethanes, Biodegradation, Pathway, Microorganism, Half-time

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-GE Geological & Soil Environment

[A-GE42] Interactions between Earth Critical Zone Hydrogeological Processes and Ecosystem

convener:Wang Wenke(Chang'an University), Yaqian Zhao(Xian University of Technology), Jet-Chau Wen(National Yunlin University of Science and Technology), Ming Zhang(Institute for Geo-Resources and Environment, Geological Survey of Japan, AIST)

This session provides a broad platform for the discussion and presentation of fundamental and up-to-date scientific results related to near-surface, earth critical zone hydrogeological processes, ecological system, and interactions between them. Presentations on but not limited to the research topics targeted to arid and semiarid regions are especially welcome. In addition, presentations on related research areas, such as climate change, environmental conservation, ecological risk assessment, water resource management, sand control and desert greening are also encouraged.

Introduction

[AGE42-01] Subsurface hydrology and ecological effect in arid and semi-arid regions
★Invited Papers

*Wang Wenke[1], Lei Duan[1], Zhoufeng Wang[1], Zaiyong Zhang[1] (1.Chang'an University)

[AGE42-02] **Using the Artificial Lake to Evaluate the Efficiency of Groundwater Recharge in Taiwan**

*Yi-Yu Li[1], Sheng-Hsin Hsieh[2], Ming-Der Hong[2], Jyun-Lin Chen[3], Hong-Ru Lin[4], Shao-Yang Huang[3], Jet-Chau Wen[3,5] (1.Graduate School of Safety Health and Environmental Engineering, National Yunlin University of Science and Technology, 2.Department of Irrigation and Engineering, Council of Agriculture, Executive Yuan, 3.Research Center for Soil and Water Resources and Natural Disaster Prevention (SWAN), National Yunlin University of Science and Technology, 4.Graduate School of Engineering Science and Technology, National Yunlin University of Science and Technology, 5.Department and Graduate School of Safety Health and Environmental Engineering, National Yunlin University of Science and Technology)

[AGE42-03] **Assessment of acidification hazard by acid sulfate soils in the critical zone of Muthurajawela marsh, Sri Lanka**

*Prashani Amoditha Kumari Ulapane[1], Chamindra L Vithana[1,2], Rohana Chandrajith[1], Leigh A Sullivan[3], Jochen Bundschuh[4], Atula Senaratne[1], Nick J Ward[2], Nadia Toppler[5] (1.Department of Geology, University of Peradeniya, Sri Lanka, 2.Southern Cross Geoscience, Southern Cross University, Australia, 3.University of Canberra, Australia, 4.University of Southern Queensland, Australia, 5.Environmental Analysis Laboratory, Southern Cross University, Australia)

[AGE42-04] **Analysis of one-dimensional vertical unsaturated flow in layered soils**

*Zaiyong Zhang[1], Wenke Wang[1], Chengcheng Gong[1], Tian-chyi Jim Yeh[2], Zhan Wang[1] (1.Chang'an University, 2.University of Arizona)

[AGE42-05] **Simulation of karst spring discharge using deep learning**

Lixing An[1], *Yonghong Hao[1], Tian-Chyi Jim Yeh [2], Yan Liu[1] (1.Tianjin Normal University, 2.The University of Arizona)

Discussion

Subsurface hydrology and ecological effect in arid and semi-arid regions

*Wang Wenke[1], Lei Duan[1], Zhoufeng Wang[1], Zaiyong Zhang[1]

1. Chang'an University

There is about 1/3 of the land in the world is arid and semi-arid, and about half of the world’s countries are affected by drought to varying degrees. The arid and semi-arid area of China accounts for about 25% of the land area, while it's short of water due to drought. The water resources are short supply, which causes the ecological environment fragile. The groundwater resources are widely distributed in arid and semi-arid areas. Therefore, groundwater plays an important role in maintaining industrial and agricultural production. However, the scientific problems of the subsurface hydrological and ecological effects in arid areas are still unclear. To better understand the Subsurface hydrology and ecological effect in arid and semi-arid regions, we analyzed the formations and evolution mechanisms of groundwater. Then, the functions of groundwater resources, including economy, ecology, landscape, material migration and transformation, in arid area were proposed. On this basis, the research status, existing problems, and development trend of domestic and abroad are proposed.

Keywords: Subsurface hydrology , ecological effect, arid and semi-arid regions

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Using the Artificial Lake to Evaluate the Efficiency of Groundwater Recharge in Taiwan

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Due to the temporal and spatial distribution of rainfall in Taiwan, there are apparent differences between rainy and dry season. This reason led to the management and deployment difficulties of water resources, so the usage of groundwater resources has become an important issue. During the dry season, farmland often relies on pumping groundwater and causes severe groundwater depletion. For this study purpose, the experiment of an artificial lake to discuss the benefits of groundwater recharge and to relieve this situation.
The artificial lake is the sedimentation lake (SL), and the infiltration lake (IL) is located in Gu-Keng Township, Yunlin County, Taiwan. Water from the agriculture channel first flows into SL, then precipitates and overflows to IL. The Hydraulic conductivity (K) of the artificial lake was obtained through the double-ring infiltration test and pumping test. The groundwater data from 4 observation wells around the artificial lake. Inflow and overflow were monitored in SL and IL. The estimated K is used in calculating the effective infiltration capacity (EIC) of the SL by Darcy's law. The real infiltration capacity (RIC) of the SL was calculated by the water balance equation and compared the differences between each other.
The results showed that there is a linear relationship among the water depth of SL, the inflow, and the RIC. However, the RIC is higher than the EIC; one possible explanation may be that the silt has not entirely clogged the bottom base of the SL, thus when the lake water depth increases, the RIC also increases. Nevertheless, it can also be known that the artificial lake in this study is still effective for groundwater recharge.

Keywords: Artificial Lake, Groundwater Recharge, Water Balance Equation

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Assessment of acidification hazard by acid sulfate soils in the critical zone of Muthurajawela marsh, Sri Lanka

*Prashani Amoditha Kumari Ulapane[1], Chamindra L Vithana[1,2], Rohana Chandrajith[1], Leigh A Sullivan[3], Jochen Bundschuh[4], Atula Senaratne[1], Nick J Ward[2], Nadia Toppler[5]

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Muthurajawela marsh, located on the western coastal belt and about 10 km north of Colombo City, is the largest peat bog in Sri Lanka. The northern end of the marsh connects to the Negombo lagoon, forming an integrated, tidally influenced coastal wetland ecosystem. Both Muthurajawela marsh and the associated coastal ecosystem have unique biodiversity and are home to a number of endemic fauna and flora species. The marsh is ecologically important as a floodwater basin, wildlife habitat and breeding ground for many fish and crustacean species. Economically, it provides multiple benefits to people in the vicinity by supporting livelihood activities. Being located in a rapidly developing and densely populated urban area, the marsh is greatly exploited at an alarming rate by various anthropogenic activities (e.g. landfilling, infrastructural developments and illegal human settlements etc.). The critical zone of the marsh is known to contain acid sulfate soils (ASS), i.e. sulfidic soil materials and their oxidized products. Anthropogenic and natural activities (e.g. drainage and prolonged droughts) in and around the marsh may expose the underneath sulfidic soil materials resulting in their oxidation which can generate substantial amounts of acidity. Acidity and trace metal elements mobilized by the acidity may pose a severe threat on the components of the critical zone (i.e. vegetation, soil, ground and surface water) in the marsh. However, the current status of the acidity and its potential impacts on the critical zone of the marsh are unknown. The main objective of this study was to assess the acidity hazard in the marsh by quantifying the “Net Acidity” level using the Acid-Base Accounting (ABA) approach. Soil profiles up to 1.5 m were collected from northern, middle and southern regions of the marsh. All three soil profiles contained substantial amount of net acidity with appreciable amount of potential sulfidic acidity (PSA) as indicated by the chromium reducible sulfur (CRS) content. In all three soil profiles, the CRS values below 0.5 m depth exceeded the recommended threshold sulfur and net acidity values of 0.06 % S and 18 mol H^+/t respectively set for the medium texture (i.e. clayey sand to light clay) soils. The field data were consistent with the lab results. The field pH peroxide test (i.e. pH_{FOX}) data of all depths in three soil profiles also indicated the presence of sulfidic sediments (i.e. $pH_{FOX} < 4.5$) with high to volcanic effervescence when reacting with hydrogen peroxide. Presence of sulfidic materials in all three soil profiles was further supported by the natural incubation pH (pH_{INC}) data: when soils were incubated under natural environment pH_{INC} dropped to < 4.5 before 19 weeks. The results revealed that Muthurajawela marsh contains hypersulfidic soil materials within the critical zone that can generate appreciable amount of acidity (i.e. PSA) in the event of exposure. Under such exposed conditions, the acidity and the trace elements mobilized by the acidity can cause detrimental impacts on soil, vegetation, ground and surface water in the marsh and thereby can adversely affect the entire ecosystem of the Muthurajawela marsh and the people living in the surrounding area. The study suggest that it is critically important to minimize any kind of disturbance of soil in Muthurajawela marsh to protect the ecosystem.

Keywords: Acid-Base Accounting, Hypersulfidic, Chromium Reducible Sulfur, Wetland, Anthropogenic activities, Net acidity

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Analysis of one-dimensional vertical unsaturated flow in layered soils

*Zaiyong Zhang[1], Wenke Wang[1], Chengcheng Gong[1], Tian-chyi Jim Yeh[2], Zhan Wang[1]

1. Chang'an University, 2. University of Arizona

It is well known that there are typical discontinuities in the water content, the variable of Kirchhoff transform (K transform) and the gradients of both the flux and the pressure head at the interface between two dissimilar soils. Although, using the K transform has advantageous in simulating in the infiltration equation in vadose zone, it has severely restricted to apply in nonhomogeneous soils because K transform highly counts on the soil hydraulic properties. This paper proposed a new algorithm, which use finite analytic method (FAM) to combine the continuity of pressure head and flux conservation at a heterogeneous interface, to simulate one-dimensional water movement in the vadose zone of layered soils. The model establishes on typical stability and convergence. To verify the model, the results of FAM are established in numerous test problems by comparing the numerical results with the analytical solutions. In addition, FAM is also compared with modified Picard finite different method (MPFD) by using mass balance error and local error. The results show that the proposed method not only can obtain high accuracy, quite stability numerical solutions and significantly reduce the mass balance errors, but also can effective handle the discontinuity across the boundary between different soils.

Keywords: finite analytic method, heterogeneous soils, modified Picard finite different method

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Simulation of karst spring discharge using deep learning

Lixing An[1], *Yonghong Hao[1], Tian-Chyi Jim Yeh [2], Yan Liu[1]

1. Tianjin Normal University, 2. The University of Arizona

Karst springs discharge time series are strongly nonlinear and nonstationary and contain multiple frequency subsequences, which make it difficult to obtain satisfactory prediction results. For improving the prediction accuracy of karst springs discharge, this study first applied the time-frequency analysis methods including Singular Spectrum Analysis (SSA) and Ensemble Empirical Mode Decomposition (EEMD) to extract frequency and trend feature of Niangziguan Springs discharge. Then the Long Short-Term Memory (LSTM) was used to simulate each frequency subsequence. Subsequently, the prediction of spring discharge was completed by a combination of the simulated results. Finally, the performances of LSTM, SSA-LSTM, and EEMD-LSTM under different inputs were compared. The results show that the performance of SSA-LSTM and EEMD-LSTM are better than LSTM, and the EEMD-LSTM model achieved the best prediction performance.

Keywords: Karst spring discharge, Nonlinear and nonstationary time series, Singular spectrum analysis (SSA), Ensemble empirical mode decomposition (EEMD), Long short-term memory (LSTM), Deep learning

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-GE Geological & Soil Environment

[A-GE43] Extending Hydropedology- -in memory of Professor Henry Lin

convener:Kosuke Noborio(Meiji University), Yasushi Mori(Graduate School of Environmental and Life Science, Okayama University)

To commemorate Prof. Henry Lin of Pennsylvania State University who passed away at the age of 54 on September 26, 2019, we intend to extend interdisciplinary hydropedology with hydrology and pedology that he proposed in his life. We expect presentations from the interdisciplinary fields. Of course, presentations on water transfer in soil are also welcome.

[AGE43-01] Performance of moisture release curves created using *in situ* measurements for estimating infiltration and runoff

★Invited Papers

*Colin Campbell[1], Alton Campbell[2], Neil Hansen[2] (1.METER Group, Inc., 2.Dept. of Plant and Wildlife Sciences, Brigham Young University)

[AGE43-02] **Inverse Estimation of Soil Water Retention Curve from Infiltration Data**

*Hamed Ebrahimian[1,2], Mehrnaz Amini[3], Abdolmajid Liaghat[4], Haruyuki Fujimaki[5] (1.Associate professor, Department of Irrigation and Reclamation Engineering, University of Tehran, Karaj, Iran , 2.Visiting associate professor, Arid Land Research Center, Tottori University, Tottori, Japan., 3.Graduate student, Department of Irrigation and Reclamation Engineering, University of Tehran, Karaj, Iran., 4.Professor, Department of Irrigation and Reclamation Engineering, University of Tehran, Karaj, Iran., 5.Professor, Arid Land Research Center, Tottori University, Tottori, Japan.)

[AGE43-03] Soil moisture estimation using low-cost GPS multipath receiver.

*Yasushi Mori[1], Hiromitsu Funahashi[1], Tadaomi Saito[2], Kosuke Noborio[3] (1.Graduate School of Environmental and Life Science, Okayama University, 2.Fac. of Agriculture, Tottori University, 3.Fac. of Agriculture, Meiji University)

[AGE43-04] **Relationship between Soil Thermal Conductivity and Electrical Conductivity at Room Temperatures**

★Invited Papers

Lin Liu[1], Weiliu Li[1], Yili Lu[1], *Tusheng Ren[1] (1.China Agricultural University)

[AGE43-05] Gravity effect on water movement in pore space of glass beads porous media under microgravity.

*Yuichi Maruo[1], Naoto Sato[2], Kento Nogawa[1], Maho Tsukano[3], Hayato Mizutani[3], Natsumi Naganuma[1], Kosuke Noborio[3] (1.Graduate school of Agriculture, Meiji University, 2.Organization for the Strategic Coordination of Research and Intellectual Property, Meiji University, 3.Department of Agriculture, Meiji University)

Discussion

Performance of moisture release curves created using *in situ* measurements for estimating infiltration and runoff

*Colin Campbell[1], Alton Campbell[2], Neil Hansen[2]

1. METER Group, Inc., 2. Dept. of Plant and Wildlife Sciences, Brigham Young University

The moisture release curve (MRC) has been described as the most critical information about an unsaturated soil and can be thought of as a soil’s fingerprint. It provides key information like water availability, infiltration, unsaturated hydraulic conductivity, and soil type. Despite the desirability of knowing the MRC, often it is simply estimated from soil type parameters. In the past, actually making an MRC was limited by long and sometimes complicated laboratory processes. While recent developments like the Wind Schindler method have improved this, it is still impractical to evaluate every soil of interest in the lab. The objective of this study was to investigate the quality of *in situ* MRCs created in-part using a newly-released, accurate soil matric potential sensor. Soil water content and matric potential sensors were collocated at multiple depths in three actively managed landscapes with different soils: loamy sand, sandy loam, and clay loam. An entire season of data was collected to include multiple drying and wetting events. Results were compared to MRCs created in the lab using a Wind Schindler method combined with a chilled mirror instrument. Curves showed good agreement between the two approaches. *In situ* -generated curves also provided good estimates of soil type as well. Roots in the loamy sand samples clearly shift moisture release curves and appear to be responsible for the largest disparity between lab (with roots dead or removed) and field data. *In situ* MRCs cannot substitute for the quality of curves generated in the lab, but they will produce good approximations that will help fill the MRC knowledge gap and be much improved from those estimated from soil type. Using this approach, it may be possible to partition infiltration and runoff in marginal areas like the contaminated forested areas around Iitate Village.

Keywords: Moisture release curves, water content, water potential, infiltration, sensors

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Inverse Estimation of Soil Water Retention Curve from Infiltration Data

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Many applications involving water flow and solute transport in the vadose zone require unsaturated soil hydraulic properties. Direct methods for measuring hydraulic properties are often costly and time consuming. Inverse modeling approach uses information from easily measured data to estimate soil properties which are usually difficult to obtain. This approach has become an alternative to direct measurements. In this study, soil water retention curve was determined by inverse method using infiltration data and then compared with those obtained by conventional laboratory experiments. The field experiments were carried out at the research farm of the College of Agriculture and Natural Resources, University of Tehran, located in the Alborz Province, Karaj, Iran. Soil sample collection was carried out together with the field infiltration experiment. All measured values of water content were specified using pressure plates at pressure heads (h) of -300, -1000, -3000, -5000 and -10700 cm. Soil samples were taken to determine Mualem–van Genuchten hydraulic parameters (θ_r, residual water content, θ_s, saturated water content, α and n, shape parameters, and K_s, lab saturated hydraulic conductivity). A double ring infiltrometer was utilized to conduct the field infiltration experiments. The infiltration experiments were conducted for 240 minutes. The diameter of inner and outer rings was 0.2 and 0.5 m, respectively. Infiltration measurements were taken in the inner ring with three replications. Soil texture of the experimental field was mainly loam based on the USDA soil classification, characterized by a soil bulk density of 1.3 g/cm^3. Electrical Conductivity (EC) and Sodium Adsorption Ratio (SAR) of soil were 1.6 dS/m and 1.5, respectively. Soil water retention curve were inversely estimated using HYDRUS-1D model and infiltration data. HYDRUS-1D simulates water flow in the soil by the Richards equation. Variable flux, free drainage and soil water content were considered as the upper boundary, lower boundary and initial conditions, respectively. The soil hydraulic parameters were inversely estimated by minimizing the difference between observed and simulated values of cumulative infiltration data using Marquardt optimization algorithm. The coefficient of determination (R^2), root mean square errors (*RMSE*), the mean absolute error (*MAE*) and Nash–Sutcliffe efficiency (C_e) were used as evaluation criteria. The infiltration data simulated by the inverse modeling procedure (HYDRUS-1D) matched well with the observed ones (Fig. 1). The final cumulative infiltration depth (after 240 min) was 22.9 cm. There was no significant difference between the measured and simulated values of infiltration depth according to the Paired-Samples T Test procedure ($p>0.05$). Values of R^2, *RMSE*, *MAE* and C_e between the measured and simulated infiltration depths were 0.999, 0.012 cm, 0.010 cm and 0.999, respectively. Soil water retention curves were obtained regarding the optimized Mualem–van Genuchten soil hydraulic parameters (θ_r, θ_s, α, n and K_s). The estimated water retention curve is also presented in Fig. 1. The values of R^2, *RMSE*, *MAE* and C_e between measured and simulated soil-water content at different pressure heads were 0.877, 0.041 cm^3/cm^3, 0.031 cm^3/cm^3 and 0.83, respectively. As a consequence, the soil hydraulic parameters were adequately estimated. The estimated retention curve by the inverse solution was in good agreement with that fitted to laboratory data. The soil hydraulic parameters could be inversely estimated using the measured double-ring infiltration data. Using the inverse procedure provided a relatively simple, rapid, and reliable alternative method for determining soil water retention curve. The costs of determining soil hydraulic properties (double rings vs. pressure plate apparatus) would

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be also reduced.

Keywords: Soil hydraulic properties, HYDRUS, Inverse solution, Infiltration

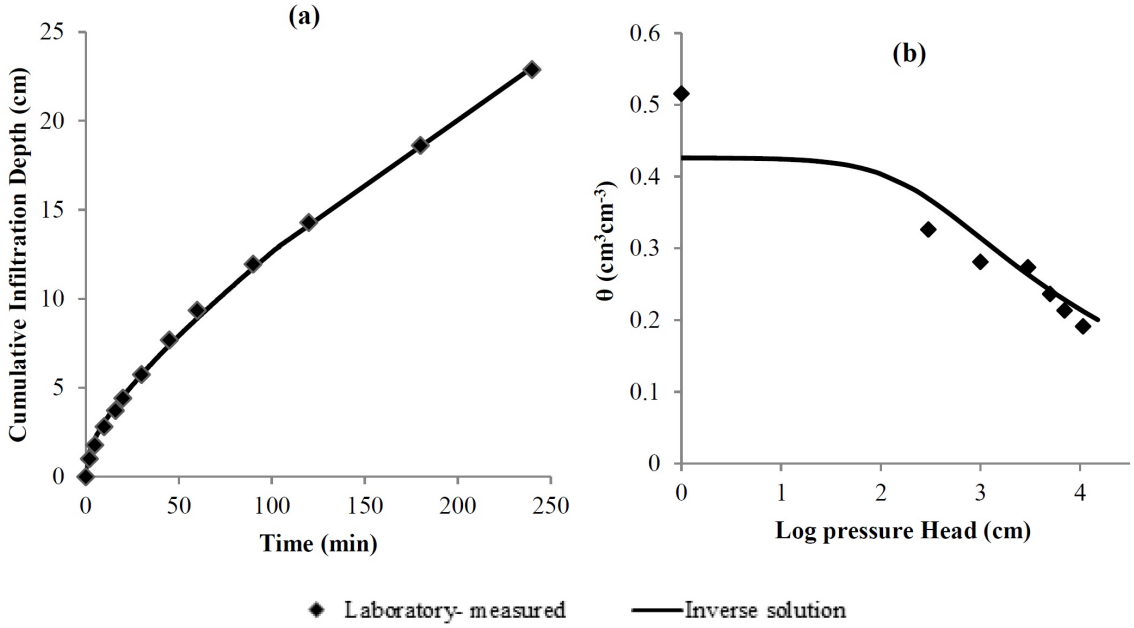

Fig. 1. Measured and estimated cumulative infiltration depths, (a); and soil water content versus pressure head, *θ(h)*, (b)

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Soil moisture estimation using low-cost GPS multipath receiver.

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GPS is a very useful tool for providing global position information on the earth. The GPS receiver identifies its position by receiving the electromagnetic waves emitted from the GPS orbiting satellite. However, the GPS receiver receives not only the direct electromagnetic wave but also the reflected wave at the ground, so this multipath affects the receiving accuracy. Since the transmitted radio waves of GPS satellites use electromagnetic waves in the 1GHz band, when reflected off the ground, if there is a place with a lot of water, the reflected wave will be delayed based on the amount of soil moisture. Therefore, we employed low-cost GPS receiver and the satellite's signal to noise ratio (SNR) data is extracted from the NMEA sentence output from the receiver to find fluctuation of the SNR which is affected by the multi-path signal. First, satellite number and travel direction (ascending or descending) were selected because only three or four satellite could be used for the analysis and each satellite had its own characteristics of the multipath noise. We chose #7, 28 and 30 for our analysis. Theoretical superposition of waves gave the SNR oscillations with the angle shift at the SNR peaks and also the peak value. The relationship between the elevation angle of the satellite and SNR was plotted on the graph to figure out how phase shift or SNR peak were affected by soil moisture. However, only the change of the SNR peak value was observed with our low-cost system. When the peak of SNR oscillation and the soil moisture were plotted, a positive proportional relationship was obtained, and the RMSE was about 3%. It had the similar accuracy as TDR, regardless fine or cloudy weather, probably because the reflection near the ground was the targeted area. Also measurement area of several to tens meter is appropriate for the field measurement in Asian country where land use changes in relatively small scale. Although, effective calibration will be needed, our preliminary experiment showed the possibility of soil moisture measurement by low-cost GPS multipath receiver.

Keywords: GPS, multipath, soil moisture

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Relationship between Soil Thermal Conductivity and Electrical Conductivity at Room Temperatures

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Soil thermal conductivity and electrical conductivity are both affected by soil texture, water content, bulk density , and pore-size distribution. However, there is a lack of understanding about the quantitative relationship between thermal conductivity and electrical conductivity, and limited datasets and models are available for describing the dynamics of electrical conductivity under field conditions. In this study, we show that soil thermal conductivity and electrical conductivity curves are interrelated and can be described with a unified series-parallel model. When normalized thermal conductivity and electrical conductivity values are plotted against the degree of saturation, a “mirror image” is observed between the two curves. Based on this phenomenon, a normalized electrical conductivity model is developed from the Lu et al. (2007) thermal conductivity model, which estimates electrical conductivity from measurements of soil texture, bulk density, and water content. Experimental examination on three soils indicates that the predicted electrical conductivity values agree well with measured data with RMSEs lower than 0.098 dS m^{-1}, and bias from -0.080 to 0.011 dS m^{-1}. The model has important implications in studying coupled processes of heat, water and nutrients in the field.

Keywords: Soil physics, Heat conduction, Electricity conduction

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Gravity effect on water movement in pore space of glass beads porous media under microgravity.

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Water movement in porous media plays an important role, not only under Earth gravity (1 G), but also under microgravity. Previous research, glowing red romaine lettuce under microgravity on International Space Station, reported that water hardly infiltrate into porous media by capillary force and the lettuce was stunted by low water event. Another research reported that water infiltration rate in porous media was slower under microgravity than under 1 G. Development of air entrapment on pore space and fingering of wetting front may restrict water movement under microgravity. Furthermore, square widening shape (0.8 mm to 2.3 mm) restricted capillary flow in glass tube under microgravity, it is, however, unclear that widening shape of pore space in porous media, which is smaller and has concave surface, restrict water movement under microgravity. Our objectives of this study are (1) to evaluate gravity dependence on development of air entrapment and fingering of wetting front in porous media, and (2) to reveal the shape which restricts capillary flow in porous media under microgravity, especially the widening shape which was reported as restricting factor of capillary flow in glass tube. To capillary flow visible, thin acrylic column (20 x 70 x 2 mm inside dimension) was chosen. 2 layers of glass beads which were 40 mm layer of 0.8 mm glass beads and 30 mm layer of 1.0 mm glass beads were filled into the column to create widening shapes on the border of beads layer. Distilled water dyed by methylene blue solution was infiltrated into the glass beads and capillary flow was captured by high speed (960 fps) and closeup camera (DSC-RX100M5A, SONY). The movie was split into image sequences and the pictures were analyzed by PC software (ImageJ). The experiment was conducted both under 1 G and under 2.4 s microgravity induced by 45 m free fall from drop tower. Both under 1G and under microgravity, capillary flow temporarily stopped on 2 points which is before concave surface of bead and on pore space between bead and next bead. Once wetting front lost balance and overleaped the concave surface or attached to the next glass beads, water moved fast to the next stop point. Although, capillary flow restricted on widening shape of pore space, there were no gravity dependences on capillary flow restriction. Development of air entrapment on pore space and fingering of wetting front were not observed in this research. Narrower particle size distribution (0.71 mm to 0.99 mm) may restrict development of fingering of wetting front comparing with particle distribution in previous research (1 mm to 2 mm). Capillary flow on the border of the glass beads layer stopped longer than on other pore space. When the head of wetting front reached to the border of glass beads layer, the wetting front stopped on the border until surrounding wetting front caught up. The border disturbed the wetting, however, did not shut off the capillary flow.

Keywords: Water movement, Porous media, Microgravity, Infiltration, Capillary flow, Space Agriculture

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG44] Extratropical oceans and atmosphere

convener:Youichi Kamae(Faculty of Life and Environmental Sciences, University of Tsukuba), Toyama Katsuya(Meteorological Research Institute), Hyodae Seo(Woods Hole Oceanographic Institution), Yoshi N(Hokkaido University)

The extratropical ocean had been considered passive to atmospheric variability. Recent studies, however, revealed active roles of the extratropical ocean in modulating the atmosphere. The goal of this session is to deepen our understanding of the air-sea interaction in the extratropics. A wide variety of researches whose topics range from meso-scale to basin-scale interactions, and from daily to global warming timescales are welcomed. Researches on topics related to extratropical air-sea interaction, including cloud, aerosol, and ecosystem, are also welcomed.

[ACG44-01] **Western boundary currents and their extension regions as conduits for the ejection of bomb-radiocarbon from the thermocline**

★Invited Papers

*Keith Bradley Rodgers[1,2], Ping Zhai[3], Richard D Slater[3], Brendan R Carter[4,5], Daniele Iudicone[6], Olivier Aumont[7], Jesse Farmer[8,9], Ivy Frenger[10], Yves Plancherel[11], Laure Replandy[12], Andrea Fassbdner[13], Katsuya Toyama[14] (1.IBS Center for Climate Physics, Busan, Republic of Korea, 2.Pusan National University, Busan, Republic of Korea, 3.Atmospheric and Oceanic Sciences Program, Princeton University, NJ, 4.Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Seattle, WA, 5.NOAA Pacific Marine Environmental Laboratory, Seattle, WA, 6.Department of Integrated Marine Ecology, Stazione Zoologica, Anton Dohrn, Naples, Italy, 7.Sorbonne Universités, UPMC, Univ. Paris 06-CNRS-IRD-MHNH, LOCEAN/IPSL, Paris, France, 8.Princeton University, Department of Geosciences, Princeton, NJ, 9.Climate Geochemistry, Max-Planck INstitute for Chemistry, Mainz, Germany, 10.GEOMAR Helmholz Centre for Ocean Research, Kiel, Germany, 11.Grantham Institute, Imperial College, London, UK, 12.Princeton Environmental Institute, Princeton, NJ, 13.Monterey Bay Aquarium Research Institute, Moss Landing, CA, 14.Oceanography and Geochemsitry Research Department, Meteorological Research Insistute, Japan Meteorological Agency, Tsukuba, Japan)

[ACG44-02] Modulation of western boundary current influence on the troposphere by atmospheric fronts

*Rhys Parfitt[1,2], Hyodae Seo[2], Young-Oh Kwon[2] (1.Florida State University, 2.Woods Hole Oceanographic Institution)

[ACG44-03] Processes Shaping the Time-Mean Surface Wind Convergence Patterns Aound the Kuroshio Extension and Gulf Stream in Winter

*Ryusuke Masunaga[1], Hisashi Nakamura[2], Bunmei Taguchi[4], Takafumi Miyasaka[3,2] (1.International Pacific Research Center, University of Hawaii, 2.Research Center for Advanced Science and Technology, The university of Tokyo, 3.Japan Meteorological Business Support Center, 4.University of Toyama)

[ACG44-04] *Climatic Hotspot2* project in Japan

★Invited Papers

*Masami Nonaka[1] (1.Application Laboratory, Research Institute for Value-Added Information Generation, Japan Agency for Marine-Earth Science and Technology)

[ACG44-05] Coupled ocean-atmosphere interactions over oceanic boundary currents

*Hyodae Seo[1] (1.Woods Hole Oceanographic Institution)

[ACG44-06] **Forced atmospheric circulation response and its uncertainty to decadal SST variability in the Kuroshio Extension**

*Bunmei Taguchi[1,2], Kazuaki Nishii[3,2], Hisashi Nakamura[2,4] (1.Faculty of Sustainable Design, University of Toyama, 2.Research Center for Advanced Science and Technology, The University of Tokyo, 3.Graduate School of Bioresources, Mie University , 4.APL, Japan Agency for Marine-Earth Science and Technology)

Western boundary currents and their extension regions as conduits for the ejection of bomb-radiocarbon from the thermocline

*Keith Bradley Rodgers[1,2], Ping Zhai[3], Richard D Slater[3], Brendan R Carter[4,5], Daniele Iudicone[6], Olivier Aumont[7], Jesse Farmer[8,9], Ivy Frenger[10], Yves Plancherel[11], Laure Replandy[12], Andrea Fassbdner[13], Katsuya Toyama[14]

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The western boundary currents and their extension regions have long been expected to play an important role in the ocean’ s carbon cycle. However, it is still uncertain how western boundary currents impact the ocean uptake pathways of anthropogenic carbon (C_{ant}), and if they sustain a new transfer of $C_{ant}$from thermocline to subpolar water masses. Here we consider water mass transformation diagnostics applied to a forward ocean circulation model in conjunction with an analysis of bomb-DI^{14}C (bomb-radiocarbon) as a proxy for a “pulsed” atmospheric source function of C_{ant}over the period 1955-1963. Our main result is that the extension regions of the western boundary currents play an important role in sustaining rapid (32±3 years) renewal timescales for the full ocean volume above the density horizon of the base of the thermocline. This rapid renewal timescale sustains a vigorous exchange of the waters with maximum bomb-DI^{14}C content. In 1995 in the model (mid-WOCE) 66% of the global cumulative air-sea flux of bomb-$^{14}CO_2$enters the ocean directly into thermocline densities, but with only 42% of the inventory in the thermocline. Approximately 70% of the net transfer of bomb-DI^{14}C from subtropical to subpolar waters in 1995 is shown to occur south of 30˚S, sustained largely through the densification of near-surface waters through the release of heat to the atmosphere within the western boundary currents and their extension regions. The results may help to understand pathways of C_{ant}within the ocean under a future transition to zero or negative emissions.

Keywords: Western Boundary Currents, Air-Sea Interaction, Radiocarbon, Thermocline

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Modulation of western boundary current influence on the troposphere by atmospheric fronts

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1. Florida State University, 2. Woods Hole Oceanographic Institution

It is now well-known that western boundary currents anchor vertical ascent deep into the troposphere in the climatological mean, resulting in a striking imprint of the meandering ocean currents on the near-surface and upper tropospheric wind convergence fields. Traditionally, this air-sea coupling has been described mechanistically through time-mean processes. Here, by decomposing the atmosphere into frontal and non-frontal components, we illustrate that the oceanic imprint on both the near-surface and upper tropospheric time-mean wind convergence fields can be explained almost entirely by the frontal components alone (i.e. on a synoptic time-scale). Furthermore, not all atmospheric fronts contribute equally - it is in fact a small subset that do so in conditions preferential for the enhancement of the local frontal air-sea interaction. Critically, this suggests that the influence of western boundary currents on many aspects of the climatological atmosphere can be inferred from discrete, rare interactions occurring on a synoptic time-scale.

Keywords: Air-sea Interaction

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Processes Shaping the Time-Mean Surface Wind Convergence Patterns Aound the Kuroshio Extension and Gulf Stream in Winter

*Ryusuke Masunaga[1], Hisashi Nakamura[2], Bunmei Taguchi[4], Takafumi Miyasaka[3,2]

1. International Pacific Research Center, University of Hawaii, 2. Research Center for Advanced Science and Technology, The university of Tokyo, 3. Japan Meteorological Business Support Center, 4. University of Toyama

High-resolution satellite observations and numerical simulations have revealed that climatological-man surface wind convergence and precipitation are enhanced locally around the midlatitude warm western boundary currents (WBCs) with divergence slightly to the poleward. While steep sea-surface temperature (SST) fronts along the WBCs have been believed to play an important role in shaping those frontal-scale atmospheric structures, the mechanisms and processes involved are still under debate. The present study explores specific daily-scale atmospheric processes that are essential for shaping the frontal-scale atmospheric structures around the Kuroshio Extension (KE) and Gulf Stream in winter, taking advantage of a new product of global atmospheric reanalysis. Cluster analysis and case studies reveal that a zonally-extending narrow band of surface wind convergence frequently emerges along the KE, which is typically observed under the surface northerlies after the passage of a developed synoptic-sale cyclone. Unlike its counterpart around the cyclone center and associated cold front, the surface convergence is in moderate strength and persistent. Nevertheless, the moderate convergence accompanies ascent and convective precipitation. The band of convergence is a manifestation of a weak stationary atmospheric front anchored along the SST front or generation of a weak meso-alpha scale cyclone. Latent heating through convective processes induced by surface convergence play an important role in shaping the frontal-scale atmospheric structures by acting to reinforce the ascent and convergence. The Gulf Stream region exhibits similar characteristics, while the contribution from meso-alpha scale cyclones seems to be less dominant.

Keywords: Kuroshio Extension, Gulf Stream, air-sea interaction, frontogenesis

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Climatic Hotspot2 project in Japan

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1. Application Laboratory, Research Institute for Value-Added Information Generation, Japan Agency for Marine-Earth Science and Technology

Frequency of extreme rainfalls and snowfalls has been increasing these years, and those events severely affect human lives and properties. It has been considered that tropical ocean and atmosphere variability such as El Niño and Indian Ocean Dipole mode, as well as the warming climate, remotely influences mid-latitude extreme weather/climate, while the mid-latitude ocean is passive to atmospheric variability. Current operational seasonal climate predictions are conducted based on this climate "assumption."

Recent high-resolution ocean/atmospheric data analyses, however, have revealed that mid-latitude ocean also influences atmospheric circulations and their variability. Rediscovering strong warm current (e.g., the Kuroshio and the Gulf Stream) and associated strong ocean frontal zones as "*climate hotspot*", we have elucidated mechanisms of ocean-atmosphere interactions and established a new paradigm of active roles of mid-latitude oceans in the climate system, replacing the conventional "assumption."

The research progress has prompted a new crucial task: application of such new knowledge to predictions of extreme rainfalls/snowfalls and climate variability. For the new task, we have started a new research project called "*Climatic Hotspot2*" with more than 60 collaborators. In this project, I) we will further our understandings of mid-latitude ocean-atmosphere interaction processes that span multiple spatio-temporal scales and interplay among them through tight collaborations of latest observational and numerical modeling tools. Also, based on the improved understandings, II) we will investigate predictability of extreme weather (such as typhoons and bomb cyclones), of persistent atmospheric circulation anomalies that induce those extremes, projection of climate changes, and active roles of mid-latitude oceans in those phenomena. The purposes of the project are then deepening of the previously established paradigm and showing its scientific and societal importance and validity.

Keywords: air-sea interaction, extratropical, extreme weather

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Coupled ocean-atmosphere interactions over oceanic boundary currents

*Hyodae Seo[1]

1. Woods Hole Oceanographic Institution

The oceanic boundary current systems are often characterized by the intense and narrow currents and the enhanced eddy activity. The induced SSTs and surface currents induce significant and persistent spatial variations in the momentum, heat, and moisture fluxes, whose impacts are manifested not just on the stability of the currents and the upper ocean stratification but also extends to the downstream development of the atmospheric processes. Two types of eddy-induced coupled feedbacks exist, one that arises from the mesoscale SST impacting the surface wind, and another through the surface current that modulates the stress through relative wind effect. These thermal and mechanical couplings co-exist in nature, but their impacts are shown to be rather distinctive. The goal of this presentation is to review these distinctive effects of eddy-induced air-sea coupled feedbacks, examine spatial scale dependence of the coupling, and explore their coupled effect on the large-scale atmospheric circulation. The presentation will focus on several oceanic boundary current systems, including the California Current System in the Northeast Pacific and two seasonal western boundary currents in the Indian Ocean. The relevance of the result to other, more significant western boundary currents in the extratropics will also be discussed.

Keywords: boundary currents, air-sea interactions, mesoscale eddies

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Forced atmospheric circulation response and its uncertainty to decadal SST variability in the Kuroshio Extension

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1. Faculty of Sustainable Design, University of Toyama, 2. Research Center for Advanced Science and Technology, The University of Tokyo, 3. Graduate School of Bioresources, Mie University , 4. APL, Japan Agency for Marine-Earth Science and Technology

Despite the recent progress on extra-tropical oceanic influences on the atmospheric circulation variability, their observational and modeling estimates are still diverse among studies. Some studies emphasize the importance of high-resolution for models to simulate realistic atmospheric responses, while other studies report success with lower-resolution simulations. These modeling studies tend to still underestimate the amplitude of the observed response, which also shows large uncertainty. A required task is to make a consistent comparison between the observed and simulated atmospheric responses by separating the forced response from internal variability that is inevitable in the observational estimate due to the limited record length.

Here we separate out a forced component of extra-tropical-ocean-driven atmospheric circulation anomaly with a joint analysis of an atmospheric reanalysis and large ensemble AGCM simulations with two different resolutions and two different SST boundary conditions. SVD analysis is applied to winter-time mean near-surface baroclinicity in the Kuroshio Extension (KE) region between all the AGCM ensemble members and the reanalysis data. This yields temporally co-varying patterns for the two datasets as components that are forced by underlying SST anomalies. The leading SVD mode is characterized by a pulsing of the baroclinicity over the KE on the decadal time scale. Associated with the forced baroclinicity mode in both the AGCM and reanalysis, lower-tropospheric storm track activity is enhanced over the KE region, which is accompanied by upper-tropospheric geopotential anomalies in the Pacific sector. The forced upper-tropospheric wave train extends further downstream over the US continent and into the Atlantic sector, exhibiting the Aleutian and Icelandic low seesaw pattern in the reanalysis.

Keywords: large ensemble AGCM, resolution dependency, atmospheric internal variability , jet stream, Aleutian-Icelandic low seesaw

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG44] Extratropical oceans and atmosphere

convener:Youichi Kamae(Faculty of Life and Environmental Sciences, University of Tsukuba), Toyama Katsuya(Meteorological Research Institute), Hyodae Seo(Woods Hole Oceanographic Institution), Yoshi N(Hokkaido University)

The extratropical ocean had been considered passive to atmospheric variability. Recent studies, however, revealed active roles of the extratropical ocean in modulating the atmosphere. The goal of this session is to deepen our understanding of the air-sea interaction in the extratropics. A wide variety of researches whose topics range from meso-scale to basin-scale interactions, and from daily to global warming timescales are welcomed. Researches on topics related to extratropical air-sea interaction, including cloud, aerosol, and ecosystem, are also welcomed.

[ACG44-07] Deep learning for mesoscale air-sea interactions

★Invited Papers

*Thomas Kilpatrick[1], Shang-Ping Xie[1], Will Chapman[1] (1.Scripps Institution of Oceanography)

[ACG44-08] Extratropical cyclone processes as a key to understanding climate sensitivity

*Daniel McCoy[1], Paul Field[1,2], Alejandro Bodas-Salcedo[2], Gregory Elsaesser[3], Mark Zelinka[4] (1.University of Leeds, 2.UK Met Office, 3.Columbia University and NASA Goddard Institute for Space Studies, 4.Lawrence Livermore National Laboratory)

[ACG44-09] Stability Index for Marine Low Cloud Cover over the Mid-latitudes

*Hideaki Kawai[1], Tsuyoshi Koshiro[1] (1.Meteorological Research Institute)

[ACG44-10] Air-sea fluxes and ocean variability associated with atmospheric rivers

*Toshiaki Shinoda[1], Weiqing Han[2], Luis Zamudio[3], Joe Metzger[4], Chris Fairall[5], Yanjuan Guo[6] (1.Texas A&M University Corpus Christi, 2.University of Colorado, 3.Florida State University, 4.Naval Research Laboratory, 5.NOAA, 6.University of Maryland)

[ACG44-11] On the Importance of a Midlatitude Oceanic Frontal Zone for the Baroclinic Annular Mode

*Morio Nakayama[1], Hisashi Nakamura[1], Fumiaki Ogawa[2] (1.Research Center for Advanced Science and Technology, the University of Tokyo , 2.University of Bergen)

[ACG44-12] North and South Pacific Decadal Oscillations: Tropical Pacific Forcing versus Internal Variability

*Yu Zhang[1,2], Shang-Ping Xie[3], Yu Kosaka[4], Jun-Chao Yang[1,2] (1.Physical Oceanography Laboratory, Ocean University of China, 2.Qingdao National Laboratory for Marine Science and Technology, 3.Scripps Institution of Oceanography, University of California San Diego, 4.Research Center for Advanced Science and Technology, The University of Tokyo)

Deep learning for mesoscale air-sea interactions

*Thomas Kilpatrick[1], Shang-Ping Xie[1], Will Chapman[1]

1. Scripps Institution of Oceanography

In the field of machine learning, convolutional neural networks have enabled breakthroughs in computer vision and natural language processing. Here we explore the use of convolutional neural networks, or deep learning, to study mesoscale air-sea interactions. We train our deep learning model with satellite observations of SST and surface winds, and compare the model performance to conventional methods that utilize linear regression in physical space and Fourier wavenumber space. Given enough data, the deep learning model has the potential to outperform conventional methods based on a mean square error loss metric. This will allow for ocean model simulations forced by observed satellite winds that are adjusted to remove wind effects due to spontaneous mesoscale eddy activity, and thus consistent forcing of ocean models with satellite-observed winds.

Keywords: mesoscale eddy, air-sea interaction, machine learning

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Extratropical cyclone processes as a key to understanding climate sensitivity

*Daniel McCoy[1], Paul Field[1,2], Alejandro Bodas-Salcedo[2], Gregory Elsaesser[3], Mark Zelinka[4]

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Global climate models (GCMs) differ greatly in their shortwave cloud feedback. One feature that is consistent across GCMs is a positive shortwave cloud feedback in the subtropics, and a negative shortwave cloud feedback across the extratropics. Confidence has grown in the mechanisms that lead to, and the strength of, the subtropical shortwave cloud feedback, but the extratropical negative shortwave cloud feedback is not well-constrained or well-understood. It is critical to reduce uncertainty in extratropical shortwave cloud feedback. A more positive extratropical shortwave cloud feedback in the sixth coupled model intercomparison project (CMIP6) has been found to be one of the primary causes of the increased climate sensitivity of CMIP6 models relative to CMIP5. We show that changes in extratropical cyclones in future climates are the primary cause of the negative shortwave cloud feedback and are thus key to understanding the high climate sensitivity in the most recent GCMs. Warming-induced changes in cloud liquid water path in extratropical cyclones can almost entirely be explained by Clausius-Clapeyron increasing moisture convergence into cyclones. One concern with simulating extratropical cyclones is the lack of predictive skill at low resolution. A more realistic relationship between moisture flux and cyclone liquid content is found at high horizontal resolution (dx<25km), but the cloud feedback within cyclones can be explained by increased moisture convergence across low- and high-resolution models. Observations and models agree that the extratropical shortwave cloud feedback is moderated by precipitation processes in cyclones. This rules out a large contribution from ice-to-liquid transitions, as has been hypothesized in previous studies. Understanding and constraining these precipitation processes is crucial to constraining the response of extratropical cyclones to warming and by extension climate sensitivity.

Keywords: Cloud feedback, Extratropics, Climate sensitivity, Southern Ocean, Cyclone, Precipitation

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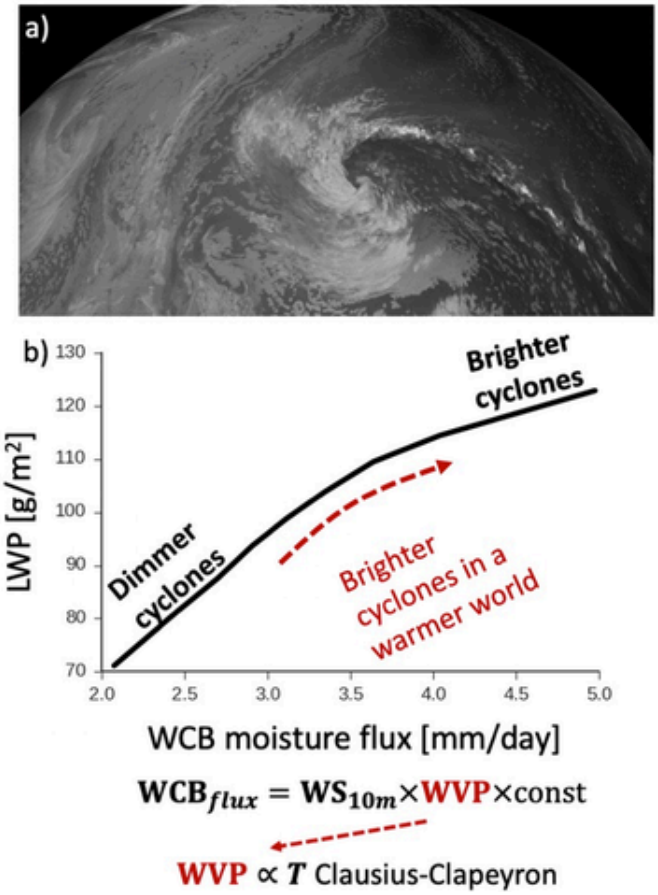

(a) Convection-permitting simulations in the UK Met Office model of a cyclone. The moisture flux along the warm conveyor belt (WCB) of a cyclone plays a central role in determining cyclone cloud liquid water path (LWP) **(b)**. Because WCB scales with water vapor path (WVP) and surface wind speed, WCB moisture flux increases following Clausius-Clapeyron and predicts a negative extratropical cloud feedback.

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Stability Index for Marine Low Cloud Cover over the Mid-latitudes

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1. Meteorological Research Institute

The estimated inversion strength (EIS; Wood & Bretherton 2006) is a well-known index that highly correlates with marine low-cloud cover and has been used in many studies. The index estimates strength of inversion at the top of the atmospheric mixed layer based on the potential temperature at 700 hPa and near the sea surface. However, marine low-cloud cover over the mid-latitudes, which is rather large, is slightly underestimated by EIS. On the other hand, the estimated cloud-top entrainment index (ECTEI; Kawai et al. 2017), which is developed from EIS, corresponds better to large low-cloud cover over the mid-latitudes than EIS (Fig. 1).

The reason can be explained as follows. The EIS takes into account only the temperature profile and does not include information on water vapor. On the other hand, the ECTEI, which is deduced from a criterion of cloud top entrainment that can destroy low-clouds, includes information on the vertical profile of water vapor (specific humidity at 700 hPa and near the sea surface) as well as that of temperature. Even though the EIS has similar values over the subtropics and the mid-latitudes, marine low-clouds over the mid-latitudes are less easily destroyed because of lower sea surface temperature and larger relative humidity around 700 hPa. The ECTEI can simply explain that these two factors contribute to large marine low-cloud cover over the mid-latitudes.

In addition, it is briefly introduced that climate model MRI-ESM2, which utilizes ECTEI in the cloud parameterization, reasonably reproduces marine low clouds over the mid-latitudes and the corresponding radiation bias is small.

Keywords: marine low cloud, mid-latitudes, cloud parameterization, climate model

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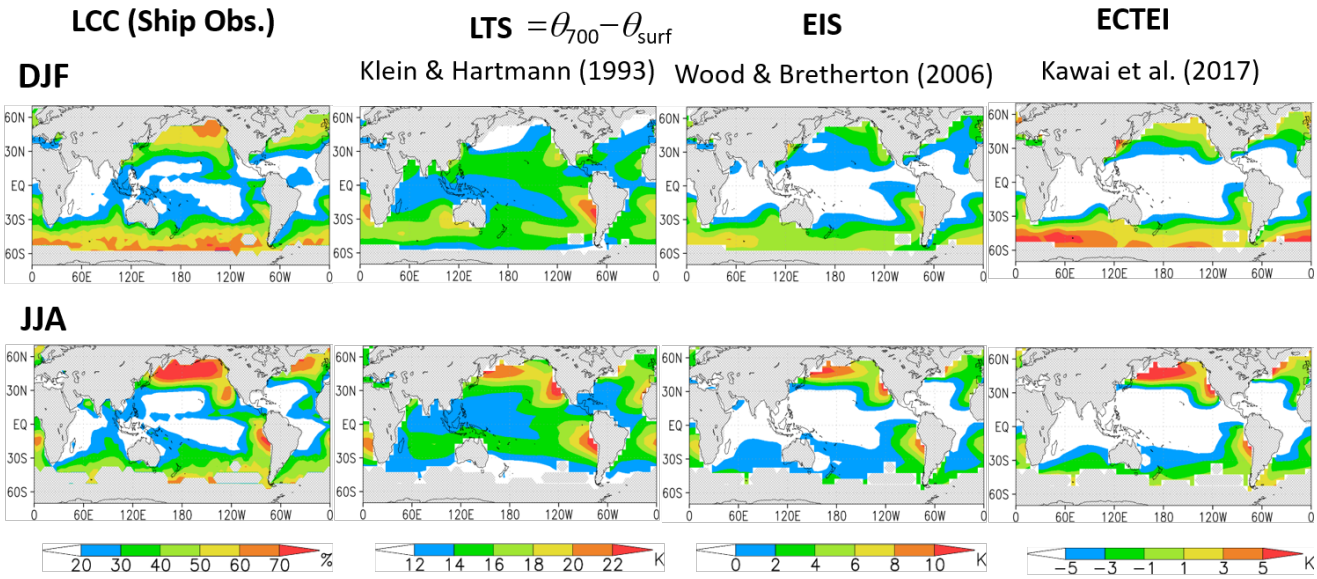

Figure 1: Climatologies of low stratiform cloud cover (%), LTS (K), EIS (K) and ECTEI (K) for December to February and June to August (modified after fig. 12 in Kawai et al. 2019, *GMD*). Cloud cover data were obtained from EECRA shipboard observations, and stability indexes were calculated using ERA-40 data (1957–2002).

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Air-sea fluxes and ocean variability associated with atmospheric rivers

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Atmospheric rivers (ARs) generate strong upper ocean variability and substantial air-sea fluxes in the northeast Pacific and southeast Indian Oceans. In this presentation, we summarize dynamical and thermodynamical oceanic responses to AR-associated air-sea fluxes in these two regions, and discuss the similarity and differences between these regions. While the overall structure of large-scale latent heat flux (evaporation) variability associated with ARs are similar in the northeast Pacific and southeast Indian Oceans, a zonal and meridional extent of the areas of significant latent heat flux are different because of the different spatial pattern of the cyclonic circulation associated with ARs. While AR-associated latent heat flux is very small around the west coast of north America where the equatorward boundary current generates relatively cold SSTs, a significant latent heat flux is evident along the west coast of Australia because of the poleward flowing Leeuwin Current which maintains relatively warm SSTs in all seasons. The poleward coastal jets are generated by winds associated with landfalling ARs in the west coast of north America and Australia. However, a significant difference in the vertical structure is found, in which the poleward currents are nearly barotropic along the Australian coast, suggesting the effect of the relatively broad continental shelf and slope. The propagation of these coastal currents and associated sea level along the coasts are further discussed.

Keywords: Atmospheric river, Air-sea flux, Upper ocean process

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On the Importance of a Midlatitude Oceanic Frontal Zone for the Baroclinic Annular Mode

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Large-scale tropospheric variability in the extratropical Southern Hemisphere is characterized by two major modes. One is the well-known Southern Annular Mode (SAM), which represents meridional shifts of the eddy-driven polar-front jet (PFJ). The other mode, “Baroclinic Annular Mode (BAM)”, represents pulsing of stormtrack activity, which is well reproduced in a perpetual aqua-planet atmospheric general circulation model (AGCM) experiment where frontal sea-surface temperature (SST) gradient is realistically prescribed at 45º latitude. The BAM variability is greatly weakened in another aqua-planet AGCM experiment where the frontal SST gradient is artificially removed. The weakening is particularly marked in the variability of low-level poleward eddy heat flux. Our experiments suggest that the midlatitude oceanic frontal zone enhances and anchors the BAM variability by strengthening stormtrack activity through maintaining near-surface baroclinicity and moisture supply to cyclones. Specifically, anomalous sensible heat flux around the SST front acts to restore meridional gradient in surface air temperature (SAT) efficiently under continuous modifications added by BAM activity through anomalous meridional eddy heat flux, and this effect is enhanced enormously around the frontal SST gradient.

In addition, the two of our AGCM experiments indicate that BAM accompanies modest but robust meridional shift of PFJ. Unlike in any previous studies, this study suggests a certain level of co-variability between BAM and SAM which is supported by significant correlation and coherence between their time series. In both experiments, BAM spectra indicates its quasi-periodic behaver as the internal mode of atmospheric variability. These results in our AGCM expriments are generally consistent with those observed.

Keywords: annular mode, oceanic frontal zone, stormtrack

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North and South Pacific Decadal Oscillations: Tropical Pacific Forcing versus Internal Variability

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The Pacific decadal oscillation (PDO) is the leading mode of sea surface temperature (SST) variability over the North Pacific (north of 20˚N). Its South Pacific counterpart (south of 20˚S) is the South Pacific decadal oscillation (SPDO). The effects of tropical eastern Pacific (TEP) SST forcing and internal atmospheric variability are investigated for both the PDO and SPDO using a 10-member ensemble tropical Pacific pacemaker experiment. Each member is forced by the historical radiative forcing and observed SST anomalies in the TEP region. Outside the TEP region, the ocean and atmosphere are fully coupled and freely evolve. The TEP-forced PDO (54% variance) and SPDO (46% variance) are correlated in time and exhibit a symmetric structure about the equator, driven by the Pacific–North American (PNA) and Pacific–South American teleconnections, respectively. The internal PDO resembles the TEP-forced component but is related to internal Aleutian low (AL) variability associated with the Northern Hemisphere annular mode and PNA pattern. The internal variability is locally enhanced by barotropic energy conversion in the westerly jet exit region around the Aleutians. By contrast, barotropic energy conversion is weak associated with the internal SPDO, resulting in weak geographical preference of sea level pressure variability. Therefore, the internal SPDO differs from the TEP-forced counterpart and features SST anomalies along ~60˚S in association with the Southern Hemisphere annular mode. Isolating the internal component from observations is limited, partly due to the small degrees of freedom in the instrumental record. Nevertheless, internal PDO variability appears to contribute significantly to the North Pacific regime shift in the 1940s. Our study demonstrates that the PDO differs from the so-called Interdecadal Pacific Oscillation (IPO), the latter of which is manifested as the TEP-forced covariation of the PDO and SPDO. We highly recommend not to mix up to use the terminologies between the PDO and IPO in future climate research.

Keywords: Pacific decadal oscillation, South Pacific decadal oscillation, tropical Pacific forcing, internal variability, barotropic energy conversion

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG45] Multi-scale ocean-atmosphere interaction in the tropical Indo-Pacific region

convener:Yu Kosaka(Research Center for Advanced Science and Technology, University of Tokyo), Sang-Wook Yeh(Hanyang University), Takanori Horii(Research and Development Center for Global Change (RCGC), Strategic Research and Development Area, Japan Agency for Marine-Earth Science and Technology (JAMSTEC)), Hiroki Tokinaga(Disaster Prevention Research Institute, Kyoto University)

Tropical Indo-Pacific Oceans are home to ocean-atmosphere interaction on a broad range of spatio-temporal scales. Teleconnections induced by the tropical Indo-Pacific variability exert a significant imprint on global climate. Since the 1980s, in-situ and satellite observations, reanalysis products, and advancements in climate modeling have led to depicting various aspects of intraseasonal (e.g., MJO), interannual (e.g., ENSO and IOD) and decadal (e.g., IPO) variability in the tropical Indo-Pacific Oceans and their impacts on tropical (e.g., monsoons) and extratropical (e.g., storm track) climate. Newer studies find an active role of salinity in ocean-atmosphere interaction in the tropical Indian Ocean. Other recent studies highlight the inter-basin coupling between the tropical Pacific and the Indian Ocean in seasonal prediction of the Asian summer monsoon and decadal redistribution of ocean heat content associated with the so-called "hiatus" of global warming. Long term change in the Pacific Walker circulation has been recapturing attention in terms of the pattern effect of warming on climate feedback and sensitivity against radiative forcing as well as ENSO modulations under a warmer climate. A variety of processes are mutually interrelated and shape the climate, its variability, and change. To examine these challenging issues from various perspectives and foster understanding of the role of tropical air-sea interaction in the climate system, this session offers a forum to discuss recent progress in observational, modeling and theoretical studies of multi-scale tropical ocean-atmosphere interaction in the tropical Indo-Pacific Oceans.

[ACG45-01] **Impacts of Arabian Sea SST biases on Indian monsoon precipitation and eastern Mediterranean climate in a coupled GCM**

★Invited Papers

*Yoko Yamagami[1], Hiroaki Tatebe[2], Masahiro Watanabe[1] (1.Atmosphere and Ocean Research Institute, The University of Tokyo, 2.Japan Agency for Marine-Earth Science and Technology)

[ACG45-02] Radiative impacts of low-level clouds on the subtropical high in the South Indian Ocean and their seasonal differences simulated in a coupled general circulation model

*Ayumu Miyamoto[1], Hisashi Nakamura[1], Takafumi Miyasaka[1,2], Yu Kosaka[1] (1.Research Center for Advanced Science and Technology, The University of Tokyo, 2.Japan Meteorological Business Support Center)

[ACG45-03] Salt-Stratified Barrier Layers in the Eastern Tropical North Pacific

*Shota Katsura[1], Janet Sprintall[1] (1.Scripps Institution of Oceanography, University of California, San Diego)

[ACG45-04] **ENSO Modulation of ISO intensity and Upscale Feedback of ISO on Seasonal Mean SST in the Western North Pacific**

★Invited Papers

*Renguang Wu[1], Xi Cao[2], Yuqi Wang[2] (1.Zhejiang University, 2.Institute of Atmospheric Physics, Chinese Academy of Sciences)

[ACG45-05] Incorporating the convection-SST sensitivity to understand ENSO and its diversity

*Ruihuang Xie[1] (1.Institute of Oceanology, Chinese Academy of Sciences)

[ACG45-06] **Effects of Tropical Cyclones on ENSO**

*Tao Lian[1], Hongli Ren[2] (1.State Key Laboratory of Satellite Ocean Environment Dynamics, Second Institute of Oceanography, Ministry of Natural Resources, Hangzhou, China, 2.Laboratory for Climate Studies, National Climate Center, China Meteorological Administration, Beijing, China)

Impacts of Arabian Sea SST biases on Indian monsoon precipitation and eastern Mediterranean climate in a coupled GCM

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1. Atmosphere and Ocean Research Institute, The University of Tokyo, 2. Japan Agency for Marine-Earth Science and Technology

We investigated impacts of sea surface temperature (SST) biases in the Arabian Sea on Indian summer monsoon precipitation and eastern Mediterranean climate, using a climate model called MIROC6 with two configurations (standard and eddy-permitting ocean model referred to as “Subhires”).
In the Subhires model, resolving the warm water outflow from marginal seas and heat transport by mesoscale eddies reduce mean cold SST biases over the Arabian Sea. Higher SST in the Arabian Sea results in cyclonic atmospheric circulation over the northern Arabian Sea, which increases precipitation in northwestern India during summer. Atmospheric general circulation model (AGCM) sensitivity experiments show that SST differences only in the northern Arabian Sea can lead to atmospheric circulation anomalies and precipitation increase in northwestern India.
It is also found that the Subhires model simulates a teleconnection from the monsoon rainfall better than the standard model. The teleconnection occurs at an interannual time scale between the Indian summer monsoon rainfall variability and descent over the eastern Mediterranean Sea, resulting from a monsoon-desert mechanism. AGCM sensitivity experiments show that higher SST in the northern Arabian Sea enhances descent anomalies in the eastern Mediterranean region, responding to precipitation increase in northwestern India.

Keywords: Arabian Sea, Monsoon-desert mechanism, Mesoscale eddy, Climate model

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Radiative impacts of low-level clouds on the subtropical high in the South Indian Ocean and their seasonal differences simulated in a coupled general circulation model

*Ayumu Miyamoto[1], Hisashi Nakamura[1], Takafumi Miyasaka[1,2], Yu Kosaka[1]

1. Research Center for Advanced Science and Technology, The University of Tokyo, 2. Japan Meteorological Business Support Center

Radiative impacts of low-level clouds are important for air-sea coupled systems because they can not only drive large-scale atmospheric circulation through cloud-top radiative cooling but also cool the underlying SST by shielding sunlight (albedo effect). In the present study, we assess their effects on the subtropical high in the South Indian Ocean, using a coupled general circulation model. By comparing a freely coupled control run (CTL) and no low-cloud run (NoCRE) where the radiative effects of low-level clouds are artificially turned off, we find that low-level clouds act to reinforce the subtropical high. In winter, enhanced in-atmosphere radiative cooling from their cloud-top strengthens the subtropical high. In summer, in addition to the above mechanism, lowered SST by their albedo effect reduces deep convective precipitation, which strengthens the subtropical high by inducing a Matsuno-Gill type response. Associated reduction of high-top clouds further augments in-atmosphere radiative cooling. Their summertime impacts on the subtropical high are so significant that the subtropical high is almost missing in the NoCRE experiment, suggesting their essential role in the existence of the subtropical high.

Keywords: low-level clouds, subtropical high, South Indian Ocean

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Salt-Stratified Barrier Layers in the Eastern Tropical North Pacific

*Shota Katsura[1], Janet Sprintall[1]

1. Scripps Institution of Oceanography, University of California, San Diego

A knowledge of the role of salinity in setting the stratification within the upper ocean is important for understanding climate variability, air-sea interaction and biogeochemical processes. For example, salinity stratified barrier layers (BLs) impede heat and momentum exchange between surface and subsurface layers that can significantly affect sea surface temperature and thus impact air-sea interaction. In the north-eastern tropical Pacific Ocean BLs are thought to influence ENSO variability but we know little about the mechanisms that result in their formation in this region. Seasonality and formation of BLs and associated temperature inversions (TIs) in the eastern tropical North Pacific were investigated using Argo profiling float data, satellite data and various sea surface flux data sets. BLs were observed frequently in boreal summer and autumn along the sea surface salinity (SSS) front south of the eastern Pacific fresh pool. TIs were found within the gap between the western and eastern Pacific warm pools in autumn when BLs were thickest. A mixed layer salinity budget revealed that Ekman advection works to freshen the eastern tropical North Pacific in autumn and contributes to the formation of the thickest BLs. Cooler water is also advected by Ekman flows in the gap between the warm pools in autumn contributing to TI formation. Collectively, this suggests the formation of autumn BLs and TIs through the tilting of the SSS front caused by Ekman advection. Since the largest rainfall associated with the Intertropical Convergence Zone (ITCZ) mostly occurred north of the band of thickest BLs in autumn, precipitation is a secondary contributor to BL formation. The idea that Ekman advection contributes most to the formation of the thickest BLs with warm TIs was further corroborated as the horizontal salinity gradient was the dominant contributor to the density gradient, and so favorable for BL and TI formation. BLs are also prevalent during summer but are thinner and without associated TIs and are primary formed through precipitation. The geostrophic advection of salinity did not coherently contribute to the formation of BLs or TIs. In our study, we find that the seasonality of BLs and TIs reflects the wind direction and the intensity of the SSS front. Thus, BLs and TIs may be closely coupled to the trade wind, that is, their presence and thickness are not only affected by the trade wind but in turn can also affect the wind field by modifying the SST.

Keywords: Pacific Ocean, Tropical Region, Barrier Layer, Salinity

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ENSO Modulation of ISO intensity and Upscale Feedback of ISO on Seasonal Mean SST in the Western North Pacific

*Renguang Wu[1], Xi Cao[2], Yuqi Wang[2]

1. Zhejiang University, 2. Institute of Atmospheric Physics, Chinese Academy of Sciences

The present study presents evidence for modulation of El Niño-Southern Oscillation (ENSO) on the ISO intensity and feedback of ISO on seasonal mean SST in the tropical western North Pacific region during boreal summer. A pronounced difference is found in the relationship of the tropical western North Pacific 10-20-day and 30-60-day ISO intensity to ENSO. The 10-20-day ISO intensity is enhanced during the El Niño developing summer, whereas the 30-60-day ISO intensity is enhanced during the La Niña decaying summer. The distinct relationship is interpreted based on the different modulation of ENSO on seasonal mean background fields and the different sources and propagation paths of the 10-20-day and 30-60-day ISOs that reach the tropical western North Pacific. An upscale feedback of ISO intensity on local seasonal mean SST change is identified in the tropical western North Pacific, which is more prominent from the 10-20-day than the 30-60-day ISO intensity change. The upscale feedback is due to a net effect of ISOs on surface heat flux anomalies. This is demonstrated by separating latent heat flux anomalies into components on different time scales. The ISO-induced latent heat flux anomalies may accumulate in a season and overcome interannual anomalies due to seasonal mean changes. Thus, the ISO-induced surface heat flux change may play an important role in the seasonal mean SST anomaly in the tropical western North Pacific.

Keywords: ENSO modulation, ISO feedback, Western North Pacific

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Incorporating the convection-SST sensitivity to understand ENSO and its diversity

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1. Institute of Oceanology, Chinese Academy of Sciences

The relationship between sea surface temperature (SST) and convection indicates that convection has nonlinear sensitivity to El Niño-Southern Oscillation (ENSO) SST anomalies (SSTA), depending on the background SST. Existing SSTA-based ENSO indices failed to imply the nonlinearity in the convection response. This study demonstrates that the convection-SST sensitivity must be considered to understand ENSO and its diversity. The convection-SST sensitivity is quasi-linear to SST so that it helps to identify the high-impact SSTs in the range of 25.25–30.25˚C, in which SSTA induces large changes in convection. By incorporating the convection-SST sensitivity, the traditional focus on SSTA is shifted to on the changes in the convection induced by the changes of the high-impact SSTs, which are defined as the *fluctuations of the accumulated convection strength* (FACT). FACT reflects the simultaneous changes of SST and convection sensitivity, and carries the nonlinearity in the Bjerknes feedback that positive (negative) SSTA enhances (weakens) the convection sensitivity and induce larger (smaller) convection response. New ENSO indices defined from FACT (InFACT) show that ENSO diversity manifests more as differences in the intensity. However, an intensity-pattern interdependence is noticed in El Niño, with strong (moderate and weak) events having maximal SSTA in the equatorial eastern (central) Pacific. This interdependence arises from the different extensions of high-impact SST over 27˚C into the eastern Pacific. Due to weak nonlinearity in FACT caused by the negative SSTA and low convection-SST sensitivity, La Niña events show weak pattern diversity. Our approach and InFACT provide another way to look at ENSO and its diversity in a convection perspective.

Keywords: convection-SST sensitivity, ENSO diversity

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Effects of Tropical Cyclones on ENSO

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1. State Key Laboratory of Satellite Ocean Environment Dynamics, Second Institute of Oceanography, Ministry of Natural Resources, Hangzhou, China, 2. Laboratory for Climate Studies, National Climate Center, China Meteorological Administration, Beijing, China

Numerous studies have investigated the role of the El Niño–Southern Oscillation (ENSO) in modulating the activity of tropical cyclones (TCs) in the western Pacific on interannual timescales, but the effects of TCs on ENSO are less discussed. Some studies have found that TCs sharply increase surface westerly anomalies over the equatorial western–central Pacific and maintain them there for a few days. Given the strong influence of equatorial surface westerly wind bursts on ENSO, as confirmed by many recent literatures, the effects of TCs on ENSO may be much greater than previously expected.

Using recently released observations and reanalysis datasets, it is found that the majority of near-equatorial TCs (TCs hereafter) are associated with strong westerly anomalies at the equator, and the number and longitude of TCs are significantly correlated with ENSO strength. When TC-related wind stresses are added into an intermediate coupled model, the simulated ENSO becomes more irregular, and both ENSO magnitude and skewness approach those of observations, as compared with simulations without TCs. Adding TCs into the model system does not break the linkage between the heat content anomaly and subsequent ENSO event in the model, which manifest the classic recharge–discharge ENSO dynamics. However, the influence of TCs on ENSO is so strong that ENSO magnitude and sometimes its final state—i.e. either an El Niño or a La Niña—largely depend on the number and timing of TCs during the event year. Our findings suggest that TCs play a prominent role in ENSO dynamics, and their effects must be considered in ENSO forecast models.

Keywords: ENSO, Tropical Cyclone, Interaction

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG45] Multi-scale ocean-atmosphere interaction in the tropical Indo-Pacific region

convener:Yu Kosaka(Research Center for Advanced Science and Technology, University of Tokyo), Sang-Wook Yeh(Hanyang University), Takanori Horii(Research and Development Center for Global Change (RCGC), Strategic Research and Development Area, Japan Agency for Marine-Earth Science and Technology (JAMSTEC)), Hiroki Tokinaga(Disaster Prevention Research Institute, Kyoto University)

Tropical Indo-Pacific Oceans are home to ocean-atmosphere interaction on a broad range of spatio-temporal scales. Teleconnections induced by the tropical Indo-Pacific variability exert a significant imprint on global climate. Since the 1980s, in-situ and satellite observations, reanalysis products, and advancements in climate modeling have led to depicting various aspects of intraseasonal (e.g., MJO), interannual (e.g., ENSO and IOD) and decadal (e.g., IPO) variability in the tropical Indo-Pacific Oceans and their impacts on tropical (e.g., monsoons) and extratropical (e.g., storm track) climate. Newer studies find an active role of salinity in ocean-atmosphere interaction in the tropical Indian Ocean. Other recent studies highlight the inter-basin coupling between the tropical Pacific and the Indian Ocean in seasonal prediction of the Asian summer monsoon and decadal redistribution of ocean heat content associated with the so-called "hiatus" of global warming. Long term change in the Pacific Walker circulation has been recapturing attention in terms of the pattern effect of warming on climate feedback and sensitivity against radiative forcing as well as ENSO modulations under a warmer climate. A variety of processes are mutually interrelated and shape the climate, its variability, and change. To examine these challenging issues from various perspectives and foster understanding of the role of tropical air-sea interaction in the climate system, this session offers a forum to discuss recent progress in observational, modeling and theoretical studies of multi-scale tropical ocean-atmosphere interaction in the tropical Indo-Pacific Oceans.

[ACG45-07] Marginal sea surface temperature variation as a pre-cursor of heat waves over the Korean Peninsula

★Invited Papers

*Yoo-Geun Ham[1] (1.Department of Oceanography, Chonnam National University)

[ACG45-08] Rethinking the ENSO–monsoon relationship in light of trans-basin interactions

★Invited Papers

*Yuhei Takaya[1], Yu Kosaka[2], Masahiro Watanabe[3], Shuhei Maeda[1], Naoaki Saito[1], Ichiro Ishikawa[1] (1.Meteorological Research Institute, 2.Research Center for Advanced Science and Technology, University of Tokyo, 3.Atmosphere and Ocean Research Institute, University of Tokyo)

[ACG45-09] Indo-Pacific Climate Modes in Warming Climate: Consensus and Uncertainty Across Model Projections

*Xiao-Tong Zheng[1] (1.Ocean University of China)

[ACG45-10] Understanding the mechanisms associated with an unstable relationship between Pacific Decadal Oscillation and Indian Ocean Basin mode

*Sang-Wook Yeh[1] (1.Hanyang University)

[ACG45-11] Observed cross-basin interaction of decadal climate variability over the Indo-Pacific region

*Yuma Miyaji[1], Youichi Tanimoto[2] (1.Hokkaido University, Graduate School of Environmental Science, 2.Hokkaido University, Faculty of Environmental Earth Science)

[ACG45-12] Origin of Equatorial Pacific Decadal Variability: Thermodynamic or Dynamic Coupling?

*Yu Zhang[1,2], Shang-Ping Xie[3], Dillon J. Amaya[4,5], Qihua Peng[6], Yu Kosaka[7], Xiaopei Lin[1,2], Jun-Chao Yang[1,2], Sarah M. Larson[8], Arthur J. Miller[3] (1.Physical Oceanography Laboratory, Ocean University of China, 2.Qingdao National Laboratory for Marine Science and Technology, 3.Scripps Institution of

Oceanography, University of California San Diego, 4.Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, 5.Department of Atmospheric and Oceanic Sciences, University of Colorado Boulder, 6.State Key Laboratory of Tropical Oceanography, South China Sea Institute of Oceanology, Chinese Academy of Sciences, 7.Research Center for Advanced Science and Technology, The University of Tokyo, 8.Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University)

Marginal sea surface temperature variation as a pre-cursor of heat waves over the Korean Peninsula

*Yoo-Geun Ham[1]

1. Department of Oceanography, Chonnam National University

This study examines the role of the marginal sea surface temperature (SST) on heat waves over Korea. It is found that sea surface warming in the south sea of Korea/Japan (122-138˚E, 24-33˚N) causes heat waves after about a week. Due to the frictional force, the positive geopotential height anomalies associated with the south sea warming induce divergent flows over the boundary layer. This divergent flow induces the southerly in Korea, which leads to a positive temperature advection. On the other hand, over the free-atmosphere, the geostrophic wind around high-pressure anomalies flows in a westerly direction over Korea during the south sea warming, which is not effective in temperature advection. Therefore, the positive temperature advection in Korea due to the south sea warming decreases with height. This reduces the vertical potential temperature gradient, which indicates a negative potential vorticity (PV) tendency over Korea. Therefore, the high-pressure anomaly over the south sea of Korea is propagated northward, which results in heat waves due to more incoming solar radiation.

Keywords: North Pacific SST variability, Heatwave over the East Asia, Seasonal prediction

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Rethinking the ENSO–monsoon relationship in light of trans-basin interactions

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The Asian summer monsoon interacts with the tropical oceans through various processes. Relations between the El Niño–Southern Oscillation (ENSO) in the equatorial Pacific and the Asian summer monsoon has been a major topic for the Asian monsoon study. Prior studies found that the association between the seasonal prediction skill and reproducibility of ENSO–monsoon relationship in climate models. However, its complete mechanisms including its pathways, decadal modulations and statistical robustness, are still unclear. Recently, a broader concept of the trans-basin interactions across global tropical oceans including the Atlantic has been put forward by Cai et al (2019). Based on the recent understanding, we recognize that the ENSO–monsoon relationship requires reconsideration in light of the trans-basin interactions among the tropical Pacific, Indian Ocean and Atlantic. The present study analyzes ensemble hindcast experiments with the latest seasonal prediction system at the Japan Meteorological Agency, JMA/MRI-CPS2, to investigate the ENSO–monsoon relationship and seasonal predictability through the trans-basin interactions. The ensemble simulations initialized with observed conditions provide us with another tool, in addition to historical observations and pacemaker experiments, to examine the trans-basin interaction processes and resultant predictability. The model reproduces the trans-basin interactions generally well. Results present marked variability of the Indo-western Pacific Ocean Capacitor (IPOC) mode and its pervasive influence over the Asian monsoon, giving much longer predictability than previously thought. The model captures the multiple interactions between the interannual variability in the tropical Indian Ocean, Pacific and Atlantic. A better representation of the interannual trans-basin interaction is the key to success of the extended long-range climate prediction of the Asian summer monsoon.

Keywords: trans-basin interaction, seasonal prediction, monsoon, ENSO

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Indo-Pacific Climate Modes in Warming Climate: Consensus and Uncertainty Across Model Projections

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Understanding the changes in climate variability in a warming climate is crucial for reliable projections of future climate change. In this talk, we show the recent progress in studies of how climate modes in the Indo-Pacific respond to greenhouse warming, including the consensus and uncertainty across climate models. Recent studies revealed a range of robust changes in the properties of climate modes, often associated with the mean state changes in the tropical Indo-Pacific. In particular, the intermodel diversity in the ocean warming pattern is a prominent source of uncertainty in mode changes. The internal variability also plays an important role in projected changes in climate modes. Model biases and intermodel variability remain major challenges for reducing uncertainty in projecting climate mode changes in warming climate. Improved models and research linking simulated present-day climate and future changes are essential for reliable projections of climate mode changes. In addition, large ensembles should be used for each model to reduce the uncertainty from internal variability and isolate the forced response to global warming.

Keywords: ENSO, Indian Ocean Dipole, Indo-western Pacific Oceanic Capacitor, Global Warming, Internal Variability, Uncertainty in model projections

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Understanding the mechanisms associated with an unstable relationship between Pacific Decadal Oscillation and Indian Ocean Basin mode

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1. Hanyang University

It is known that a low frequency variability of sea surface temperature in the Pacific and Indian Ocean, i.e., Pacific Decadal Oscillation (PDO) and Indian Ocean Basin Mode (IOBM) not only affects a local marine ecosystem but also influences weather and climate in the globe via atmospheric teleconnections. In addition, the PDO and IOBM interacts with each other. While many previous studies have discussed the interaction between PDO and IOBM, it is still useful to understand the relationship of PDO and IOBM. To examine this, we analyzed the observational datasets and pacemaker experiments using the Nanjing University of Information Science and Technology Earth System Model version 3 (NESM.v3). A low frequency running correlation between PDO and IOBM indies shows that the relationship of PDO and IOBM is not stable on the low frequency timescales. We found that the PDO structure during each decade is quite different, which subsequently leads to a different response of temperature and precipitation in the globe. By conducting pacemaker experiments, we found that a non-stationary relationship of PDO-IOBM is mainly due to a negative phase of PDO in recent decades.

Keywords: PDO, IOBM, Unstable relationship

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Observed cross-basin interaction of decadal climate variability over the Indo-Pacific region

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We investigate remote effects of the decadal sea surface temperature (SST) variability over the tropical Pacific onto the thermal structure of the surface layers over the Indian Ocean. To extract the internal variability from the observed records, we employed the multi-model ensemble data of Coupled Model Intercomparison Project 5 (CMIP5) to evaluate the externally forced component contained in the observations.

An SST warming trend in recent decades is quite pronounced in the Indian Ocean than in the other tropical basins. Therefore, the SST warming trend and the decadal SST variability over the Indian Ocean have comparable variances and mixed in the observed records. While the previous studies attempted to obtain the cross-basin relationship of the decadal SST variability between over the Pacific and over the Indian Ocean, those results depend on the separating treatment of the internal variability and the externally forced component. Here, we present a new method to estimate the externally forced component in the observations by using multi-model ensemble mean of global mean surface temperatures from the CMIP5 historical simulations. Our analysis onto the extracted internal variability in the observed records shows positive correlation of decadal temperature anomalies over the Indian Ocean surface layers and the SST anomalies over the tropical Pacific. Intensification (weakened) of the wind-driven ocean circulation over the Indian Ocean has a significant contribution in forming positive (negative) temperature anomalies of surface layers. The enhanced (reduced) surface winds over the Indian Ocean are induced by the modified Walker Circulation associated with the positive (negative) SST anomalies over the tropical Pacific. This ocean advection effect on SST overwhelms the damping effect of surface heat flux on local SST. Thus, the internal variability extracted by this method shows the single coherent ocean-atmosphere interaction over the Indo–Pacific region all through the analyzed period.

Keywords: Air-sea interction, Decadal variability, Global warming

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Origin of Equatorial Pacific Decadal Variability: Thermodynamic or Dynamic Coupling?

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In the equatorial Pacific, the El Niño-Southern Oscillation (ENSO) is the dominant mode of ocean-atmosphere coupled variability on interannual timescales. Additionally, the equatorial Pacific also exhibits significant decadal variability (EPDV hereafter). While it is well known that ENSO originates from air-sea coupling and wind-driven ocean dynamics, the origins of EPDV are still under debate. Several studies suggest that EPDV is similar to ENSO in that it originates from ocean-atmosphere dynamical coupling but is associated with lower frequency ocean dynamics. Other studies based on slab ocean model simulations suggest that EPDV is primarily driven by air-sea thermodynamic coupling independent of ocean dynamics. Here we test these hypotheses and demonstrate that EPDV originates from the dynamical coupling. We conduct a novel coupled model experiment, named Clim-τ, in which wind stress to the ocean is fixed to its climatology over the tropical Pacific. The simulation is thus free of anomalous wind-driven ocean dynamics but includes air-sea thermodynamic coupling and the effect of mean ocean circulation on ocean temperature anomalies, the latter of which is missing in slab ocean models. The Clim-τ experiment fills the gap between slab ocean models and fully coupled dynamical ocean models, allowing investigation of the origin of EPDV step by step. We find that the amplitude of EPDV is significantly reduced in Clim-τ compared to slab ocean models due to damping by the central-eastern equatorial climatological upwelling. In fully coupled models, EPDV re-emerges, suggesting an amplification through interactive ocean dynamics driven by anomalous wind stress. Additionally, anomalous surface net heat flux plays an important role in damping EPDV. With dynamical damping due to mean upwelling, EPDV is only attributed to air-sea dynamical coupling along with interactive ocean dynamics. We also find that the ocean dynamics for EPDV is distinct from ENSO in the eastern equatorial Pacific, the former of which shows much weaker zonal advection feedback and thermocline feedback. This difference implies timescale-dependent ocean dynamics in the eastern equatorial Pacific, which partly depends on the frequency of zonal wind stress forcing over the central equatorial Pacific as simulated in a shallow water model. Our study demonstrates that although results from slab ocean models are comparable to the fully coupled models, they might be misleading in the strong climatological upwelling regions where upper ocean temperature will be further influenced by dynamical damping. Our results may contribute to improving the long-term predictability of the equatorial Pacific coupled system.

Keywords: equatorial Pacific decadal variability, El Niño-Southern Oscillation, air-sea dynamic coupling, air-sea thermodynamic coupling, equatorial upwelling

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG47] Global Carbon Cycle Observation and Analysis

convener:Kazuhito Ichii(Chiba University), Prabir Patra(Research Institute for Global Change, JAMSTEC), Forrest M. Hoffman(Oak Ridge National Laboratory), Makoto Saito(National Institute of Environmental Studies)

The Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC) is a landmark agreement, which aims at reduction of greenhouse gases (GHGs) emission to keep the global warming below 2 degC. The national commitments and progress should be carefully monitored and verified by international bodies using different but complementary methodologies.

In recent years, many observations and techniques to monitor GHGs budget have expanded. The improvements include observational platforms for monitoring atmospheric GHGs, national or regional emission inventories, top-down models (e.g. atmospheric inverse models), and bottom-up models (e.g. process-based models). However, due to uncertainties in modeling and sparse observation networks, large uncertainties exist in GHG sources/sinks estimations at global and regional scales. These uncertainties lead to large variations in future projections of GHG budgets and climate changes.

The purpose of the session is to discuss state-of-the-art techniques for estimation of GHG (e.g. CO2, CH4, N2O) budgets at global and regional scales. The topic includes natural and anthropogenic processes, various methodologies (e.g. in-situ observation, aircraft monitoring, remote sensing, modeling), and various targets (e.g. atmosphere, terrestrial, and ocean), various spatial and temporal coverage (e.g. regional to global scales and past-present-future). Improved estimates of emissions from land use change, forest fires, and other anthropogenic sources (urban developments and thermal power station etc.) are also of interest. We also welcome discussions for designs and plans for future studies targeting urban and rural scale emission estimations using sophisticated modeling tools and inventories.

[ACG47-01] Relative contributions of different methane emission categories in the continental East Asia inferred from stable carbon isotope measurements at Hateruma Station

★Invited Papers

*Taku Umezawa[1], Takuya Saito[1], Yasunori Tohjima[1], Yukio Terao[1], Akihiko Ito[1] (1.National Institute of Environmental Studies)

[ACG47-02] **Process analysis of GHGs seasonal variabilty in the UT/LS region on account of emissions, dynamics and atmospheric chemistry**

*Jagat Bisht[1], Prabir Patra[1,2], Naveen Chandra[1], Toshinobu Machida[3], Naoko Saitoh[2] (1.Research Institute for Global Change (RIGC), JAMSTEC, Yokohama, 236-0001, Japan, 2.Center for Environmental Remote Sensing, Chiba University, Chiba, 263-8522, Japan, 3.CGER, National Institute for Environmental Studies, Tsukuba, Japan)

[ACG47-03] An observation-based synthetic reconstruction of surface ocean inorganic carbon variables

*Yosuke Iida[1,2], Yusuke Takatani[1], Atsushi Kojima[1], Takashi Nakamura[1,2], Masao Ishii[2,1] (1.Japan Meterological Agency, 2.Meteorological Research Institute)

[ACG47-04] Decoupling of projected oceanic uptake of carbon and heat in the 21st century in a high carbon emission pathway

*Eric Mortenson[1], Andrew Lenton[1,2,3], Tom Trull[1,2], Elizabeth Shadwick[1,2,3], Xuebin Zhang[1,3], Matt Chamberlain[1] (1.Commonwealth Scientific and Industrial Research Organization, Australia, 2.Australian Antarctic Program Partnership, 3.The Centre for Southern Hemisphere Oceans Research)

[ACG47-05] **Utility of total column CO_2 observations by satellites and atmospheric CO_2 inversion for evaluating carbon cycle processes in the Earth System Models**

*Prabir Patra[1,2], Tomohiro Hajima[1], Ryu Saito[3], Naveen Chandra[1], Yukio Yoshida[4], Michio Kawamiya[1], Masayuki Kondo[2], Kazuhito Ichii[2], Akihiko Ito[4], Dave Crisp[5] (1.Research Institute for Global Change,

JAMSTEC, 2.Center for Environmental Remote Sensing, Chiba University, Chiba 263-8522, Japan, 3.Disaster Risk Reduction and Environ. SBU, Kokusai Kogyo Co., Ltd., Tokyo, 183-0057, Japan, 4.Center for Global Environmental Research, NIES, Tsukuba, 305-8506, Japan, 5.NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA)

[ACG47-06] Diagnosing Climate–Carbon Cycle Feedbacks Constrained by ILAMB

*Forrest M. Hoffman[1,2], Nathan Collier[1], Mingquan Mu[3], Cheng-En Yang[2], Gretchen Keppel-Aleks[4], David M. Lawrence[5], Charles D. Koven[6], William J. Riley[6], James T. Randerson[3] (1.Oak Ridge National Laboratory, 2.University of Tennessee Knoxville, 3.University of California Irvine, 4.University of Michigan, 5.National Center for Atmospheric Research, 6.Lawrence Berkeley National Laboratory)

Relative contributions of different methane emission categories in the continental East Asia inferred from stable carbon isotope measurements at Hateruma Station

*Taku Umezawa[1], Takuya Saito[1], Yasunori Tohjima[1], Yukio Terao[1], Akihiko Ito[1]

1. National Institute of Environmental Studies

Methane (CH_4) is a radiatively and chemically important atmospheric trace gas. Accurate understanding of its global, regional and national-scale budgets is needed for efficient mitigation actions against climate change under the Paris Agreement. To better understand distribution and magnitude of individual CH_4 emission sectors in East Asia, we started measurements of stable carbon isotope ratio ($\delta^{13}C$) of atmospheric CH_4 at Hateruma Station, Japan, using a new cryogen-free measurement system (Umezawa et al. 2020). Wintertime atmospheric CH_4 variations at Hateruma Island, located ~220 km east of Taiwan, is characterized by frequent increases due to advection of air mass from the continental East Asia (Tohjima et al. 2014). During winter of 2017 to 2019, we collected series of air samples during 15 high-CH_4 events and analyzed them for $\delta^{13}C$. By using relationship between CH_4 concentration and $\delta^{13}C$, $\delta^{13}C$ signatures contributing to these high-CH_4 events were estimated, which ranged from −57.9 to −37.8 ‰. These values are considered to be result of CH_4 source mixture of different emission sectors in northeastern China, the region which our footprint calculation mainly point to for such high-CH_4 events. Combining FLEXPART-based footprint (http://db.cger.nies.go.jp/metex/flexcpp.html) and CH_4 emission map (Ito et al. 2019), we examined contributions of different CH_4 emission sectors on the high-CH_4 events and possible corresponding variations in $\delta^{13}C$. The comparison showed that the source $\delta^{13}C$ signatures estimated by observations were in most cases higher than those estimated by simulations. One possible explanation is underestimate of relative contribution of fossil fuel sectors in the simulation. More number of $\delta^{13}C$ data and more detailed information on $\delta^{13}C$ signatures of individual CH_4 source sectors are needed for better evaluation of CH_4 emission databases.

Umezawa et al. (2020) A cryogen-free automated measurement system of stable carbon isotope ratio of atmospheric methane, Journal of the Meteorological Society of Japan, https://doi.org/10.2151/jmsj.2020-007.

Tohjima et al. (2014) Temporal changes in the emissions of CH_4 and CO from China estimated from CH_4 /CO_2 and CO/CO_2 correlations observed at Hateruma Island, Atmos. Chem. Phys., https://doi.org/10.5194/acp-14-1663-2014.

Ito et al. (2019) Methane budget of East Asia, 1990–2015: A bottom-up evaluation, Science of the Total Environment, https://doi.org/10.1016/j.scitotenv.2019.04.263.

Keywords: methane, isotope, East Asia

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Process analysis of GHGs seasonal variabilty in the UT/LS region on account of emissions, dynamics and atmospheric chemistry

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The seasonal variability of four important greenhouse-gases (GHGs): carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and sulphur hexafluoride (SF_6), has been studied in the upper troposphere and lower stratosphere (UT/LS) region. The dynamical and chemical processes involved in distribution of the long-lived GHGs are elucidated using MIROC4 (Model for Interdisciplinary Research On Climate Earth System Model version 4) atmospheric chemistry transport model (ACTM) and CONTRAIL (Comprehensive Observation Network for Trace gases by AIrLiner) aircraft observations. The GHGs concentration has been analysed over western pacific in multiple latitude bands (between equator and 30°N) and over the Eurasian continent (50°N-70°N). The observed seasonality in GHGs at different latitude and longitude bands have been discussed comprehensively by emphasising the role of emissions, dynamics, and atmospheric chemistry with the help of MIROC4-ACTM. For an example, we be able to distinguish the predominant role of OH chemistry in the CH_4 seasonal cycle in the tropical low latitude bands in upper troposphere, while, over high latitude the role of both OH loss and emission prevailed. Further, the dynamical components associated with GHGs seasonality has been studied by segregating the contribution from convection and advection tendencies as modelled in the ACTM. The zonally averaged transect of age of air and GHGs simulations from MIROC4-ACTM make it easier to explain the GHGs variability in the lower troposphere (Figure 1).

Figure 1: Zonal averaged age of air (AoA) from MIROC4-ACTM for (a) January 2014; arrow indicates the fast-downward movement of stratospheric air due to deeper branch of Brewer-Dobson circulation and (b) July 2014; arrow indicates diffusion of air with younger age towards extratropical tropopause by the swallower branch of Brewer-Dobson circulation. The zonal averaged CH_4 concentration has been also shown for (c) CH_4 January 2014 (d) CH_4 July 2014. The black and white asterisk indicate the approximate altitude at $\Delta\Theta > 50.0$K and $\Delta\Theta = 37.5 - 50.0$K respectively.

Keywords: GHGs, CONTRAIL, MIROC4-ACTM

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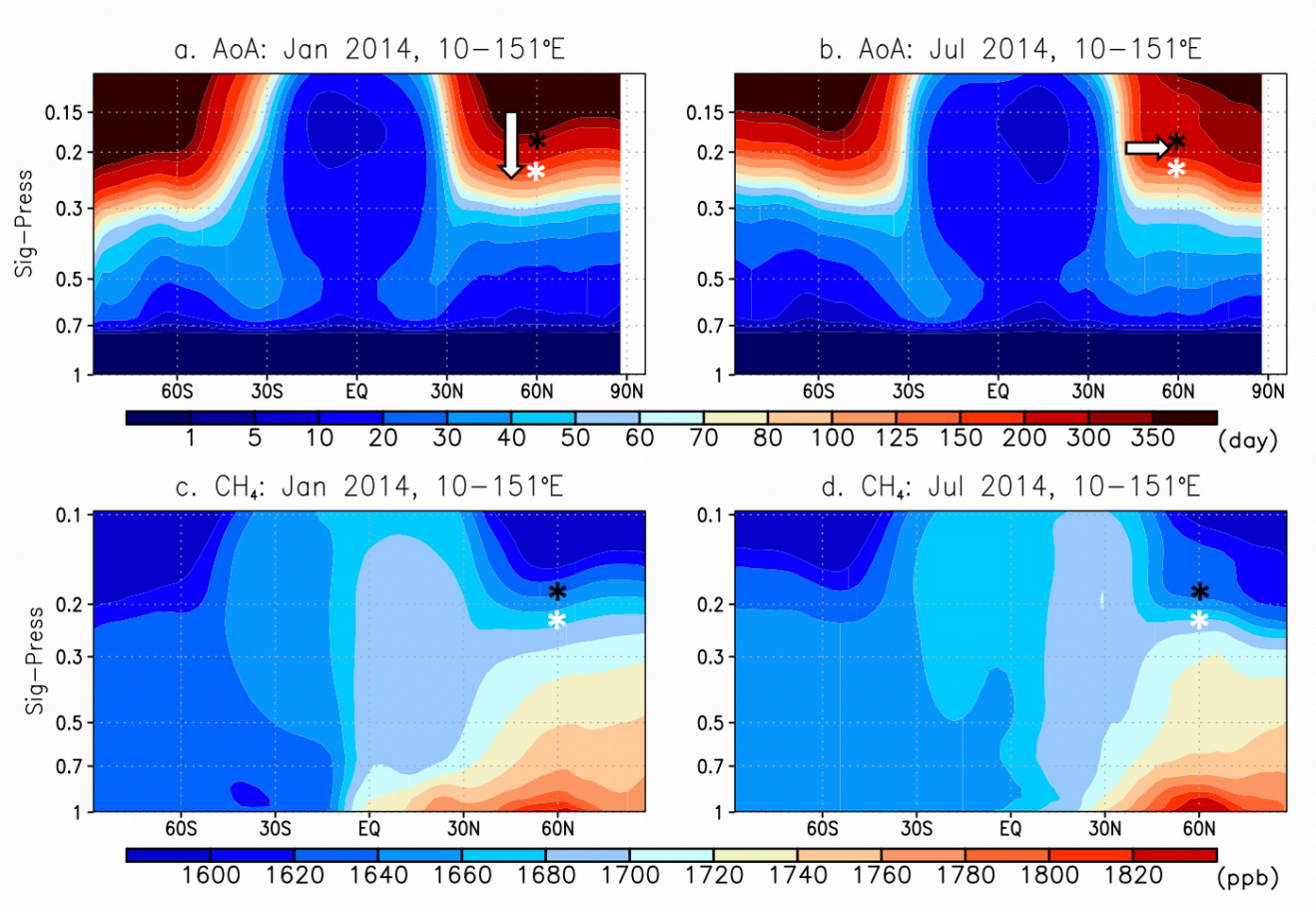

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An observation-based synthetic reconstruction of surface ocean inorganic carbon variables

*Yosuke Iida[1,2], Yusuke Takatani[1], Atsushi Kojima[1], Takashi Nakamura[1,2], Masao Ishii[2,1]

1. Japan Meterological Agency, 2. Meteorological Research Institute

Ocean acidification is an issue of great concern for the global carbon cycle and has adverse impacts on marine ecosystem and socioeconomical activities such as fisheries and tourism industries. In order to project the ocean acidification as well as the carbon-climate feedback with high confidence, it is critical to understand the current status, variability and trends of ocean inorganic carbon variables and carbon sink. However, oceanographic observations have been conducted sparsely in time and space, and it is still needed to reconstruct carbon system variables in global scale from spatiotemporally limited observations in spite of the recent increase in observations of those variables. We made synthetic reconstructions of surface ocean total alkalinity (TA) and dissolved inorganic carbon (DIC) by monthly 1°×1° grid for the period from 1993 to 2018 based on measurements of CO_2 partial pressure in surface seawaters (pCO_2 sea) and TA by using a multiple linear regression approach. The gridded data of DIC and TA were converted to pCO_2sea, pH and aragonite saturation state according to seawater carbonate chemistry, and sea-air CO_2 flux in combination with atmospheric CO_2 and wind speed. The estimated mean annual ocean CO_2 uptake and its trend of increase were 2.0±0.5 PgC/year and 0.3±0.1 (PgC/year)/decade, respectively, showing significant decadal variability of decrease of sink in 1990s and increase after 2000. The globally averaged pH trend was estimated to be -0.0181±0.0001/decade, which is consistent with atmospheric CO_2 growth. The gridded data of sea-air CO_2 flux analyzed in this study can be used as a prior ocean flux in atmospheric inversion analysis, and the global pH could help verifying the indicator for sustainable development goals SDG 14.3.

Keywords: oceanic carbon sink, ocean acidification, SDGs

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Decoupling of projected oceanic uptake of carbon and heat in the 21st century in a high carbon emission pathway

*Eric Mortenson[1], Andrew Lenton[1,2,3], Tom Trull[1,2], Elizabeth Shadwick[1,2,3], Xuebin Zhang[1,3], Matt Chamberlain[1]

1. Commonwealth Scientific and Industrial Research Organization, Australia, 2. Australian Antarctic Program Partnership, 3. The Centre for Southern Hemisphere Oceans Research

The global oceans have been a major sink of anthropogenic CO_2 and heat since the preindustrial era, thereby slowing the increase in atmospheric carbon and heat content. At the same time, the uptake of heat and carbon affect the marine environment through changes to the chemistry and temperature of the oceans. While air-sea exchange of both carbon and heat are dependent on similar mechanisms (e.g., air-sea gradients and wind speed), with the general pattern of net storage showing agreement, there is the potential for a divergence due to mechanisms that do not affect both properties (e.g. chemical buffering capacity, temperature-mediated solubility of carbon, andthe role of humidity in heat exchange). This study addresses the question of when, where, and by how much will the pathways for oceanic uptake of heat and carbon diverge in the “Business-as-Usual” (RCP8.5) scenario of atmospheric CO_2changes over the 21st century via the Ocean Forecasting Australia Model with an eddy-resolving horizontal resolution (0.1˚). This higher resolution is employed, rather than conventional 1-degree CMIP-style models, as eddies have the potential to contribute substantially to mixing in the ocean. The simulation projects that 21st century cumulative uptake of anthropogenic carbon and heat will be three and ten times higher, respectively, than estimates for the period 1870-1995, with a net storage of carbon of 350 petagrams carbon and heat of $2*10^{24}$ joules in the upper 2000 m of the global ocean. The simulation projects that the carbon uptake rate of the ocean will level off, to between 4 and 4.5 petagrams of carbon per year, by the last quarter of the century, whereas the rate of increase of ocean heat content will continue to rise. Regional analysis indicates that the Southern Ocean south of 40˚ S will remain the major hotspot for both heat and carbon uptake throughout the century. In general, polar oceans experience most of the uptake, and subtropical oceans (between 10 and 40˚ latitude, N and S) experience most of the change in inventory for both anthropogenic heat and carbon. Regional trajectories of uptake and storage indicate a decoupling of the uptake and transport processes involved for heat and carbon, respectively. Further analysis of the differences between heat and carbon properties will be discussed. Understanding the distinct trajectories of heat and carbon uptake is essential to projecting their impacts on the marine environment and their feedbacks to climate.

Keywords: Ocean model, Biogeochemistry, Ocean uptake of carbon and heat

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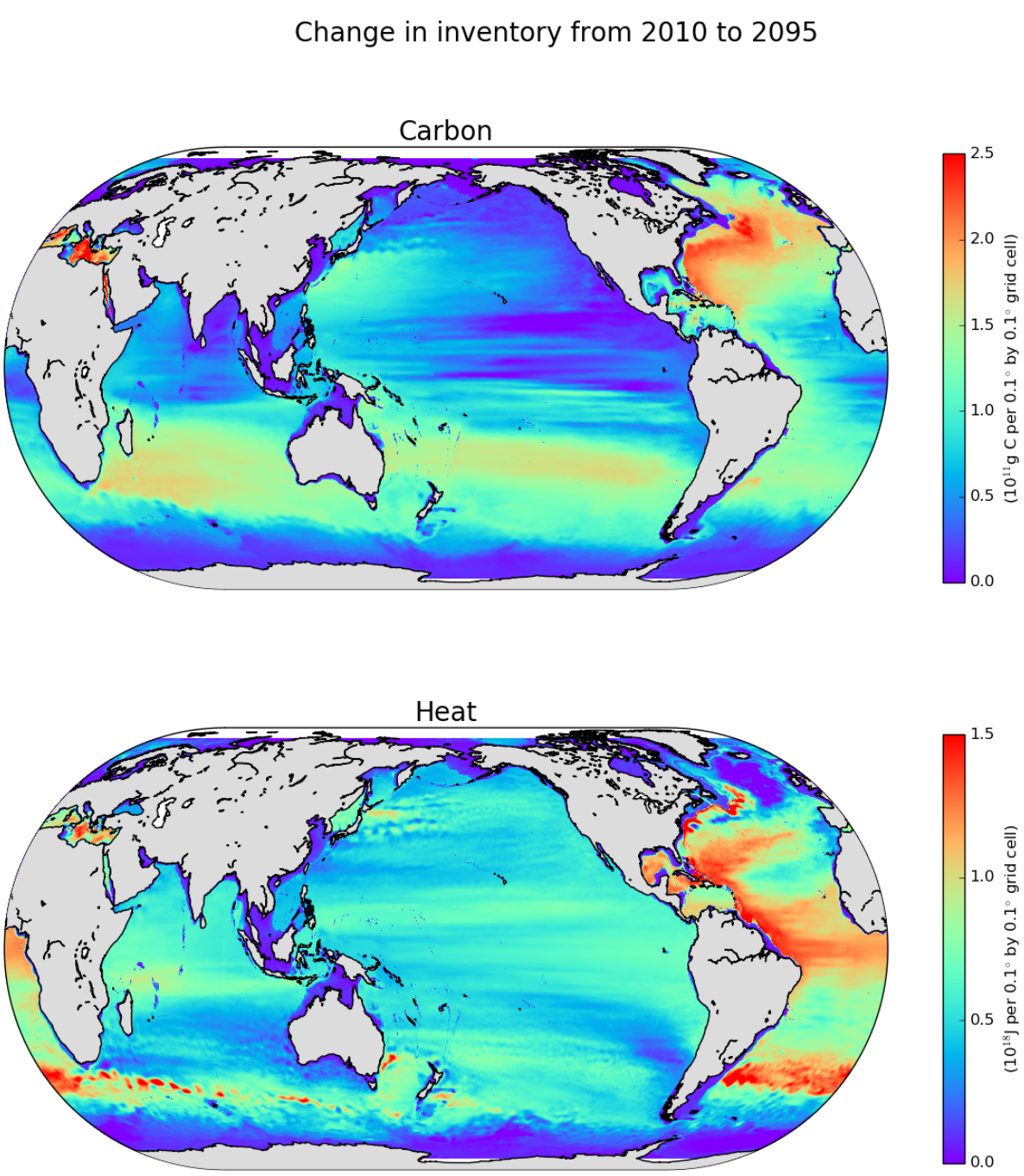

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Utility of total column CO_2 observations by satellites and atmospheric CO_2 inversion for evaluating carbon cycle processes in the Earth System Models

*Prabir Patra[1,2], Tomohiro Hajima[1], Ryu Saito[3], Naveen Chandra[1], Yukio Yoshida[4], Michio Kawamiya[1], Masayuki Kondo[2], Kazuhito Ichii[2], Akihiko Ito[4], Dave Crisp[5]

1. Research Institute for Global Change, JAMSTEC, 2. Center for Environmental Remote Sensing, Chiba University, Chiba 263-8522, Japan, 3. Disaster Risk Reduction and Environ. SBU, Kokusai Kogyo Co., Ltd., Tokyo, 183-0057, Japan, 4. Center for Global Environmental Research, NIES, Tsukuba, 305-8506, Japan, 5. NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA

The measurements of one of the major greenhouse gases, carbon dioxide (CO_2), are being made using dedicated satellite remote sensing since the launch of the greenhouse gases observing satellite (GOSAT) by JAXA in 2009. The Thermal And Near infrared Sensor for carbon Observation Fourier Transform Spectrometer (TANSO-FTS) onboard GOSAT has now acquired more than 10 years of total column-averaged CO_2 concentrations (XCO_2) from space covering almost all parts of the globe in all seasons. In the past 10 years, the models for estimation of CO_2 fluxes from land and ocean using the earth system models (ESMs) and inverse modelling of in situ atmospheric CO_2 data have made significant progress. In this article, we attempt, for the first time, to evaluate the CO_2 fluxes simulated by an earth system model (MIROC-ES2L) using GOSAT observations and the fluxes estimated by an inverse model (MIROC4-Inv) for the period 2009-2014. Further, we use the OCO-2 (NASA’s Orbiting Carbon Observatory-2) measurements for testing the consistency of inversion results for the period 2014-2018, along with the GOSAT data. Both MIROC-ES2L and MIROC4-Inv fluxes are used in the MIROC4-atmospheric chemistry transport model (referred to as ACTM_ES2LF and ACTM_InvF, respectively) for calculating CO_2 concentrations that are sampled at the time and location of the satellite measurements. Our results suggest the inverse model using in situ data are more consistent with the OCO-2 retrievals, compared to those of the GOSAT XCO_2 data, suggesting possible improvements in the present GOSAT retrieval system by better accounting for the degradation correction of the TANSO-FTS. The ACTM_ES2LF simulation shows a slightly weaker seasonal cycle for the meridional profiles of CO_2 fluxes, compared to that from the ACTM_InvF. This difference is revealed by greater ACTM_ES2LF vs GOSAT differences, compared to those of ACTM_InvF vs GOSAT. We also find that the simulated seasonal cycle amplitude of XCO_2 by ACTM_ES2LF are slightly weaker compared to those observed by GOSAT or ACTM_InvF. Our results clearly suggest the usefulness of XCO_2 measurements by satellite remote sensing for evaluation of large-scale ESMs, which so far remained untested by the sparse in situ data.

Keywords: Atmospheric CO2 inversion, Earth System Models, Satellite remote sensing of CO2

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Diagnosing Climate–Carbon Cycle Feedbacks Constrained by ILAMB

*Forrest M. Hoffman[1,2], Nathan Collier[1], Mingquan Mu[3], Cheng-En Yang[2], Gretchen Keppel-Aleks[4], David M. Lawrence[5], Charles D. Koven[6], William J. Riley[6], James T. Randerson[3]

1. Oak Ridge National Laboratory, 2. University of Tennessee Knoxville, 3. University of California Irvine, 4. University of Michigan, 5. National Center for Atmospheric Research, 6. Lawrence Berkeley National Laboratory

Better representation of biogeochemistry–climate feedbacks and ecosystem processes in Earth system models (ESMs) are essential for reducing uncertainties associated with projections of climate change during the remainder of the 21st century and beyond. Model–data intercomparison and integration activities are required to inform improvement of land carbon cycle models and the design of new measurement campaigns aimed at reducing uncertainties associated with key land surface processes. The International Land Model Benchmarking (ILAMB) Package was designed to facilitate systematic and comprehensive model–data intercomparison and improve understanding of factors influencing model fidelity. We used ILAMB to benchmark and intercompare terrestrial carbon cycle models coupled within ESMs used to conduct historical simulations for the Fifth and Sixth Phases of the Coupled Model Intercomparison Project (CMIP5 and CMIP6). Results indicate that the suite of CMIP6 land models exhibits better performance than the suite of CMIP5 land models in comparison with observations for a variety of biogeochemical, hydrological, and energy-related variables. To test the hypothesis that the multi-model range of climate–carbon cycle feedback strengths from more realistic models would diverge less over time, we calculated and compared the ranges of concentration–carbon and climate–carbon sensitivity parameters and the trajectories of land carbon uptake from CMIP5 and CMIP6 models. Since the multi-model means of both the CMIP5 and CMIP6 land models performed better across most variables than any single model that contributed to the means, we also calculated the CMIP5 and CMIP6 multi-model mean feedback sensitivities and uptake trajectories. In an attempt to further reduce uncertainties in carbon cycle projections, we used the ILAMB benchmark performance scores to weight model contributions to the CMIP5 and CMIP6 multi-model means for land carbon uptake and related variables and compared them with observationally constrained estimates for the historical period.

Keywords: land surface model, carbon cycle, CMIP6, ILAMB

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG47] Global Carbon Cycle Observation and Analysis

convener:Kazuhito Ichii(Chiba University), Prabir Patra(Research Institute for Global Change, JAMSTEC), Forrest M. Hoffman(Oak Ridge National Laboratory), Makoto Saito(National Institute of Environmental Studies)

The Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC) is a landmark agreement, which aims at reduction of greenhouse gases (GHGs) emission to keep the global warming below 2 degC. The national commitments and progress should be carefully monitored and verified by international bodies using different but complementary methodologies.

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The purpose of the session is to discuss state-of-the-art techniques for estimation of GHG (e.g. CO2, CH4, N2O) budgets at global and regional scales. The topic includes natural and anthropogenic processes, various methodologies (e.g. in-situ observation, aircraft monitoring, remote sensing, modeling), and various targets (e.g. atmosphere, terrestrial, and ocean), various spatial and temporal coverage (e.g. regional to global scales and past-present-future). Improved estimates of emissions from land use change, forest fires, and other anthropogenic sources (urban developments and thermal power station etc.) are also of interest. We also welcome discussions for designs and plans for future studies targeting urban and rural scale emission estimations using sophisticated modeling tools and inventories.

[ACG47-07] On reliable pattern of historical land-use and land-cover change transition in Southeast Asia

★Invited Papers

*Masayuki Kondo[1] (1. Center for Environmental Remote Sensing, Chiba University)

[ACG47-08] Detecting the Borneo ecosystem changes caused by 2015 El Nino events using Satellite SIF data

*Kazutaka Murakami[1], Makoto Saito[1], Hibiki M Noda[1], Haruki Oshio[1], Yukio Yoshida[1], Kazuhito Ichii[2,1] (1.National Institute for Environmental Studies, 2.Chiba University)

[ACG47-09] **Response of tropical terrestrial gross primary production to the super El Niño event in 2015**

*Jiawen Zhu[1], Minghua Zhang[2], Yao Zhang[3], Xiaodong Zeng[1], Xiangming Xiao[4] (1.Institute of Atmospheric Physics, CAS, 2.Stony Brook Univ., 3.Columbia Univ., 4.Univ. of Oklahoma)

[ACG47-10] **Fixed Nonlinear Multiregression Based Spectral Modelling Approach for Predictive Quantification of Biomass and Carbon stocks of Tree Outside Forest areas (TOFs) over Arid zone of Jodhpur, Rajasthan, India**

*SWATI UNIYAL[1], Sitiraju Srinivasa Rao[2], Eadara Amminedu[1] (1.Andhra University,Visakhapatnam,Andhra Pradesh,India, 2.National Remote Sensing Center,Hyderabad,India)

[ACG47-11] Updating data-driven estimation of terrestrial carbon fluxes across Asia

*Kazuhito Ichii[1], Riku Kawase[1], Zhiyan Liu[1] (1.Chiba University)

[ACG47-12] **Regional estimates of CO_2 budget using inverse modelling for the past two decades (1996-2018)**

*Naveen Chandra[1], Prabir Patra[1] (1.Japan Agency for Marine Earth Science and Technology)

On reliable pattern of historical land-use and land-cover change transition in Southeast Asia

*Masayuki Kondo[1]

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Unmanaged deforestation and agricultural land development are considered as one of the factors that accelerate the risk of global warming. Due to persistently active land-use activities for years, Southeast Asia is the region known for the highest rate of forest loss among the global tropics. Recent biogeochemical models have incorporated processes of land-use changes (LUC) so as to be able to simulate effects of the use and development of agricultural and forestry resources on the terrestrial carbon balance. However, complexity of land-use processes hampers to establish the accuracy of model estimates, especially for Southeast Asia.

Southeast Asian LUC emissions by biogeochemical models have drastically changed between before and after the update of land-use and land-cover changes forcing for models (i.e., Land-Use Harmonization: LUH). Before the update, (1) LUC emissions increased from the 1980s to the 1990s, then decreased in the 2000s. After the update, (2) LUC emissions were kept at a low level for the 1980s-1990s, then started increasing in the 2000s and continued to increase towards the recent years. These changes question whether efforts of land-use management strategies in the past decades has been effective, thus deliver different messages to policy makers. Based on results of multiple estimates of LUC emissions including biogeochemical models (the TRENDY series, ver. 2 to ver. 7), statistical approaches (inventories and country statistics), and remote-sensing, this study evaluates how reliable pattern of historical land-use and land-cover change transition in Southeast Asia should be.

Keywords: Land-use change, Southeast Asia, Biogeochemical model

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Detecting the Borneo ecosystem changes caused by 2015 El Nino events using Satellite SIF data

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In the Asian monsoon, there is a high risk that forest fire will increase due to drought frequency increases in the future. El Nino events for 2014-2016 were the largest in recent years and it had a large impact on the tropics, such as significant reduction of precipitation and severe forest fires on Borneo Island in Southeast Asia. Borneo is a very important land for considering biodiversity, ecosystem services, and it has a very large carbon stock.

In recent years, satellite observations of Solar Induced chlorophyll Fluorescence (SIF) has been used to obtain information on photosynthetic production or environmental stress for plants. The temporal changes in the satellite-based SIF can be a good index to evaluate the changes in ecosystem functions. A lot of studies have discussed the relationships between SIF and ecosystem functions on various spatial scales from point to global. Although several studies focused on a regional scale, there is not much the case that detecting directly the regional ecosystem change from the SIF data. Regional scale such as country level research is the optimal scale for human activities that are neither too broad nor too small to see the effects of climate change. In the previous studies, vegetation indicators such as NDVI and EVI have been widely used for such scales. In these days, long-term SIF data, observed by various satellites (GOSAT, GOME-2, etc.) is available. Therefore, satellite-based SIF could be an indicator for observing terrestrial ecosystems.

The purpose of this study is that detecting the impact on 2015 El Nino in Borneo Island by using three satellite SIF (GOSAT, GOME-2, and OCO-2) and, indicating the usefulness of SIF data. We found that the SIF values dropped during El Nino events. The reduction in SIF might be caused by the droughts occurred during this period and increased fires. This trend was indicated particularly in the southern hemisphere of Borneo Island.

Keywords: SIF, Borneo, 2015 El Nino

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Response of tropical terrestrial gross primary production to the super El Niño event in 2015

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The Gross Primary Production (GPP) in tropical terrestrial ecosystems plays a critical role in the global carbon cycle and climate change. The strong 2015–2016 El Niño event offers a unique opportunity to investigate how GPP in the tropical terrestrial ecosystems responds to climatic forcing. This study uses two GPP products and concurrent climate data to investigate the GPP anomalies and their underlying causes. We find that both GPP products show an enhanced GPP in 2015 for the tropical terrestrial ecosystem as a whole relative to the multi-year mean of 2001–2015, and this enhancement is the net result of GPP increase in tropical forests and decrease in non-forests. We show that the increased GPP in tropical forests during the El Nino event is consistent with increased photosynthesis active radiation as a result of a reduction in clouds, while the decreased GPP in non-forests is consistent with increased water stress as a result of a reduction of precipitation and an increase of temperature. These results reveal the strong coupling of ecosystem and climate that is different in forest and non-forest ecosystems, and provide a test case for carbon cycle parameterization and carbon-climate feedback simulation in models.

Keywords: gross primary production, tropical terrestrial ecosystem, El Niño-Southern Oscillation

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Fixed Nonlinear Multiregression Based Spectral Modelling Approach for Predictive Quantification of Biomass and Carbon stocks of Tree Outside Forest areas (TOFs) over Arid zone of Jodhpur, Rajasthan, India

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Quantification of TOFs is very necessary to have a better understanding of their role in continuous purification of the atmosphere by mere absorption of CO2 and the release of oxygen during photosynthesis, considering the large amounts of carbon accumulated per hectare in most TOFs.
This work demonstrates a Multiregression based spectral modelling approach for assessment of carbon uptake by TOFs, first ever for Arid zone i.e. Jodhpur, Rajasthan using Landsat 8 data. Data from 46 plots including Leaf area Index (LAI) and Chlorophyll inventory were surveyed for three different TOFs type (Scattered, Linear, and Plantation) to calculate carbon stocks in their biomass. Stand biomass for each plot was computed from ground inventory using diameter, height, generalized species and interspecies allometric equations.
255 spectral models have been tested using 37 spectral vegetation indices and red, green, NIR, SWIR bands with observed biomass, LAI and Chlorophyll, using nonlinear transformation functions. The best fit models were used for prediction analysis.
For scattered areas Moisture Stress Index(MSI),Soil and Atmospherically Resistant Vegetation Index(SARVI) combined with SQRT and natural log function surprisingly found to be best model ($r2=0.87, p<0.0002$) with predicted biomass in the range of 0.74-188.99t/ha and carbon 0.34-88tC ,for linear areas NIR and SWIR combined with SQRT and natural log function found best model ($r2=0.85, p<0.00004$) with predicted biomass 0.4-122.302t/ha and carbon 0.22-58.09tC, for plantation MSI and SWIR with natural log function found best model ($r2=0.9, p<0.00015$) with predicted biomass 0.18-45.97t/ha and carbon 0.08-21.83tC.For LAI and chlorophyll Green NDVI and red band with logarithmic function found to be best model ($r2=0.8, p<0$).Correlation between LAI and Scattered area found less significant($r2=0.46$) compared to linear and plantations ($r2=0.8$). For the study area Predicted Co2 sequestration noted in the range of 0.25-175.051tCo2.
Observed and predicted values stated a correlation of ($r2=0.8$) indicating this approach to be significant for ToFs carbon stocks estimation and their role for Carbon Sequestration over arid regions. Study indicates that for Arid areas trees can produce economical biomass yields under water stress conditions also.

Keywords: Multi regression, Spectral modelling, Biomass, Tree Outside Forest

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Updating data-driven estimation of terrestrial carbon fluxes across Asia

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Asia, which is characterized by monsoon climate and intense human activities, is one of the prominent understudied regions in terms of terrestrial carbon budgets and mechanisms of carbon exchange. To better understand terrestrial carbon cycle in Asia, data-driven approach, which relies on widely available network observation, provide important and independent datasets. We have been working on data-driven estimations using AsiaFlux observation network and remote sensing datasets (Ichii et al. 2017). In the previous study, we used MODIS Collection 5 datasets as input. However, issues on sensor calibration remains in the datasets (Wang et al. 2012). Therefore, update of MODIS data (from Collection 5 to 6) into our data-driven estimate was urgently required. In this study, we updated our data-driven estimation of terrestrial CO2 fluxes across Asia using MODIS Collection 6 datasets. Since our estimation relies on MODIS datasets, we can evaluate the effects of updating MODIS data on estimated terrestrial CO2 fluxes. We prepared all site-level and spatial inputs with MODIS C6 datasets, and trained and tested the model with updated input dataset. We found that site-level evaluation does not make significant changes between estimations based on MODIS C5 and C6. In addition, spatial patterns of GPP and NEE also did not change significantly. However, interannual variations show very large difference among MODIS version, and estimation with MODIS C6 shows significant increases in GPP across Asia from 2000 to 2019.

Keywords: terrestrial monitoring, Asiaflux, Machine Learning, Remote Sensing

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Regional estimates of CO_2 budget using inverse modelling for the past two decades (1996-2018)

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An improved understanding of the magnitude and location of the CO_2 sources (mainly from fossil fuel emissions) and sink (mainly from biospheric and oceanic uptake) is essential for the predictions of future climate feedback. Atmospheric inverse modelling is a powerful tool to estimate spatio-temporal variation of fluxes from an optimal fit to atmospheric CO_2 measurements.

Monthly CO_2 fluxes are estimated using a Time-Dependent Inverse (TDI) model, measurements from 30 sites across the globe and MIROC4-ACTM forward model for the period of 1996-2018. The inversion fluxes are evaluated in details using the independent CO_2 measurements made onboard aircraft over 74 sites across the globe. The simulations of CO_2 concentrations using inverted fluxes agree within 0.5 ppm at all the aircraft vertical profile sites. The long-term mean land CO_2 fluxes are estimated to the -2.2±0.5, 0.04±0.3 and -0.5±0.2 PgC yr^{-1} in the most recent decade (2009-2018), respectively, for the northern extratropics (NET: 30-90N), tropics (TR: 30S-30N) and southern extratropics (SET: 30-90S). The ocean CO_2 fluxes for the same time period and regions are estimated to be -0.9±0.1, 0.3±0.2 and -1.1±0.1 PgC yr^{-1}, respectively. Considering the fossil fuel emissions and land-oceanic sink, the NET and TR regions act as net sources while SET region acts as a net sink. A large fraction of the interannual variability in global CO_2 flux anomaly originates over the tropical land regions, induced by El-Niño southern oscillation. Sensitivity studies using different observational network suggest that the use of JAL/NIES CONTRAIL aircraft data between Japan and Australia helps us to better constrain the interannual variations in CO_2 fluxes over the Southeast Asia region.

Keywords: Atmospheric inversion, CO2 fluxes, regional scale

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG48] Projection and detection of global environmental change

convener:Michio Kawamiya(Japan Agency for Marine-Earth Science and Technology), Kaoru Tachiiri(Japan Agency for Marine-Earth Science and Technology), Hiroaki Tatebe(Japan Agency for Marine-Earth Science and Technology), V Ramaswamy(NOAA GFDL)

Anthropogenic forcings on global environment are expected to cause intensification of extreme events, sea level rise, ocean acidification and deoxygenation, as well as large-scale ecosystem changes. Earth System modeling groups across the world performed simulations and published projection data toward 6th IPCC assessment report due in 2021. Various new types of studies, such as event attribution and coupling of socio-economic processes and Earth system dynamics, are emerging in the field of global change projections. In addition, observational studies are becoming increasingly more important for grasping changes in the global environment and evaluating model projections. Interactions and collaborations beyond boundaries of conventional scientific disciplines are desired for dealing with the issue of global changes. This session thus aims to deepen our understanding on global change, from both disciplinary and interdisciplinary viewpoints.

[ACG48-01] Exploring physical and biological environmental responses to differing rates of carbon emissions

★Invited Papers

*John P Krasting[1], John P Dunne[1], Jasmin G John[1], Michael Winton[1] (1.NOAA - Geophysical Fluid Dynamics Laboratory)

[ACG48-02] Highlighted results from the latest MIROC-based ESM and activities of TOUGOU-B

*Michio Kawamiya[1], Kaoru Tachiiri[1], Tomohiro Hajima[1], Tokuta Yokohata[2], Junichi Tsutsui[4], Takashi Arakawa[3], Takahiro Inoue[1] (1.Japan Agency for Marine-Earth Science and Technology, 2.National Institute for Environmental Studies, 3.Research Organization for Information Science and Technology, 4.Central Research Institute of Electric Power Industry)

[ACG48-03] Evaluation of carbon cycles in a suite of CMIP6-C^{4}MIP experiments by Meteorological Research Institute Earth System Model version 2.0 (MRI-ESM2.0)

*Hiroyuki Tsujino[1], Atsushi Obata[1], Seiji Yukimoto[1], Masahiro Hosaka[1], Taichu Y Tanaka[1], Toyama Katsuya[1], Tsuyoshi Koshiro[1], Shogo Urakawa[1], Hideyuki Nakano[1] (1.Japan Meteorological Agency / Meteorological Research Institute)

[ACG48-04] Evaluation of terrestrial carbon cycle processes in MIROC-ES2L

*Tomohiro Hajima[1], Akihiko Ito[2], Prabir Patra[1], Kaoru Tachiiri[1], Kazuhito Ichii[3], Manabu Abe[1] (1.Japan Agency for Marine-Earth Science and Technology, 2.National Institute for Environmental Studies, 3.Center for Environmental Remote Sensing, Chiba University)

[ACG48-05] Using UAVs and deep learning techniques to detect invasive species in forests and wetlands

*Sarah Kentsch[1,2], Maximo Larry Lopez Caceres[1], Yago Diez Donoso[1], Jens Gross[3] (1.Yamagata University, 2.United Graduate school of Agriculture Sciences (UGAS), 3.Leibniz University of Hannover)

[ACG48-06] Modeling ocean-ice shelf interaction over the Southern Ocean under RCP8.5 scenario

*Kazuya Kusahara[1], Hiroaki Tatebe[1], Tomohiro Hajima[1], Fuyuki SAITO[1] (1.Japan Agency for Marine-Earth Science and Technology)

Exploring physical and biological environmental responses to differing rates of carbon emissions

*John P Krasting[1], John P Dunne[1], Jasmin G John[1], Michael Winton[1]

1. NOAA - Geophysical Fluid Dynamics Laboratory

Earth System Models (ESMs) that feature a fully-interactive carbon cycle allow for the exploration of interactions and feedbacks between the physical climate and biogeochemical systems as both respond to increasing anthropogenic CO_2 emissions. Here, we highlight past and ongoing research using CMIP5 and CMIP6-generation ESMs developed at NOAA-GFDL that explores the relationships between cumulative carbon emissions and climate sensitivity, sea level rise, and ocean acidification. Our results demonstrate that the rate of carbon emissions plays an important role in dictating the timing, magnitude, and geographic response to forcing in the context of regional sea level rise (SLR) and the Transient Climate Response to cumulative carbon Emissions (TCRE). We also find that under high carbon emission rates, rapid surface ocean acidification in the Arctic Ocean is projected to occur during the 21st century. Using results from idealized CO_2-only forcing scenarios, as well as historical and future climate projections from the Coupled Climate-Carbon Cycle Model Intercomparison Project (C4MIP), we highlight the important physical and biogeochemical controls on these high-impact ocean responses to a warming climate. We explore these features from global and regional perspectives and quantify the role of internal climate system variability with the ultimate goal of reducing the uncertainty in future climate.

Keywords: Earth System Modelling, Carbon Cycle, Projections, TCRE, Feedbacks, Cumulative Emissions

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Highlighted results from the latest MIROC-based ESM and activities of TOUGOU-B

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Team MIROC, consisting of leading climate modeling institutes in Japan, developed a new version of the Model for Interdisciplinary Research on Climate, Earth System for Long-term simulations (MIROC-ES2L), an Earth system model (ESM) using a state-of-the-art climate model as the physical core. This model embeds a terrestrial biogeochemical component with explicit carbon–nitrogen interaction to account for soil nutrient control on plant growth and the land carbon sink. The model’s ocean biogeochemical component is largely updated to simulate biogeochemical cycles of carbon, nitrogen, phosphorus, iron, and oxygen such that oceanic primary productivity can be controlled by multiple nutrient limitations. The ocean nitrogen cycle is coupled with the land component via river discharge processes, and external inputs of iron from atmospheric deposition are considered. Comparison of a historical simulation with observation studies showed the model could reproduce reasonable historical changes in climate, the carbon cycle, and other biogeochemical variables together with reasonable spatial patterns of distribution of the present-day condition. It is our hope that the ESM could help further understanding of climate–biogeochemical interaction mechanisms, projection of future environmental changes, and exploration of our future options regarding sustainable development by evolving the processes of climate, biogeochemistry, and human activities in a holistic and interactive manner.

Keywords: Earth System Model, Climate Change, IPCC, CMIP, Carbon Cycle, Nitrogen Cycle

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Evaluation of carbon cycles in a suite of CMIP6-C^{4}MIP experiments by Meteorological Research Institute Earth System Model version 2.0 (MRI-ESM2.0)

*Hiroyuki Tsujino[1], Atsushi Obata[1], Seiji Yukimoto[1], Masahiro Hosaka[1], Taichu Y Tanaka[1], Toyama Katsuya[1], Tsuyoshi Koshiro[1], Shogo Urakawa[1], Hideyuki Nakano[1]

1. Japan Meteorological Agency / Meteorological Research Institute

Meteorological Research Institute of Japan Meteorological Agency conducted a suite of climate projection experiments to understand response of the coupled climate–carbon cycle system to increasing anthropogenic CO_2 emissions and concentrations by following protocols of the Coupled Climate–Carbon Cycle Model Intercomparison Project (C^{4}MIP) endorsed by the phase 6 of Couple Model Intercomparison Project (CMIP6). This poster will present overall evaluation of the experiments in terms of their carbon cycle by comparing with observations and similar experiments conducted by other climate modeling centers. This gives in effect an evaluation of the biogeochemical components of MRI-ESM2.0. Although the qualitative behaviors of the climate–carbon cycle system are reasonable, the carbon uptake by the land component tends to be larger than other models. This results in the atmospheric CO_2 concentrations in emission-driven experiments lower than those of the corresponding CO_2 concentration scenarios, requiring improvements for the terrestrial carbon-cycle component in a future version of MRI-ESM2.0. The poster will also present comprehensive evaluation of carbon cycle in the ocean component.

Keywords: CMIP6, C4MIP, carbon cycle, earth system model

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Evaluation of terrestrial carbon cycle processes in MIROC-ES2L

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1. Japan Agency for Marine-Earth Science and Technology, 2. National Institute for Environmental Studies, 3. Center for Environmental Remote Sensing, Chiba University

Future climate projection by Earth system models are based on the interactive simulation of climate and carbon cycle, and thus the detail evaluation on carbon cycle is necessary for improving the performance of climate-carbon cycle projection. A new Earth system model, MIROC-ES2L, has developed and CMIP6 experiments have been performed using the new model. We presented in JPGU2019 the overview of the biogeochemical processes of the model, and in this research, we examined in detail the terrestrial carbon cycle (biogeochemical) processes of the model. By comparing with observation-based global products, we confirmed the spatial distribution of primary productivity, forest carbon, and soil organic carbon are reasonably captured by the model, but the comparison on the carbon fluxes seasonality / phenology suggested there is room to improve.

Keywords: Earth system model, Carbon cycle, Terrestrial ecosystem

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Using UAVs and deep learning techniques to detect invasive species in forests and wetlands

*Sarah Kentsch[1,2], Maximo Larry Lopez Caceres[1], Yago Diez Donoso[1], Jens Gross[3]

1. Yamagata University, 2. United Graduate school of Agriculture Sciences (UGAS), 3. Leibniz University of Hannover

Nowadays, forests becoming more important since the climate change has high impact in forest ecosystems. Several studies showed the widespread shifts of tree species related to their geographic position. A special case of wide spreading trees are invasive species. Invasive tree species have a major impact on structure, properties and function of natural/seminatural ecosystems. Invasive trees disturb ecosystems, displace plant species and cause high economic and ecological costs. Those species can change the structure and diversity of ecosystems and influence the regeneration of plants, soil properties and can lead to a loss of communities and functions of ecosystems. Therefore, we want to precisely detect the location of invasive species in order to provide management possibilities.

The possibility for this detection is offered by conducting automatic field surveys. We used Unmanned Aerial Vehicles (UAVs), which have become an effective tool in several forestry application. These easy-to-use and cheap tools are able to gather images with a high resolution. Together with image orthomosaics and deep learning techniques in combination with transfer learning we researched the detection of invasive species.

In order to explore the practical use of deep learning tools for detection applications in forestry we chose two practical problems of interest in Japan and Germany. Our first study site is located in the Shonai plains in north-eastern Japan. It is a coastal forest composed of evergreen monoculture of pine trees which is invaded by black locust trees. Pine trees were planted to protect the villages from storms and wind erosions. Since the black pine is a deciduous tree it is able to weaken the function of the forest. The second study site is a wetland located Germany in the north of Hannover. Since 1933 blueberries are commercially planted but since a few decades they are invading into sensible ecosystems. In wetlands like the Lichtenmoor the plants can influence processes and the displacement of endangered species.

We will provide an effective tool to detect invasive species. Our approach is adaptable, easy and fast and can be applied in a large-scale and for long-term monitoring.

Keywords: detection, deep learning, invasive species, UAV

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Modeling ocean-ice shelf interaction over the Southern Ocean under RCP8.5 scenario

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1. Japan Agency for Marine-Earth Science and Technology

Much attention has been paid to ocean-cryosphere interactions over the Southern Ocean. Basal melting of Antarctic ice shelves has been reported to be the primary ablation process for the Antarctic ice sheets. Warm waters on the continental shelf, such as Circumpolar Deep Water (CDW) across the shelf break, play a critical role in active ice shelf basal melting. The temporal evolution and mechanisms of the basal melting and warm water intrusions under future warming climates would be crucial for better understanding Antarctic Ice sheets stability and the associated sea-level rise. Here, we conduct a numerical experiment of an ocean-sea ice-ice shelf model forced with future atmospheric conditions derived from the RCP8.5 scenario of MIROC-ESM for the period 2000–2140 to examine responses of the Antarctic ice shelf basal melting and the role of coastal water masses in the future. The modeled total mass loss from Antarctic ice shelf basal melting has gradually increased about 2-fold from 1500 Gt/yr to 3000 Gt/yr over the study period, while basal melting at the Amery Ice Shelf, East Antarctica, is dramatically increased from about 50 Gt/yr in the first half of the 21st century to about 300 Gt/yr in the 22nd century. The regional boost of the ice shelf basal melting is explained by the sudden enhancement of CDW intrusion into the ice shelf cavity. This study demonstrates that changes in the Antarctic coastal water masses are vital metrics for a better understanding of the ocean-cryosphere interaction over the Southern Ocean.

Keywords: ice-ocean interaction, Southern Ocean

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG48] Projection and detection of global environmental change

convener:Michio Kawamiya(Japan Agency for Marine-Earth Science and Technology), Kaoru Tachiiri(Japan Agency for Marine-Earth Science and Technology), Hiroaki Tatebe(Japan Agency for Marine-Earth Science and Technology), V Ramaswamy(NOAA GFDL)

Anthropogenic forcings on global environment are expected to cause intensification of extreme events, sea level rise, ocean acidification and deoxygenation, as well as large-scale ecosystem changes. Earth System modeling groups across the world performed simulations and published projection data toward 6th IPCC assessment report due in 2021. Various new types of studies, such as event attribution and coupling of socio-economic processes and Earth system dynamics, are emerging in the field of global change projections. In addition, observational studies are becoming increasingly more important for grasping changes in the global environment and evaluating model projections. Interactions and collaborations beyond boundaries of conventional scientific disciplines are desired for dealing with the issue of global changes. This session thus aims to deepen our understanding on global change, from both disciplinary and interdisciplinary viewpoints.

[ACG48-07] Toward marine ecosystem prediction with a global ESM

★Invited Papers

*Jong-yeon Park[1], Charles A. Stock[2], John P. Dunne[2], Xiaosong Yang[2], Anthony Rosati[2] (1.Jeonbuk National University (JBNU), 2.Geophysical Fluid Dynamics Laboratory (GFDL))

[ACG48-08] Estimating global air–sea and air–land CO2 flux fluctuations over the past forty years with an Earth system model incorporating a data assimilation system

*Michio Watanabe[1], Hiroaki Tatebe[1], Hiroshi Koyama, Tomohiro Hajima[1], Masahiro Watanabe[2], Michio Kawamiya[1] (1.Japan Agency for Marine-Earth Science and Technology, 2.The University of Tokyo)

[ACG48-09] Overview of the processes interacting between Earth and socio-economic systems

*Kaoru Tachiiri[1], Ken'ichi Matsumoto[2], Xuanming Su[1] (1.Japan Agency for Marine-Earth Science and Technology, 2.Nagasaki University)

[ACG48-10] **Quantify allowable warmings for 2 °C and 1.5 °C climate targets**

*Xuanming Su[1], Katsumasa Tanaka[2,3], Kaoru Tachiiri[1], Michio Watanabe[1], Michio Kawamiya[1] (1.Japan Agency for Marine-Earth Science and Technology, 2.Laboratoire des Sciences du Climat et de l'Environnement (LSCE), Commissariat à l'énergie atomique et aux énergies alternatives (CEA), Gif-sur-Yvette, France, 3.National Institute for Environmental Studies (NIES))

[ACG48-11] Impacts of climate and socio-economic changes on water, food, bio-energy and land use investigated with an integrated land surface model (MIROC-INTEG)

*Tokuta Yokohata[1], Tsuguki Kinoshita[2], Gen Sakurai[3], Akihiko Ito[1], Yusuke Satoh[1], Yadu Pokhrel[4], Masashi Okada[1], Etsushi Kato[5], KIYOSHI TAKAHASHI[1], Naota Hanasaki[1], Shinichiro Fujimori[6], Seita Emori[1] (1.National Institute for Environmental Studies, 2.Ibaraki University, 3.National Agriculture and Food Research Organization, 4.Michigan State University, 5.The Institute of Applied Energy, 6.Kyoto University)

[ACG48-12] Multi-type global drought projection using multi-model hydrological simulations

*Yusuke Satoh[1], Tokuta Yokohata[1], Yadu Pokhrel[2], Naota Hanasaki[1], Julien ERIC STANISLAS Boulange[1], Peter Burek[3], Kumiko TAKATA[1], Hideo Shiogama[1] (1.National Institute for Environmental Studies, 2.Department of Civil and Environmental Engineering, Michigan State University, 3.International Institute for Applied Systems Analysis)

Toward marine ecosystem prediction with a global ESM

*Jong-yeon Park[1], Charles A. Stock[2], John P. Dunne[2], Xiaosong Yang[2], Anthony Rosati[2]

1. Jeonbuk National University (JBNU), 2. Geophysical Fluid Dynamics Laboratory (GFDL)

Earth system models (ESMs) are vital tools to understand and predict Earth’ s interacting physical-biogeochemical system. Efforts to extend current physical climate predictions to global marine biogeochemistry predictions using ESMs, however, have been hampered by uncertainties in the model and initialization procedures. This study shows that newly developed ESM-based marine biogeochemical predictions can skillfully predict satellite-derived seasonal to multiannual chlorophyll fluctuations in many regions. Prediction skill arises from successfully simulating the chlorophyll response to the El Nino-Southern Oscillation and capturing the reemergence of subsurface nutrient anomalies by winter mixing, which subsequently affect spring and summer chlorophyll concentrations. Further investigations of the utility of biogeochemical predictions show that annual fish catches in large coastal ecosystems are significantly predictable up to 1-2 year in advance, suggesting a role for ESM-based marine biogeochemical predictions in dynamic marine resource management efforts.

Keywords: Earth system prediction, Biogeochemical model, Earth system model

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Estimating global air–sea and air–land CO2 flux fluctuations over the past forty years with an Earth system model incorporating a data assimilation system

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Increased atmospheric CO2 concentration causing global warming, which means the need for accurate prediction of fluctuations in atmospheric CO2 concentration is increasing. Uptake of CO2 at the ocean and land surfaces is one of the fundamental processes in the global carbon cycle, and it is known to fluctuate in response to inherent climate variabilities such as the El Niño–Southern Oscillation (ENSO). Therefore, representation of the interannual fluctuation of CO2 fluxes in Earth system models (ESMs) is essential for both investigation of the response of the carbon cycle to human-induced radiative perturbations and prediction of future global CO2 concentrations. In this study, we attempted to reproduce observed air–sea CO2 flux fluctuations and to reconstruct air–land CO2 flux fluctuations using an ESM, to which observed oceanic and/or atmospheric physical data were assimilated. When we assimilate both of oceanic and atmospheric data into the ESM, the most consistent results with previous estimates for CO2 flux fluctuations were obtained.We will discuss on the relationship between the assimilation variables and the resulting CO2 flux.

Keywords: Earth system model, data assimilation, air-sea CO2 flux, air-land CO2 flux

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Overview of the processes interacting between Earth and socio-economic systems

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Some existing studies indicate that economic carbon cycle feedbacks may be of comparable magnitude to natural climate-carbon cycle feedback. For considering the significance of the interaction between Earth and socio-economic systems, we report the result of our literature survey on the processes interacting between Earth and socio-economic systems. Existing literature indicates that agriculture/pastoralism, disease, energy (both of generation and demand), heat stress (including labor productivity), tourism have processes influenced by climate change, and as a whole there could be a significant impact by climate change on gross domestic product (GDP). However, our evaluation using a loosely coupled earth system of intermediate complexity and computable general equilibrium models indicates that the feedback to atmospheric CO2 concentration and global mean surface air temperature is small.

Keywords: Earth system, Socio-economic system, interaction

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Quantify allowable warmings for 2 ℃ and 1.5 ℃ climate targets

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The allowable warming is defined as the temperature that can be allowed to increase during achieving the climate targets, set in Paris Agreement, that is, to limit the global average temperature to well below 2 ℃ and to pursue efforts to avoid 1.5 ℃ above pre-industrial level. The allowable warming considers the committed warming from the historical forcing till 2016, indicating the remaining maximum warming level that can occur from the future forcing, while achieving the Paris Agreement temperature targets. In this study, we applied the SCM4OPT v2.0, with a normalized marginal method, to quantify the allowable warmings for regions in the 2 ℃ and 1.5 ℃ climate targets. Using the most up-to-date emission datasets, we first calculated the emission-related marginal effects for each emission for years of 2017-2100. Then the individual marginal temperature can be obtained by comparing the temperature difference between a full emission input scenario and the scenario with a marginal scaling. Thus, the percentage for the individual emission-related temperature in total temperature was found. We used Monte Carlo summation (n=100,000) to estimate the regional allowable warming by summing the temperature increase which belonged to the specific region.

The results show that, the global allowable warmings are 0.72±0.18 ℃ and 0.37±0.17 ℃ for 2 ℃ and 1.5 ℃ climate targets, respectively. Among them, 0.17±0.04 ℃ for 2 ℃ and 0.12±0.03 ℃ for 1.5 ℃ will be contributed by China, followed by Middle East and North Africa, with 0.12±0.02 ℃ for 2 ℃ and 0.08± 0.03 ℃ for 1.5 ℃. The allowable warmings for the USA are 0.11±0.02 ℃ and 0.05±0.02 ℃ for 2 ℃ and 1.5 ℃, respectively. Our findings here can provide a simple, but synthetical metric for policy-makers to evaluate the remaining allowable warmings within regional levels.

Keywords: Climate change, Allowable warming, Simple climate model

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Impacts of climate and socio-economic changes on water, food, bio-energy and land use investigated with an integrated land surface model (MIROC-INTEG)

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Future changes in the climate system could have significant impacts on the natural environment and human activities, which in turn affect changes in the climate system. In the interaction between natural and human systems under climate change conditions, land use is one of the elements that play an essential role. Future climate change will affect the availability of water and food, which may impact land-use change. On the other hand, human land-use change can affect the climate system through bio-geophysical and bio-geochemical effects. To investigate these interrelationships, we developed MIROC-INTEG (MIROC INTEGrated terrestrial model), an integrated model that combines the global climate model MIROC (Model for Interdisciplinary Research on Climate) with water resources, crop production, land ecosystem, and land use models [1]. In this study, we investigated impacts of future climate and socio-economic changes on the water resources, crop growth, and land use based on the simulation by MIROC-INTEG. In the historical simulations, we validated the model output such as irrigated water, crop yield, ecosystem productions, and cropland area by comparing to the observed or reanalysis data. In addition, we performed the future simulations based on the various climate (Representative Concentration Pathways, RCP) and socio-economic (Shared Socio-economic Pathways, SSP) scenarios. We extract the impact of future changes in climate and/or water resources on the food and bio-energy crop growth and land use change, by switching on/off the interaction among the sub-models (i.e., land surface, water resource, crop growth, and land use) in the MIROC-INTEG simulations.
[1] https://www.geosci-model-dev-discuss.net/gmd-2019-184/

Keywords: Climate Change, Global Modelling, Earth-Human system interaction

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Multi-type global drought projection using multi-model hydrological simulations

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A multi-drought projection that covers several draught types is required to better understand future drought. Although IPCC AR5 and SREX report state that drought is likely to intensify in several regions, overall confidence on drought is still low to medium in global scale projections. One of the reasons for such confidence levels stems from the divergent drought definition. Nonetheless, very few studies comprehensively discussed future drought taking several drought types into account within a single study, hence leaving a gap on the holistic picture of future drought.

This study presents a comprehensive multi-drought-type assessment on a global-scale until 2099. Using a set of multiple global hydrological model (GHM) simulations forced by four bias-corrected GCM projections, meteorological (precipitation), agricultural (soil moisture) and hydrological (runoff, discharge) droughts are investigated. The multi-model data set, which was developed in the Inter-Sectoral Impact Model Inter-comparison Project phase2b under a consistent simulation protocol, provides finer and detailed hydrological simulations at 0.5˚x0.5˚ resolution. To explore potential pathways of drought changes, this study examined the Representative Concentration Pathways (RCP) 2.6, 6.0 and 8.5 scenarios. For each case, four drought features; drought intensity, spatial extent, the number of events, dry spell length, were studied, compared to those of the period before the 1960s.

The results highlight the hotspots of future droughts and show the development of each drought type for each RCP scenarios. As well as consistencies, differences among drought types were found in change trends and drought features. These differences indicate that it is crucial to clearly define drought type in discussing the phenomenon, and it is critical to properly select drought types and index for one’ s interest. Also, differences among RCP scenarios pose a question for climate target discussion from the viewpoint of drought. Two types of uncertainties in this projection with respect to model (GHMs and GCMs) uncertainty and parameter uncertainty in the drought analysis methods are also presented along with the drought projections.

Keywords: Drought, climate change, multi-model, ISIMIP2b

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG49] Greenhouse Gas Monitoring from Space: Current Capabilities, Challenges, and Future Needs

convener:kurosu thomas p(Jet Propulsion Laboratory, California Institute of Technology), Annmarie Eldering(Jet Propulsion Laboratory), Akihiko Kuze(Japan Aerospace Exploration Agency), Tsuneo Matsunaga(Center for Global Environmental Research and Satellite Observation Center, National Institute for Environmental Studies)

In a circulation letter of their Position Statement on Climate, the AGU writes

"Human-caused climate change is one of the most serious issues of our time. It will cause increasing health, economic, security, and ecological risks, from heat-related deaths and illnesses, hazards such as flooding, water scarcity, wildfire, and extreme weather and impacts to coastal infrastructure, agriculture, fisheries, and global migration."

With the constantly growing threat anthropogenically-induced climate change, global to local monitoring of atmospheric greenhouse gas (GHG) concentrations becomes increasingly important. Over the past decade, space-based GHG sensors have contributed substantially to our understanding of CO2 and CH4 emission sources and natural sinks on global and regional scales. Recent advances in these sensors have now extended these capabilities for studies of more compact sources, including large urban areas. NASAs OCO-3 on the ISS and Japans TANSO-FTS-2 on GOSAT-2 include target mapping modes that continue and extend the observation records of their precursors, and the Canadian commercial GHGSat provides high spatial resolution observations of CO2 and CH4 over selectable locations on the Earth. Sentinel 5P/TROPOMI measures CH4 with a wide swath instrument with daily near-global coverage. Future GHG observing systems are expected to further improve on the bridging of global and local scales, to provide optimized data records as basis for climate change mitigation policies.

We propose a session that focuses on the following aspects of space-based GHG monitoring: (1) capabilities of currently operating sensors measuring greenhouse gases on global to local scales, including OCO-2&3, TANSO-FTS/2, GHGsat, TROPOMI, and TANSAT; (2) identification and quantification of shortfalls in current data records, and requirements for future observation strategies; and (3) future observing systems and how these will address current gaps in GHG monitoring.

[ACG49-01] Current status of GOSAT and GOSAT-2 operation

*HIROKO IMAI[1], Hiroshi Suto[1], Kei Shiomi[1], Nobuhiro Kikuchi[1], Fumie Kataoka[2], Hiroyuki Miyamoto[1], Akihiko Kuze[1] (1.Japan Aerospace Exploration Agency, 2.Remote Sensing Technology Center of Japan)

[ACG49-02] Greenhouse gas concentrations retrieved from a combined use of SWIR and TIR observations by the GOSAT series satellites

*Nobuhiro Kikuchi[1], Akihiko Kuze[1], Fumie Kataoka[2], Kei Shiomi[1], Makiko Hashimoto[1], Hiroshi Suto[1] (1.Japan Aerospace Exploration Agency, 2.Remote Sensing Technology Center of Japan)

[ACG49-03] GOSAT collaboration activities with OCO-2 for calibration and validation

*Kei Shiomi[1], Akihiko Kuze[1], Hiroshi Suto[1], Nobuhiro Kikuchi[1], Mariko HASHIMOTO[1], Fumie KATAOKA[2] (1.Japan Aerospace Exploration Agency, 2.RESTEC)

[ACG49-04] The OCO-3 Mission: Performance of the Snapshot Area Map and Target Mode Observations and Coincident Measurements with the OMPS and TROPOMI Air Quality Sensors

*thomas p kurosu[1], Annmarie Eldering[1], Ralph basilio[1], matthew Bennett[1], Christopher O'Dell[2], Peter Somkuti[2], Thomas Taylor[2], Matthäus Kiel[1], Robert Nelson[1], Gary Spiers[1], Brendan Fisher[1], Ryan Pavlick[1], Gregory Osterman[1], Joshua Laughner[3], Graziela Keller-Rodrigues[1], Shanshan Yu[1], David Crisp[1], Paul Wennberg[3] (1.NASA Jet Propulsion Laboratory/California Institute of Technology, Pasadena, CA 91109, 2.Colorado State University, Fort Collins, CO 80523, 3.California Institute of Technology, Pasadena, CA 91125)

[ACG49-05] Early Comparison of OCO-3 XCO2 Measurements with TCCON

*Matthäus Kiel[1], Joshua Laughner[2], Annmarie Eldering[1], Brendan M. Fisher[1], thomas p kurosu[1], Ryan P. Pavlick[1], Gregory B. Osterman[1], Robert R. Nelson[1], Christopher W. O'Dell[3], Peter Somkuti[3], Thomas E. Taylor[3], Coleen M. Roehl[2], TCCON Team (1.NASA Jet Propulsion Laboratory, 2.Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA (USA), 3.Colorado State University, Fort Collins, CO (USA))

[ACG49-06] Temporally and spatially coincident observation of NO_2, CO_2 and CH_4 by manned and unmanned airplanes toward to detection of anthropogenic carbon signature

*Hiroshi Suto[1], Akihiko Kuze[1] (1.JAXA)

Current status of GOSAT and GOSAT-2 operation

*HIROKO IMAI[1], Hiroshi Suto[1], Kei Shiomi[1], Nobuhiro Kikuchi[1], Fumie Kataoka[2], Hiroyuki Miyamoto[1], Akihiko Kuze[1]

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GOSAT was launched in 2009 and has been operating successfully for over eleven years. GOSAT products have been updated repeatedly and are now highly functional. The achievements of GOSAT have led to global acknowledgement of the efficacy of monitoring greenhouse gasses from space. The purposes and utility of satellite observation data as a tool for verifying greenhouse gas inventories were clarified for the first time in the *2019 Refinement to the 2006 IPCC Guidelines on National Greenhouse Gas Inventories*, which was agreed upon in the Intergovernmental Panel on Climate Change, IPCC, held in Kyoto in May 2019.

GOSAT-2 was launched on October 29th, 2018 as a joint project of MOE (Ministry of the Environment), JAXA (the Japan Aerospace Exploration Agency), and NIES (the National Institute of Environmental Studies) to succeed the original GOSAT mission, still in operation well beyond its design life, and to contribute to the environmental administration and the international framework aimed at preventing global warming. In-orbit GOSAT-2 is operating exceptionally well. The initial check of equipment and the initial calibration of the mission data have been completed and Level-1 products have now been released to the public. We are fortunate to being able to operate GOSAT and GOSAT-2 synchronously and have been obtaining valuable data from them.

In this presentation, we will present the status of GOSAT and GOSAT-2 operation.

Keywords: GOSAT, GOSAT-2

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Greenhouse gas concentrations retrieved from a combined use of SWIR and TIR observations by the GOSAT series satellites

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The Fourier Transform Spectrometers onboard the GOSAT series satellites have spectral windows in both shortwave infrared (SWIR) and thermal infrared (TIR), which enable us to simultaneously observe the Earth’ s surface reflected sunlight and the thermal emission at the exactly same footprint. SWIR spectra have information on the total column amount of carbon dioxide and methane, while TIR spectra are sensitive to these gases mainly in the upper troposphere. Combining these two windows, GOSAT and GOSAT-2 are capable of retrieving concentrations of carbon dioxide and methane in the lower troposphere, which helps the surface flux estimate of these greenhouse gases.

Another unique feature of GOSAT and GOSAT-2 is polarization measurement in the SWIR windows, which can be used to correct undesirable effects of aerosols on the accurate retrieval of the greenhouse gas concentrations. It seems clear that retrievals of greenhouse gas concentrations from the GOSAT series satellites are best performed by the algorithm that uses all the measurements from the FTS sensors.

We have developed an experimental algorithm which can be applied to both GOSAT and GOSAT-2 observations. Our approach is a so-called full physics algorithm, which uses TIR and polarimetric SWIR spectra simultaneously as measurement. Gas concentrations were retrieved as a maximum a posteriori solution. We adopted total 5 layers to represent vertical profiles of carbon dioxide and methane, with 2 layers in the troposphere. Column-averaged concentrations of carbon monoxide were derived from GOSAT-2 observations.

We compared our retrievals with ground truth data as well as other satellite retrievals including OCO-2 and TROPOMI. Preliminary result shows that our GOSAT and GOSAT-2 retrievals are both promising. In this paper we will present some of our recent progress including greenhouse gas concentrations in the north hemisphere permafrost regions and Austrian wildfire regions.

Keywords: greenhouse gas, retrieval algorithm, GOSAT

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GOSAT collaboration activities with OCO-2 for calibration and validation

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JAXA’s GOSAT has been operating since 2009 to monitor the greenhouse gases carbon dioxide (CO2) and methane (CH4) by a Fourier Transform Spectrometer (TANSO-FTS). The column-average dry air mole fractions of CO2 (XCO2), and CH4 (XCH4) are measured from space using surface-reflected sunlight at near-IR wavelengths. NASA’s OCO-2 has been operating since 2014, carries a grating spectrometer to make precise XCO2 observations with a-few-kilometer resolution. The other opportunities are target observations at particular calibration and validation sites with deploying ground-based measurements. JAXA has been operating a ground-based FTS with high spectral resolution at Saga University as a member of the Total Carbon Column Observing Network (TCCON) since July 2011. XCO2 and XCH4 are estimated from direct sunlight spectra with high accuracy. TCCON dataset is utilized to make validation for the satellite observations such as GOSAT and OCO-2 with simultaneous measurements. GOSAT team also conducts the calibration and validation campaign at Railroad Valley, Nevada US desert every summer season collaborated with OCO-2 team. We also measure XCO2 and XCH4 by a portable FTS on the field. We will present our activities.

Keywords: CO2, GOSAT, Calibration, Validation, OCO-2

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The OCO-3 Mission: Performance of the Snapshot Area Map and Target Mode Observations and Coincident Measurements with the OMPS and TROPOMI Air Quality Sensors

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The Orbiting Carbon Observatory 3 (OCO-3) was launched to the International Space Station (ISS) on 4 May 2019 and was successfully installed on 10 May 2019. First Light occurred in late June 2019, and the in-orbit check out of the instrument extended through July 2019. OCO-3 records reflected sunlight in the near-Infra Red spectral region to estimate the column average CO_2 dry air mole fraction (XCO_2) and solar-induced chlorophyll fluorescence (SIF). It complements the OCO-2 mission by employing a dedicated Snapshot Area Map (SAM) mode to map spatial areas of up to 80x80 km^2 on the Earth's surface, including cities, volcanoes, and photosynthetically active surface types. The inclination of the ISS orbit limits OCO-3 to observations within +/- 52º latitude, but allows measurements at all times of day between sunrise and sunset to resolve diurnal variations in XCO_2 and SIF.

CO_2 emissions and air quality are closely linked, particularly over large urban agglomerates. OCO-3's SAMs allows, for the first time, detailed studies of the relationship between CO_2 emissions and air quality tracers over megacities. Compared to CO_2, NO_2 is short-lived and can serve as indicator for temporally and locally enhanced fossil fuel emissions, as well as longer-term trends of urban development and growth.

We present the current status of the OCO-3 mission, with focus on SAM performance to identify anthropogenic CO_2 signals, and comparisons of OCO-3 SAM and Target Mode measurements of XCO_2 with NO_2 observations from NASA's Ozone Monitoring and Profiler Suite on Suomi/NPP and JPSS-1 and ESA's Sentinel-5 Precursor/TROPOMI. We present details on the performance of selected OCO-3 SAM and Target Mode observations, identify temporally and spatially near-coincident OMPS and TROPOMI measurements, and derive correlation statistics between CO_2 and the air quality tracers, with the aim to establish coincidence data record over the OCO-3 life time.

Keywords: Greenhouse Gas Monitoring, Carbon Cycle, International Space Station

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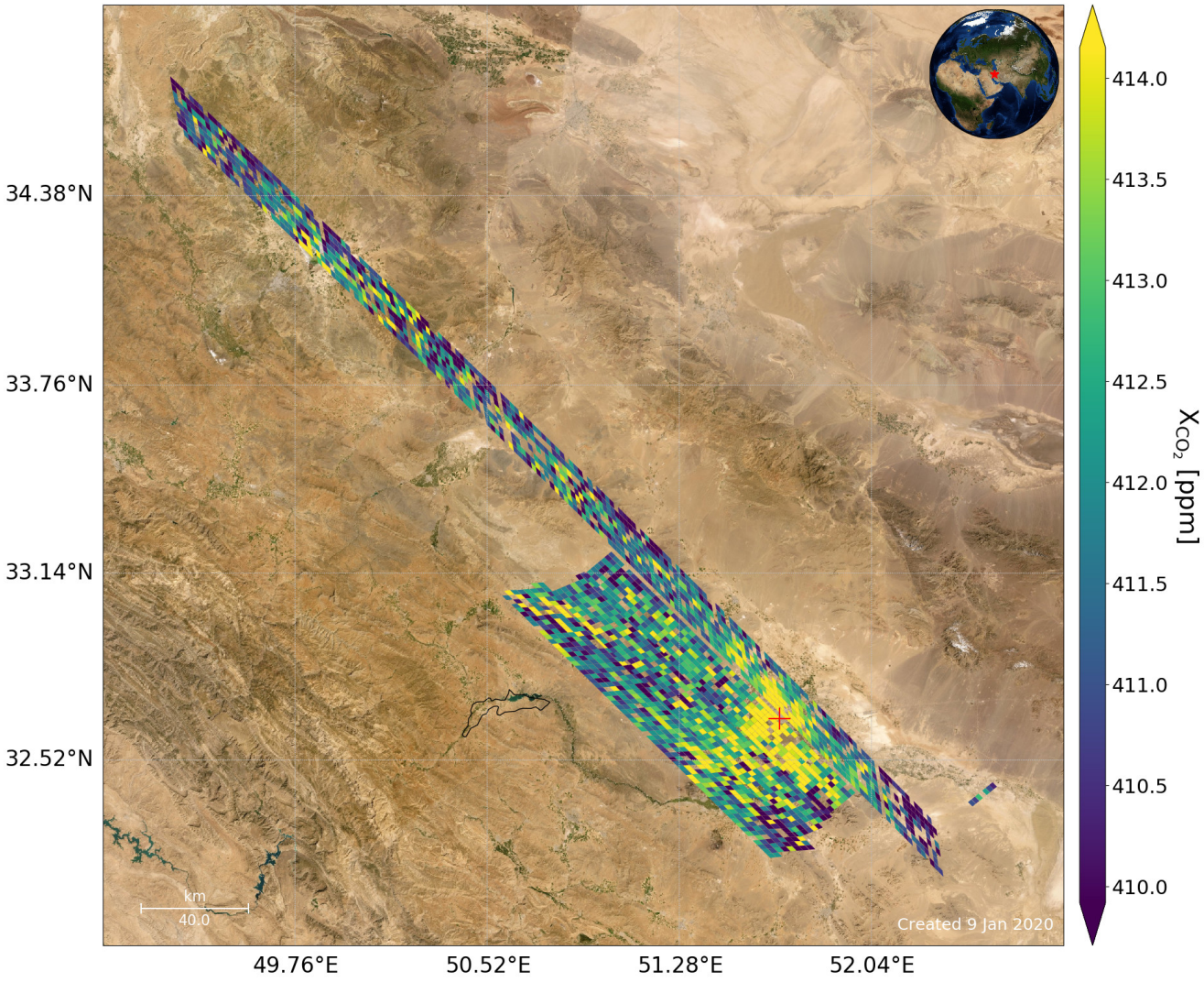
OCO-3 X_{CO_2}
SAM Mode (SRU+BAD), fossil0117, "fossil_Esfahan_Iran"
SCF_B10106_r01, 09:32 UTC 24 Dec 2019, Orbit 3630



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Early Comparison of OCO-3 XCO2 Measurements with TCCON

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The Orbiting Carbon Observatory-3 (OCO-3) was successfully launched on May 4, 2019 from Kennedy Space Center via a Space-X Falcon 9. One week later, the instrument was installed as an external payload on the International Space Station (ISS). OCO-3 extends NASA's study of carbon and measures the dry-air mole fraction of column carbon dioxide (XCO2) in the Earth’ s atmosphere from space. These space-based measurements are compared to ground-based observations from the Total Carbon Column Observing Network (TCCON). TCCON is a global network of high-resolution ground-based Fourier Transform Spectrometers that records spectra of the sun in the near-infrared spectral region. From these spectra, accurate and precise column-averaged abundances of atmospheric constituents including CO2 are retrieved. TCCON data are tied to the WMO scale and serve as the link between calibrated surface in situ measurements and OCO-3 measurements. OCO-3’ s agile 2-D pointing mirror assembly (PMA) allows the instrument to stare at a TCCON station as it passes overhead - providing information about the quality, biases, and errors in the OCO-3 data. Here, we show early comparisons between the OCO-3 XCO2 dataset collected during target mode observations and coincident TCCON measurements. Finally, we discuss site-dependent biases and its potential origins.

Keywords: CO2, International Space Station, Greenhouse Gas

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Temporally and spatially coincident observation of NO_2, CO_2 and CH_4 by manned and unmanned airplanes toward to detection of anthropogenic carbon signature

*Hiroshi Suto[1], Akihiko Kuze[1]

1. JAXA

Satellite-based carbon observation such as GOSAT, GOSAT-2, OCO-2, OCO-3, TROPOMI are successfully and operationally monitoring the global distribution of CO_2, CH_4. 15 years ago, it is a challenging issue to remotely observing Greenhouse gases with globally. Finally, it become to common tool to monitor the globe. Satellite-based observation is suitable for global mapping with several km to 10 km spatial resolution. However, a lot of anthropogenic carbon sources such as power plat, industry and coal mining are located in regional area, and it is also challenging to estimating the individual flux by satellite-based observation, since the signature of these emissions are very small against the current satellite observation detectability. To clearly detecting anthropogenic carbon signature, airborne observation is useful with fine special resolution and imaging capability. Airborne observation can detect the emission signature with several m to 100 m spatial resolution. To detecting the emission signature, the demonstration of airborne observation for greenhouse gases ands NO_2 by man and unmanned airplanes with imaging spectrometers are carried out. The latest result will be presented with our design concept and observation strategy.

Keywords: CO2, CH4, NO2, Airplane

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG50] Earth & Environmental Sciences and Artificial Intelligence

convener:Tomohiko Tomita(Faculty of Advanced Science and Technology, Kumamoto University), Shigeki Hosoda(Japan Marine-Earth Science and Technology), Ken-ichi Fukui(Osaka University), Satoshi Ono(Kagoshima University)

In recent years, we have been required to explore various gigantic data leading earth and environmental sciences such as modern meteorology, oceanography, hydrology and so on, to accomplish Society 5.0 and Sustainable Development Goals (SDGs). To examine such environmental big data faithfully, it may be required to use the techniques of artificial intelligence (AI) including spatiotemporal data modeling of AI, prediction and detection by machine learning, techniques of automated data mining, and so forth. At the present, AI is also expected to lead the data-driven science as a bridge connecting science and big data. This session first calls for various studies applying the techniques of AI to global environmental issues and then will discuss them in both natural and information sciences.

[ACG50-01] What is "Explainable AI"?

★Invited Papers

*Satoshi Hara[1] (1.Osaka University)

[ACG50-02] Predicting global potential natural vegetation with an image recognition AI

*Hisashi Sato[1], Takeshi Ise[2] (1.Department of Environmental Geochemical Cycle Research, Japan Agency for Marine-Earth Science and Technology (JAMSTEC), 2.Field Science Education and Research Center, Kyoto University)

[ACG50-03] **Digital Soil Mapping of Soil Fertility in Thung Kula Rong-Hai Region, Thailand using Machine Learning Algorithm**

*Sasirin Srisomkiew[1], Masayuki Kawahigashi[1], Pitayakon Limtong[2] (1.Tokyo Metropolitan University, 2.Land Development Department)

[ACG50-04] **Robustness of optical remote sensing of cloud by deep convolutional neural network using multi-channel imaging spectroradiometer**

*Hironobu Iwabuchi[1], Hana Kato[1], Aki Masuda[1] (1.Graduate School of Science, Tohoku University)

[ACG50-05] Multi-location meteorological observation system and micro-satellites for extreme weather forecast

★Invited Papers

*Yukihiro Takahashi[1,2], Mitsuteru Sato[1,2], Hisayuki Kubota[1,2], Kozo Yamashita[3], Tetsuro Ishida[1,2], Ellison Caparas Castro[4], Loren Joy De Vera Estrebillo[1], Purwadi Purwadi[1], Gay Perez[4], Joel Marciano[4], Jun Matsumoto[5], Jun-Ichi Hamada[5] (1.Department of Cosmosciences, Graduate School of Science, Hokkaido University, 2.Faculty of Science, Hokkaido University, 3.Faculty of Engineering, Ashikaga University, 4.University of the Philippines, Diliman, 5.Tokyo Metropolitan University)

What is "Explainable AI"?

*Satoshi Hara[1]

1. Osaka University

In this talk, I will present a brief overview of "Explainable AI". The recent developments of AI technologies enable computers to perform comparably or even better than the human on some tasks such as image recognition. However, the "black-box" nature of AI is considered as a crucial shortcoming of the current AI. That is, current AI only outputs its prediction or recognition results but it does not explain why and how such outputs are obtained in a "human interpretable" manner. To alleviate the "black-box" nature, several efforts have been made to AI to be "explainable" in the last few years. I will introduce these recent developments on "Explainable AI".

Keywords: Artificial Inteligence, Explainable AI, Machine Learning

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Predicting global potential natural vegetation with an image recognition AI

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Potential natural vegetation (PNV) is the vegetation cover equilibrium with environmental condition, which would exist at a given location without human land-conversion. For operational mapping of PNV, we developed an empirical model using a deep neural network (DNN), which was trained by an observation based PNV map (Figure 1) and graphical images of global air temperature and precipitation at 0.5 degree resolution. The trained model well reconstructs an observation based global PNV map, demonstrating that this way of DNN application can capture empirical relationships between PNV and climate. Then, the trained model was applied to projected climate at the end of the 21st century, predicting significant shift of global PNV distribution with rapid warming trends (Figure 2).

Keywords: Climate Envelope, Potential Natural Vegetation, Image Recognition AI

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Figure 1.
An observation based potential-natural-vegetation (PNV) map of the ISLSCP2.

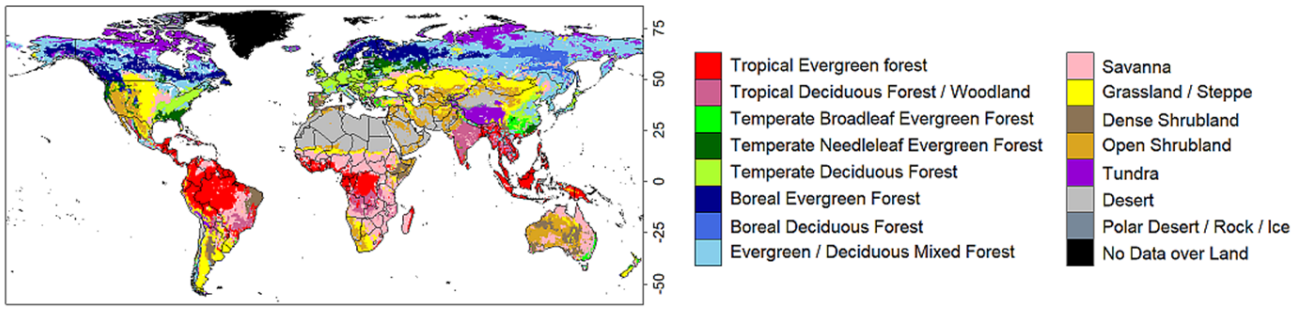
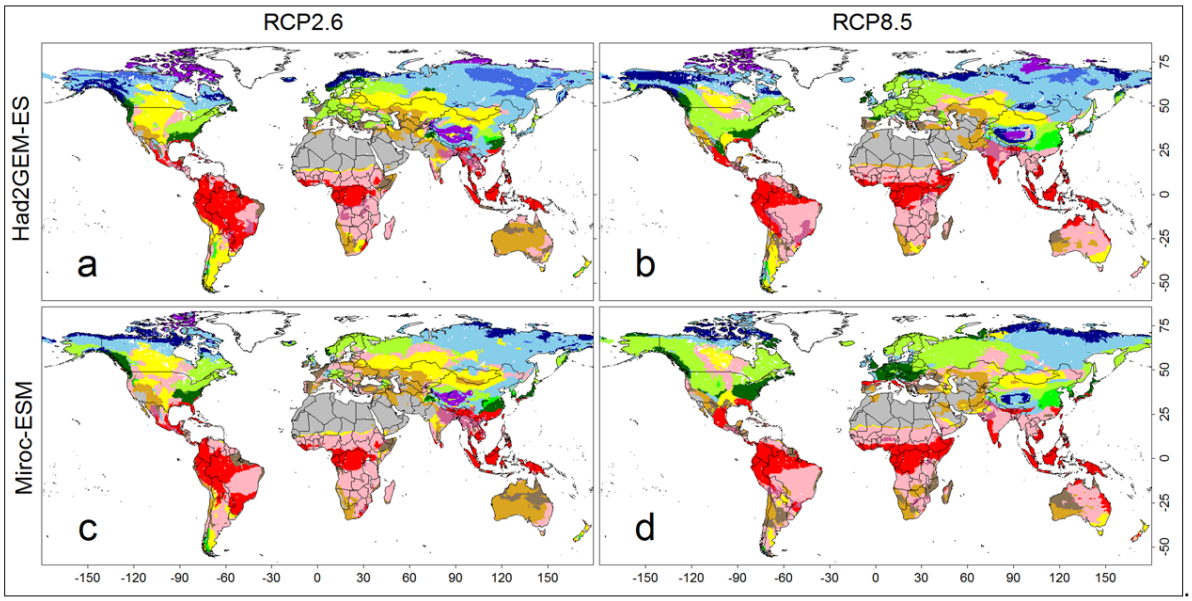


Figure 2.
Predictions of PNV map under the forecasted climate during 2091 to 2100. Monthly means of four forecasted climatic conditions, those are the combinations of two climate models (Had2GEM-ES and Miroc-ESM) and two RCP scenarios (RCP2.6 and RCP8.5), were applied for the DNN model that was trained by present climatic condition in the CRU data.



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Digital Soil Mapping of Soil Fertility in Thung Kula Rong-Hai Region, Thailand using Machine Learning Algorithm

*Sasirin Srisomkiew[1], Masayuki Kawahigashi[1], Pitayakon Limtong[2]

1. Tokyo Metropolitan University, 2. Land Development Department

Advancement in the Machine Learning (ML) Algorithm domain in the last few decades with the development of applications of machine learning are now try to apply to the field of Digital Soil Mapping (DSM) to express various soil properties on maps. However, soil fertility which is a complex feature of soil has not been mapped using various physical-chemical soil properties. This study challenges to evaluate soil fertility covering whole through a geographical area using inherited soil properties by the digital soil map with a machine learning algorithm. The target area is the Thung Kula Rong-Hai (TKR) region of Thailand, which covers a total area of 337,230 hectares. The TKR region is famous for producing high-quality jasmine rice, where has been registered as the Protected Geographical Indication (PGI) in 2010. However, the productivity of the jasmine rice in the TKR region is very low as compared to other regions in Thailand. Hence, it is necessary to know the heterogeneity of soil fertility for sustainable land use management to help increase in productivity of rice in the TKR region. In this study, remote sensing data from Landsat8 OLI and DEM data were used to characterize soil fertility covering whole through the studied region using soil properties that were pre-determined by laboratory analyses from 186 soil samples according to soil series in Thailand. Soil samples were collected in the dry season between March and May in 2016. The principal component analysis (PCA) using various soil properties extracted suitable soil parameters to map soil fertility. Following the PCA, the machine learning algorithm for Multiple Linear Regression (MLR) was applied to all available data to establish a predictable model to create the DSM of soil fertility. The obtained PC1 was explained by electrical conductivity (EC), organic matter (OM), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) with significant correlation coefficients, suggesting that PC1 can be a soil fertility parameter. On the other hand, PC2 consisting of soil pH, exchangeable iron (Fe) and copper (Cu) with significant correlations express the availability of micronutrients. The MLR analysis using obtained soil data with the principal component analysis led predictable equations using the near-infrared (NIR) and shortwave infrared (SWIR) channels of Landsat 8, as well as spectral indices of saturation (SI), normalized difference vegetation (NDVI), normalized difference water (NDWI), moisture stress (MSI) and terrain index (DEM) to produce DSM. The predictive accuracy evaluated in terms of R^2 for MLR models is acceptable to create the DSM which ranged from 0.7 to more than 0.9 for different soil parameters. The estimated DSM demonstrates that most of the cultivated areas in the TKR region are occupied by “very low” to “low” fertilities, where covered approximately 172,313 hectares or 51.1% of the total area.

Keywords: Digital soil mapping, Soil fertility, Machine learning, Principal component analysis

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Robustness of optical remote sensing of cloud by deep convolutional neural network using multi-channel imaging spectroradiometer

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Deep neural networks (DNNs) have recently been used in many problems of remote sensing. We have applied the DNNs to optical remote sensing of cloud from satellite- and ground-based imagers, for which the DNNs have been trained by a radiative transfer model (physics model). In optical remote sensing, three-dimensional (3D) radiative transfer effects significantly influence the cloud property retrieval from high-resolution optical instruments, operating across spatial elements of the cloudy atmosphere at a wide range of spatial scales. Because multispectral images contain spectral and spatial features, convolutional neural networks (CNNs) naturally trace the 3D radiative effects that appear across image pixels, which traditional single-pixel approaches cannot capture. Training data of synthetic radiances are made from simulations using a Monte Carlo 3D radiative transfer model for cloud fields simulated by a large eddy simulation model. The DNN can represent the cloud structure and 3D radiative effects that depend on many factors including sun-cloud-view geometry, cloud structure, aerosols, and surface reflection. Because satellite observation usually provide useful metadata information such as solar and satellite geometrical parameters, aerosol state, and surface reflectance, we have recently developed a new DNN architecture that is suitable for multimodal fusion of image and metadata. Furthermore, we found a way to properly treat measurement noise and bias in the DNN. If a DNN is trained on datasets of multispectral images with synthetic noise and bias of appropriate magnitude, cloud retrieval by the DNN is robust, not strongly depending on the absolute calibration and noise of instrument. If measured radiances are more uncertain, the DNN becomes to more strongly rely spatial features to estimate the cloud properties. We will show the robustness and sensitivity to noise and bias.

Keywords: remote sensing, cloud, deep neural network

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Multi-location meteorological observation system and micro-satellites for extreme weather forecast

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1. Department of Cosmosciences, Graduate School of Science, Hokkaido University, 2. Faculty of Science, Hokkaido University, 3. Faculty of Engineering, Ashikaga University, 4. University of the Philippines, Diliman, 5. Tokyo Metropolitan University

One of the strongest difficulties in forecasting extreme weathers, such as torrential rainfall by individual thunderstorm or typhoon, is the shortage of the observation point density and narrow coverage of the conventional radars. We have been developing an observation system for extreme weather monitoring, consisting of micro-satellites and automated weather stations with ground-based lightning sensor in the projects of a SATREPS “ULAT” and e-ASIA under international cooperation among Japan, Philippines, Indonesia and other SE-Asian countries supported by JST, JICA, PHL-Microsat and other fundings.

We distribute AWS with VLF radio wave lightning sensor at 12 sites in nation-wide of Philippines and those with electrostatic field sensors at 50 sites in Metro Manila. We also operate micro-satellites developed and controlled by our group in order to capture the 3 dimensional structure of the thunderstorms or clouds in typhoon eye by the on-demand operation of 50-kg micro-satellites, including the Philippine-developed satellites. Also few more lightning stations installed in Indonesia and Japan are used to cover broader area.

In this presentation, we discuss the strategy of the observation with these instrumentations which will be effectively used for the analysis with AI.

Keywords: remote sensing, lightning, micro-satellite, AI

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG51] Satellite Earth Environment Observation

convener:Riko Oki(Japan Aerospace Exploration Agency), Yoshiaki HONDA(Center for Environmental Remote Sensing, Chiba University), Yukari Takayabu(Atmosphere and Ocean Research Institute, the University of Tokyo), Tsuneo Matsunaga(Center for Global Environmental Research and Satellite Observation Center, National Institute for Environmental Studies)

In recent years, we cannot avoid facing issues on global environmental changes that occur in various spatiotemporal scales. The earth environmental observation data by satellites became the necessary basic data to tackle and solve those issues. Due to the recent advancement in the observation sensor technique and the data processing technique, the satellite observation has been showing rapid progress, and the time is changing from examining the accuracy of the observation sensor data to the advancement of the data application, leading to broaden potential users. In these days application became synergetic, so we comprehensively pick up this topic in the Atmospheric and Hydrospheric Sciences Session of this Union Meeting that enables to comprise the atmospheric, oceanic and land sciences; by combining the intelligence and the knowledge of the party, we propose a session that aims to prompt further studies towards the issues on earth environmental change, the advancement in the data application and future plans of Earth Observation missions.

[ACG51-01] GOSAT and GOSAT-2 Higher Level Products: Current Status and Future Plan

★Invited Papers

*Tsuneo Matsunaga[1], Isamu Morino[1], Yukio Yoshida[1], Makoto Saito[1], Hibiki M Noda[1], Hirofumi Ohyama[1], Yosuke Niwa[1], Akihide Kamei[1], Fumie Kawazoe[1], Tazu Saeki[1], Ryoichi Imasu[2], Naoko Saitoh[3], Takashi Nakajima[4], Teruyuki Nakajima[5], Makiko Hashimoto[5] (1.National Institute for Environmental Studies, 2.The University of Tokyo, 3.Chiba University, 4.Tokai University, 5.Japan Aerospace Exploration Agency)

[ACG51-02] Progress on validation of GOSAT and GOSAT-2 FTS SWIR L2 Products

*Isamu Morino[1], Yukitomo Tsutsumi[1], Osamu Uchino[1], Hirofumi Ohyama[1], Thi Ngoc Trieu Tran[1], Frey Max Matthias[1], Yukio Yoshida[1], Tsuneo Matsunaga[1], Akihide Kamei[1], saito makoto[1], Hibiki M Noda[1], TCCON partners[2] (1.NIES National Institute of Environmental Studies, 2.https://tccon-wiki.caltech.edu)

[ACG51-03] Spatiotemporal variabilities of ammonia in China as seen from IASI and AMoN

*Xuehui Guo[1], Rui Wang[1], Da Pan[1], Kang Sun[2], Lieven Clarisse[3], Martin Van Damme[3], Simon Whitburn[3], Pierre-François Coheur[3], Yuepeng Pan[4], Mark Zondlo[1] (1.Princeton University, 2.University at Buffalo, 3.Université libre de Bruxelles , 4.Chinese Academy of Sciences)

[ACG51-04] Scientific Overview of the GCOM-W/AMSR2 Mission and Outlook for GOSAT-GW/AMSR3

★Invited Papers

*Naoto Ebuchi[1,2], Misako Kachi[2], Hideyuki Fujii[2], Takashi Maeda[2], Nodoka Ono[2], Kazuya Inaoka[2], Marehito Kasahara[2], Yasushi Kojima[2] (1.Institute of Low Temperature Science, Hokkaido University, 2.JAXA)

[ACG51-05] Current Status of AMSR2 on board GCOM-W and Development of AMSR3 on GOSAT-GW

*Misako Kachi[1], Naoto Ebuchi[2,1], Takashi Maeda[1], Nodoka Ono[1], Hideyuki Fujii[1], Kazuya Inaoka[3], Marehito Kasahara[3], Yasushi Kojima[3] (1.Earth Observation Research Center, Japan Aerospace Exploration Agency, 2.Institute of Low Temperature Science, Hokkaido University, 3.GOSAT-GW Project Team, Japan Aerospace Exploration Agency)

[ACG51-06] The Inversion and Quality Validation of FY3 MWRI Sea Surface Temperature

*miao zhang[1] (1.National satellite meteorological center)

GOSAT and GOSAT-2 Higher Level Products: Current Status and Future Plan

*Tsuneo Matsunaga[1], Isamu Morino[1], Yukio Yoshida[1], Makoto Saito[1], Hibiki M Noda[1], Hirofumi Ohyama[1], Yosuke Niwa[1], Akihide Kamei[1], Fumie Kawazoe[1], Tazu Saeki[1], Ryoichi Imasu[2], Naoko Saitoh[3], Takashi Nakajima[4], Teruyuki Nakajima[5], Makiko Hashimoto[5]

1. National Institute for Environmental Studies, 2. The University of Tokyo, 3. Chiba University, 4. Tokai University, 5. Japan Aerospace Exploration Agency

GOSAT (Greenhouse gases Observing SATellite) and GOSAT-2 are a Japanese Earth observation satellites for greenhouse gas measurements from space and launched in 2009 and 2018, respectively. These satellits were developed and have being operated by Ministry of the Environment, JAXA (Japan Aerospace Exploration Agency), and NIES (National Institute for Environmental Studies).

NIES is responsible for the generation of GOSAT and GOSAT-2 Level 2 and Level 4 standard products such as:

(GOSAT)
1) L2 cloud flag
2) L2 CO2 column amount (SWIR)
3) L2 CH4 column amount (SWIR)
4) L2 H2O column amount (SWIR)
5) L2 CO2 profile (TIR)
6) L2 CH4 profile (TIR)
7) L4A global CO2 flux
8) L4A global CH4 flux
9) L4B global CO2 distribution
10) L4B global CH4 distribution

(GOSAT-2)
1) GOSAT-2 TANSO-CAI-2 L2 Cloud Discrimination Product
2) GOSAT-2 TANSO-CAI-2 L2 Aerosol Property Product
3) GOSAT-2 TANSO-FTS-2 SWIR L2 Chlorophyll Fluorescence and Proxy-method Product
4) GOSAT-2 TANSO-FTS-2 SWIR L2 Column-averaged Dry-air Mole Fraction Product
5) GOSAT-2 TANSO-FTS-2 TIR L2 Cloud and Aerosol Property Product
6) GOSAT-2 TANSO-FTS-2 TIR L2 Temperature and Gas Profile Product
7) GOSAT-2 L4A Global CO2 Flux Product
8) GOSAT-2 L4A Global CH4 Flux Product
9) GOSAT-2 L4B Global CO2 Distribution Product
10) GOSAT-2 L4B Global CH4 Distribution Product

All the GOSAT Level 2 and 4 standard products are freely available to the public. As for GOSAT-2, GOSAT-2 TANSO-FTS-2 SWIR L2 Column-averaged Dry-air Mole Fraction Product is being distributed to PIs of GOSAT Series Research Announcement.

In this presentation, the latest status and the future plans of these higher-level products will be

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introduced.

Keywords: Greenhouse gas, Climate Change, Satellite

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Progress on validation of GOSAT and GOSAT-2 FTS SWIR L2 Products

*Isamu Morino[1], Yukitomo Tsutsumi[1], Osamu Uchino[1], Hirofumi Ohyama[1], Thi Ngoc Trieu Tran[1], Frey Max Matthias[1], Yukio Yoshida[1], Tsuneo Matsunaga[1], Akihide Kamei[1], saito makoto[1], Hibiki M Noda[1], TCCON partners[2]

1. NIES National Institute of Environmental Studies, 2. https://tccon-wiki.caltech.edu

The Greenhouse gases Observing SATellite (GOSAT), launched on 23 Jan. 2009, is the world's first satellite dedicated to measuring the concentrations of the two major anthropogenic greenhouse gases, carbon dioxide (CO_2) and methane (CH_4), from space. Column-averaged dry air mole fractions of $CO_2$and CH_4, and water vapor (H_2O) (denoted as XCO_2, $XCH_4$and XH_2O) are retrieved from the Short-Wavelength InfraRed (SWIR) spectral data observed with the Thermal And Near-infrared Sensor for carbon Observation - Fourier Transform Spectrometer (TANSO-FTS) onboard GOSAT. The present NIES full physics SWIR retrieval algorithm (Ver. 02.81) for land high-gain soundings showed small biases and standard deviations, by comparing with data of the Total Carbon Column Observing Network (TCCON): -0.33 ppm and 2.17 ppm for XCO_2, -1.9 ppb and 13.4 ppb for XCH_4, and -0.80% and 33.4% for XH_2O, respectively. Retrievals from the GOSAT TANSO-FTS SWIR spectra for more than ten years are already being used for scientific research applications.

A successor of GOSAT, GOSAT-2 was launched on 29 Oct. 2018, and is now in operational. In addition to XCO_2, XCH_4, and XH_2O, XCO (column-averaged dry air mole fraction of carbon monoxide) is retrieved from GOSAT-2 TANSO-FTS-2 SWIR spectra. The main approach of acquiring validation data for GOSAT-2 is the same as those for GOSAT. Ground-based FTSs data from TCCON and NDACC IRWG (Network for the Detection of Atmospheric Composition Change-InfraRed Working Group) sites will be used, and some sites will be co-located with lidar and sky-radiometer systems for extensive validation data acquisition. In-situ measurements and/or sampling of CO_2, CH_4, and CO onboard commercial and charter aircraft by CONTRAIL (Comprehensive Observation Network for TRace gases by AIrLiner) and NOAA (National Oceanic and Atmospheric Administration) will also be employed.

In this presentation, we focus on the current status of the GOSAT product validation and preliminary evaluation of the GOSAT-2 products using the TCCON data, as well as related validation activities.

Keywords: Greenhouse Gas , Satellite Observation, Greenhouse gases Observing SATellite (GOSAT), GOSAT-2, Validation, Total Carbon Column Observing Network

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Spatiotemporal variabilities of ammonia in China as seen from IASI and AMoN

*Xuehui Guo[1], Rui Wang[1], Da Pan[1], Kang Sun[2], Lieven Clarisse[3], Martin Van Damme[3], Simon Whitburn[3], Pierre-François Coheur[3], Yuepeng Pan[4], Mark Zondlo[1]

1. Princeton University, 2. University at Buffalo, 3. Université libre de Bruxelles , 4. Chinese Academy of Sciences

Ammonia (NH_3) contributes to the formation of $PM_{2.5}$ and deposits to ecosystems, causing a series of health and environmental concerns. China is one of the largest NH_3 emitters owing to its intensive agricultural productions. While NH_3 emissions are not regulated in China, efforts are being made to include NH_3 in future emission control plans. Current NH_3 emission inventories in China have significant uncertainties and vary by a large extent. Satellite observations of NH_3 serve as a great tool to analyze the spatiotemporal variabilities of NH_3 on a national scale and can be used to constrain emission inventories. In this work, monthly averaged total columns of NH_3 from the Infrared Atmospheric Sounding Interferometer (IASI) are compared against surface concentrations measured at 48 sites of the China Ammonia Monitoring Network (AMoN). The IASI version 2.2r satellite pixels are screened by a 25-km spatial window centered on each AMoN site and oversampled on high-resolution grids (0.02×0.02˚). Results suggest that satellite total columns show increased sensitivity and correlation with surface concentrations under high NH_3 conditions. Seasonal differences in the correlation are not significant, while higher sensitivity of columns to surface concentrations is observed in spring and summer. Among the six regions studied, the Central and Northeast regions of China show the best correlations (r=0.86 and 0.64, respectively). This can be partly attributed to larger percentages of farmland, grassland and urban sites in these locations, which generally see better correlations than mountain and desert sites. Due to the early morning overpass time, IASI may miss NH_3 peaks from harvesting activities in fall. IASI matches best with AMoN in areas where the background NH_3 is high and large spatial gradients of NH_3 do not exist. In cases where IASI and AMoN do not correlate well, the spatial window used for filtering need to be revised, and site-specific criteria may need to be adopted. Ongoing analyses are investigating wind field and trajectory analyses as potential ways to refine the comparison. Site-to-site variabilities will also be discussed in the context of meteorological variables such as boundary layer height using the ERA5 atmospheric surface reanalysis data (0.25×0.25˚). Our work emphasizes the importance of considering the heterogeneity of NH_3 at the surface when applying satellite measurements to study NH_3 emissions.

Keywords: Ammonia, Satellite, In-situ, PM2.5

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Scientific Overview of the GCOM-W/AMSR2 Mission and Outlook for GOSAT-GW/AMSR3

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1. Institute of Low Temperature Science, Hokkaido University, 2. JAXA

The Global Change Observation Mission-Water (GCOM-W) satellite was launched by the Japan Aerospace Exploration Agency (JAXA) in May 2012. It carries the Advanced Microwave Scanning Radiometer 2 (AMSR2), which is a 6-band multi-frequency, dual-polarization microwave radiometer with a 2-m aperture antenna. The JAXA's standard AMSR2 data product contains the vertically integrated water vapor, cloud liquid water, precipitation, sea surface temperature, sea surface wind speed, sea ice concentration, snow depths, and soil moisture. The GCOM-W/AMSR2 completed its 5-year designed mission life in May 2017 and has transferred to extended-mission phase. Besides the 10-month gaps between AMSR-E and AMSR2, the AMSR series provide long-term global observation data for studies of the global water cycle, air-sea interactions and polar environments. An overview of these studies is given in this paper.

JAXA planed a follow-on mission to GCOM-W/AMSR2, named AMSR3, which will be carried by the Global Observing SATellite for Greenhouse gases and Water cycle (GOSAT-GW). In December 2019, The GOSAT-GW/AMSR3 mission was officially approved and have moved into Phase-B. At present, it is expected to be launched in Japanese Fiscal Year of 2023 (from April 2023 to March 2024). AMSR3 succeeds all the frequency channels and polarization combinations of AMSR2. In addition, three high-frequency channels (166 GHz, 183±3 GHz and 183±7 GHz, V-pol) and 10-GHz channels (V- and H-pol) with improved Noise Equivalent Delta Temperature (NEDT) are added for observations of solid precipitation, humidity sounding, and high accuracy measurement of sea surface temperature. The targets of the AMSR3 mission are producing long-term continuous data record from AMSR, AMSR-E and AMSR2 and enhancing operational utilizations of near-real time data (e.g., weather forecast including typhoon and hurricane analysis, fishery near the coasts, navigational assistance on arctic shipping route).

Keywords: Remote sensing, Microwave radiometer, AMSR2, GCOM-W, AMSR3, GOSAT-GW

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Current Status of AMSR2 on board GCOM-W and Development of AMSR3 on GOSAT-GW

*Misako Kachi[1], Naoto Ebuchi[2,1], Takashi Maeda[1], Nodoka Ono[1], Hideyuki Fujii[1], Kazuya Inaoka[3], Marehito Kasahara[3], Yasushi Kojima[3]

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Series of space-borne passive microwave imager, called the Advanced Microwave Scanning Radiometer (AMSR), have been developed and launched by JAXA since 2002 for understanding of global water cycle and climate variations and expanding operational applications. Currently, AMSR2 on the Global Change Observation Mission –Water (GCOM-W) has been operating in orbit since May 2012, succeeding AMSR-E observation since 2002. AMSR2 has 16 channels from 6.9 to 89 GHz and the biggest antenna among the passive microwave imagers in the world to enable higher spatial resolution. Both GCOM-W and AMSR2 are in healthy condition to continue its operation in future.

Since designed mission life of GCOM-W was 5-year and it is already operating almost 8-year, JAXA has started development of AMSR2 follow-on mission, AMSR3 on the Global Observing SATellite for Greenhouse gases and Water cycle (GOSAT-GW), since December 2019. The GOSAT-GW satellite carries AMSR3 and successor mission of Greenhouse gases Observing SATellite-2 (GOSAT-2) led by Ministry of the Environment of Japan (MOE) and National Institute for Environmental Studies (NIES). AMSR3 will have 21 channels from 6.9 to 183.3+-7 GHz with 2.0m antenna. High-frequency channels of 165.5 GHz, 183+-3 GHz, and 183+-7 GHz V-polarization are newly available for snowfall retrievals and water vapor analysis in numerical weather prediction in meteorological agencies. Additional 10 GHz V and H polarization channels with wider band width and improved NEDT are also available to develop higher resolution sea surface temperature especially for fisheries. The GOSAT-GW satellite is currently targeting the launch in Japanese Fiscal Year of 2023.

Keywords: Satellite, Microwave Imager, Water Cycle

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The Inversion and Quality Validation of FY3 MWRI Sea Surface Temperature

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1. National satellite meteorological center

Objective : Sea surface temperature (SST) is an important physical parameter in the field of marine and climate research. Passive microwave remote sensing has the advantage of completing all weather observations ignoring the clouds interference, which has received more and more attention. The Fengyun (FY)-3 satellites carry the microwave imager (MWRI) on board. So using the FY3 MWRI to retrieval SST is of important significance.
Method:FY3 MWRI SST product uses statistical algorithms. Firstly, MWRI precipitation and sea ice products were used to remove the data containing precipitation and sea ice. Then using the temporal window of 0.2 hour and spatial window of 0.2°, the MWRI brightness temperature is matched with the buoy SST, and the matchup having land within 100km were excluded. Then being divided into four latitudes, 12 months, the descending and ascending statistical relationship between the buoy SST observation and MWRI bright temperature is established respectively. A total of 4 x 12 x 2 regression coefficients were obtained and corresponding regression coefficients were used respectively in the estimation of SST. The daily SST product were obtained using a 0.25°*0.25° equal latitude and longitude projections. The quality flag is set to 51 when FY3 MWRI SST minus 30 years monthly mean SST greater than 2.5K, and it showed that these pixels basically distribute on the edge of the land and high wind speed region.
Result: After excluding the pixels with quality flag of 51 , the quality validation of FY3 MWRI SST show that, compared with the global buoy data, the precision of the ascending orbit SST product is -0.02±1.22 K, and the precision of the descending orbit SST product is -0.15±1.28 K; compared with global analysis field OISST, the precision of the ascending daily SST product is 0.00±1.03K, and the precision of the descending daily SST product is -0.09±1.08K. The accuracy of the ascending orbit is better than that of the descending orbit, this is due to the non-uniform heating of the ocean surface during the day (the descending orbit). From the monthly SST product, we can see the kuroshio current, Gulf stream, western Pacific warm pool and La Nina clearly, which suggest that this SST product can also be well applied to the climatology investigation.
Conclusion: The results of the quality validation of FY3 MWRI SST consist with the FY3 product quality control system, and the SST precision is influenced by the performance of MWRI, its calibration and positioning accuracy, the precipitation and sea ice detection accuracy, the land interference and high wind speed. How to improve the precision of SST with wind speed greater than 12 m/s is the emphasis of the next step. The buoy SST and the global analysis field OISST can’ t be referred as a completely true value, therefore, in the future, we will use the method of triple collocation to make a more comprehensive analysis of the error characteristics of the SST products.

Keywords: FY-3, microwave imager, sea surface temperature

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG51] Satellite Earth Environment Observation

convener:Riko Oki(Japan Aerospace Exploration Agency), Yoshiaki HONDA(Center for Environmental Remote Sensing, Chiba University), Yukari Takayabu(Atmosphere and Ocean Research Institute, the University of Tokyo), Tsuneo Matsunaga(Center for Global Environmental Research and Satellite Observation Center, National Institute for Environmental Studies)

In recent years, we cannot avoid facing issues on global environmental changes that occur in various spatiotemporal scales. The earth environmental observation data by satellites became the necessary basic data to tackle and solve those issues. Due to the recent advancement in the observation sensor technique and the data processing technique, the satellite observation has been showing rapid progress, and the time is changing from examining the accuracy of the observation sensor data to the advancement of the data application, leading to broaden potential users. In these days application became synergetic, so we comprehensively pick up this topic in the Atmospheric and Hydrospheric Sciences Session of this Union Meeting that enables to comprise the atmospheric, oceanic and land sciences; by combining the intelligence and the knowledge of the party, we propose a session that aims to prompt further studies towards the issues on earth environmental change, the advancement in the data application and future plans of Earth Observation missions.

[ACG51-07] 2018-2019 global environment observation by GCOM-C “SHIKISAI”
★Invited Papers

*Hiroshi Murakami[1], Masahiro Hori[1], Kazuhisa Tanada[1], Toshiyuki Kobayashi[1], Megumi Okata[1], Kazunori Ogata[1], Rigen Shimada[1], Yukio Kurihara[1] (1.Earth Observation Research Center, Japan Aerospace Exploration Agency)

[ACG51-08] Two distinct modes of variability in the Euphotic depth in the Arctic ocean as revealed by satellite obsevation

*Takafumi Hirata[1] (1.Arctic Research Center, Hokkaido University)

[ACG51-09] Retrieval of Atmospheric Aerosol Properties for geostationary and polar-orbital Satellite Imaging Sensors: GCOM-C/SGLI and Himawari8/AHI results

*Mayumi Yoshida[1], Maki Kikuchi[1], Takashi M. Nagao[2], Hiroshi Murakami[1], Keiya Yumimoto[3], Taichu Y Tanaka[4] (1.Japan Aerospace Exploration Agency, 2.Tokyo University, 3.Kyushu University, 4.Meteorological Research Institute of Japan Meteorological Agency)

[ACG51-10] Satellite analysis by a multi-wavelength multi-pixel method and simultaneous method using GCOM-C/SGLI data

*Miho Sekiguchi[1], Makiko Hashimoto[2], Hideaki Takenaka[2], Chong Shi[2], Teruyuki Nakajima[2] (1.Tokyo University of Marine Science and Technology, 2.Japan Aerospace Exploration Agency)

[ACG51-11] **Quality assessment of SGLI/GCOM-C observed cloud properties using surface observation data**

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[ACG51-12] **Variabilities of Western Himalayan Forest Fire with Relation to Primary Productivity**

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2018-2019 global environment observation by GCOM-C “SHIKISAI”

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Two-years earth environmental change captured by Global Change Observation Mission-Climate (GCOM-C) called “SHIKISAI” are introduced.

JAXA polar-orbit satellite, GCOM-C, which carries Second-generation Global Imager (SGLI), has been launched on 23 Dec. 2017, and continued global observation since 1 January 2018. The key characteristics of the SGLI are (1) 250-m spatial resolution with 1150-1400 km swath, and (2) nineteen bands in 0.38-12 um including two polarimetry bands (at 672 nm and 866 nm) with +/- 45 degree along-track tilt.

Because the polarimetry is sensitive to the small particle aerosols, SGLI could clearly capture heavy aerosols from volcanos and fires, the Hawaii volcano in May-Jul. 2018, California in Aug. and Nov. 2018, Thai in Mar.-Apr. 2019, Alaska in Jul. 2019, Siberia in Jul.-Aug. 2019, Amazon in Jul.-Aug. 2019, Indonesia in Sep. 2019, and the east Australia in Nov. 2019-Jan. 2020 (see Fig. 1).
Even in the two years, SGLI observed year-to-year difference of the earth environment changes. In the northeast Asia, spring leafing in 2019 seemed slower than one in 2018 by about 1-2 weeks, that seems to correspond to decrease of the snow cover in the early spring. Many Noctiluca red tides appeared in the coastal areas around Japan in 2018 but did not in 2019. The GCOM-C will continue the global observation and the accumulating the data products are expected to be used in both the environmental change researches and monitoring.

Keywords: GCOM-C, SGLI, SHIKISAI, remote sensing

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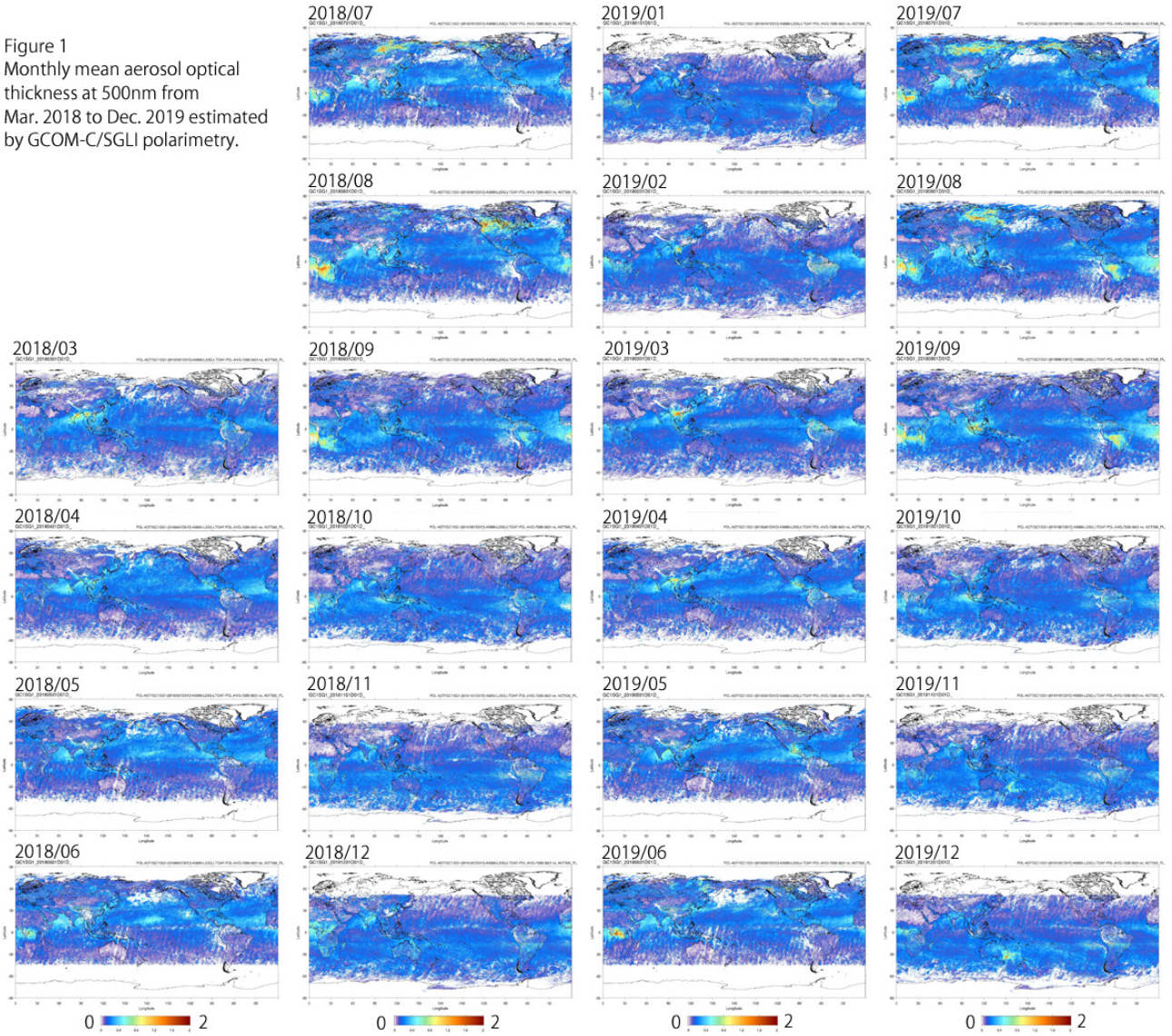

Figure 1
Monthly mean aerosol optical thickness at 500nm from Mar. 2018 to Dec. 2019 estimated by GCOM-C/SGLI polarimetry.

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Two distinct modes of variability in the Euphotic depth in the Arctic ocean as revealed by satellite obsevation

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The Arctic region is known to have been experiencing a rapid change in natural environment and ecosystems due to climate change. However, the environmental and ecological data in the Arctic is sparse in general, due to cost for, and difficulty in, access. Hence, remote sensing technology plays a significant role in the Arctic research. Currently, most of biogeochemical /ecological factors are remotely observable only by optical remote sensing. While the passive optical remote sensing in the Arctic has a limitation in that its observation is not possible in wintertime, it still provides loads of valuable Arctic data during summertime. In addition, the solar radiation, available only in summer in the Arctic, drives seasonal events not only in physics but also in biogeochemistry and ecology. One of the events is primary production which heavily rely on the availability of the sun light, from the ocean surface down to the euphotic depth. Therefore, how the euphotic depth varies during summertime in a year is of particular interest in determining the Arctic ocean productivity and biological resource in the Arctic in that year. Our objective here is to evaluate how the Euphotic depth varies in the Arctic. Satellite remote sensing data over a decade (1998-2007) were used to estimate the euphotic depth using an inversion model, and its variability was investigated for the Arctic ocean. Two distinct modes of variability of the Arctic euphotic depth was found: variablity in the euphotic depth in many regions in the Arctic seas was regulated simply by the solar zenith angle, yet variablity in the euphotic depth in the Russian Arctic seas was characterized by seawater quality, especially suspended particles. The finding implies that climate change (i.e. warming) in the Arctic may eventually lead to a reduction of light availability for photosynthesis in the Russian Arctic seas.

Keywords: Arctic, Euphotic depth

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Retrieval of Atmospheric Aerosol Properties for geostationary and polar-orbital Satellite Imaging Sensors: GCOM-C/SGLI and Himawari8/AHI results

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Aerosols influence the energy budget of the earth’ s climate system through scattering and absorbing solar radiation. The Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC, 2014) reported that the radiative forcing of the total aerosol effect in the atmosphere, which includes cloud adjustments due to aerosols, is −0.9 W m−2 and results from a negative forcing from most aerosols with a positive contribution from black carbon absorption of solar radiation. However, the range of the uncertainties remains large (−1.9 W m−2 to −0.1 W m−2).

For a more precise estimation of the impact of aerosols on climate systems, investigation of the behavior of aerosols on a global scale is essential but challenging because aerosol amounts and characteristics vary over space and time.

Aerosol remote sensing studies have been carried out using polar-orbital Earth observation satellites. JAXA has launched Global Change Observation Mission-Climate (GCOM-C)/Second-generation GLobal Imager (SGLI) at the end of 2017, and Greenhouse gases Observing SATellite- 2 (GOSAT-2)/Cloud and Aerosol Imager 2 (CAI-2) in 2018. In several years, Earth Clouds Aerosols and Radiation Explorer (EarthCARE)/ Multi-Spectral Imager (MSI) will be launched.

In addition, the next-generation geostationary satellite of the Japan Meteorology Agency (JMA), Himawari-8, was launched on October 7, 2014. It carries the Advanced Himawari Imager (AHI), which has six bands from visible to near-infrared wavelengths. It is significantly different from the previous Himawari-6/7 having only one channel in the wavelengths, which made the estimation of aerosol difficult because the assumption of aerosol type is necessary. Himawari-8/AHI observes the top of atmosphere (TOA) visible and near-infrared radiance at a resolution of 0.5–2.0 km over Asia and Oceania at every 10 min, which enables frequent aerosol estimation over the same ground targets.

The synergistic uses of these various imaging sensors on both geostationary and polar-orbital satellites are helpful to understand a complete picture of aerosol distribution in the global scale. For this purpose, we developed the common retrieval algorithm of the atmospheric aerosol properties for various satellite sensors and over both land and ocean.

The method was applied to GCOM-C/SGLI and Himawari-8/AHI. The retrieved aerosol properties are validated using ground observation data, such as Aerosol Robotic Network (AERONET) and SKYNET.

In addition, we improved the retrievals by utilizing the forecast of aerosol transport model. The results showed that the spatially finer distributions than the model forecast and less noisy distributions than the

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old algorithm.

Keywords: aerosol, remote sensing, GCOM-C, Himawari, aerosol transport model, algorithm

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Satellite analysis by a multi-wavelength multi-pixel method and simultaneous method using GCOM-C/SGLI data

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Atmospheric aerosols have a significant impact on the global climate through direct and indirect climate effects. Emissions of anthropogenic aerosols are said to be increasing year by year, and more accurate estimates are needed to suppress them. In remote sensing of land and ocean, aerosols are contaminants that cause serious errors, and it is important to remove it. In this study, we performed an analysis of atmospheric aerosol by the new satellite analysis algorithm, the multi-wavelength multi-pixel method (MWP method)(Hashimoto and Nakajima, 2017), and an analysis of atmospheric aerosol and chlorophyll concentrations by the simultaneous method (Shi and Nakajima, 2017). The MWP method is a solution method in which observation values of multiple channels are used for multiple pixels at once, and the aerosol distribution is limited and derived to be smooth. The spatial distribution of the AOT obtained even in an urban area that is complicated in the horizontal direction, the smoothness, or the superiority of this method. In the simultaneous method, it is necessary to consider the effect of ocean color when analyzing aerosols, and in the contradictory situation where it is necessary to consider aerosols when analyzing ocean color, the radiative transfer process in the ocean is considered. There is a technique that allows simultaneous estimation. By using many observation data at a time, more parameters can be estimated at once than before. This problem that the computational cost for these methods was high, is being overcome by using the Neural Network method (Takenaka et al., 2011) for the radiative transfer model, which is based on a narrow band radiative transfer code, Rstar (Nakajima and Tanaka, 1986; Sekiguchi and Nakajima 2007).

In this presentation, we apply GCOM-C / SGLI observation data to these methods and show the results of atmospheric aerosols in the Kanto area, which is an urban area, and in the Amazon area, where a large-scale forest fire occurred. We also show the results of aerosols and ocean color analysis in the Ariake and Yellow Sea areas. Also, the validation results are shown with SKYNET and AERONET, and compare variables that could not be obtained with the current algorithm. For single scattering albedo, similar time dependencies are shown.

Keywords: atmospheric aerosols, satellite analysis, GCOM-C/SGLI

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Quality assessment of SGLI/GCOM-C observed cloud properties using surface observation data

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Along with the advancement of satellite remote sensing, scientific community has made a significant progress in understanding the Earth’ s atmosphere and climate system. Though satellite observations from space have large spatial coverage, their accuracy is a great concern to research community; thus, quality assessment of satellite products has become a very important issue in recent years. Like several other satellite observed atmospheric components, cloud products from satellite observations need to be validated thoroughly by using reliable surface observation data. As part of it, we developed a new cloud retrieval algorithm applicable for sky radiometer and sun photometer instruments belonging to SKYNET and AERONET ground-based networks, and performed quality assessment of daytime MODIS and AHI observed water cloud properties in the past. This study deals with quality assessment of the Second-generation Global Imager (SGLI) aboard the Global Change Observation Mission-Climate (GCOM-C, “Shikisai” in Japanese), which was launched on December 23, 2017.The daytime cloud properties (Cloud optical thickness COT and cloud-particle effective radius CER) of both water and ice clouds are compared with those observed at surface by sky radiometer at five typical SKYNET observation sites within Japan for a period of January, 2018 to October, 2019. The surface observed global flux data are also used separately to understand the quality of SGLI observed CODs and cross check the comparison between sky radiometer and SGLI CODs. Like MODIS and AHI daytime CODs, SGLI daytime CODs are found to be overestimated (underestimated) for thin (thick) clouds for a majority of samples. This indicates that reflectance based COD observation from space can have this common feature, irrespective of sensor type. Further, CERs between satellite and surface observations are poorly correlated, and the large difference can occur for optically thin clouds rather than optically thick clouds.

Keywords: SGLI, cloud, validation

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Variabilities of Western Himalayan Forest Fire with Relation to Primary Productivity

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Forest fire is a regular anthropogenic and physical hazard over western Himalaya during hot and dry pre-monsoon season. The causality factors of forest fire have varied over time and space. The present study has focused on long-term fire variability and its relation with primary productivity over Himachal Pradesh and Uttarakhand, parts of western Himalaya. To characterize the fire occurrences, we have been used monthly burn area product of MODIS (MCD64A1 c6) in 500 meters and fire dataset of Climate Change Initiatives project of ESA (Fire CCI v5.1) with 250 meters spatial resolution. The temporal analysis of fire counts in respect of different forest types has revealed that western Himalaya faced some short cycle or phase (~5 years) of fire events. The spatial variability has been estimated in every 5 years phase which has been identified by temporal oscillation analysis from 2001 to 2018. The spatial intensity and coverage of fire incidences have a propensity of increasing and spreading over the southern mountainous slope. The linear regression functions and Sen’ s Slope accounted that fire events were increasing in 236 and 124 fire counts in every year. The Gross Primary Productivity (GPP) was evaluated over the study periods from (2001-2018). GPP was estimated using a recent developed remote sensing-based model Southampton Carbon Flux (SCARF) and Carnegie Ames Stanford Approach (CASA) model function. MODIS Terra derived GPP in 500 meters (MOD17A2H.006) was used to compare with the model produced GPPs. The MOD17A2H.006 GPP is underestimating in comparison to two models derived GPP. The pre-monsoonal GPP variabilities and trend has a significant connection with spatial clusters and temporal variation of fire. Along the southern slope of western Himalaya, the primary productivity has been degrading in a rate of 2-6 g C m2year1 and 1-50 g C m2year1 GPP (according to Sen’ s slope) in 90% significant-level ($p < 0.1$) of CASA and SCARF model, respectively. The spatial relation reflected that forest and grassland productivity has been degrading over the fire-prone area. We have also used ALOS World 3D - 30m (AW3D30) global digital surface model (DSM) to evaluate the forest fire scenario and its impacts upon primary productivity in respect of elevation. The elevation wise analysis suggested that the southern parts of the study area, range from 173 to ~4000 meters is mostly affected by fire occurrences which directly and indirectly functioning to deteriorate the primary productivity of the area.

Keywords: Forest Fire , Western Himalaya, Primary Productivity, SCARF Model, CASA

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG51] Satellite Earth Environment Observation

convener:Riko Oki(Japan Aerospace Exploration Agency), Yoshiaki HONDA(Center for Environmental Remote Sensing, Chiba University), Yukari Takayabu(Atmosphere and Ocean Research Institute, the University of Tokyo), Tsuneo Matsunaga(Center for Global Environmental Research and Satellite Observation Center, National Institute for Environmental Studies)

In recent years, we cannot avoid facing issues on global environmental changes that occur in various spatiotemporal scales. The earth environmental observation data by satellites became the necessary basic data to tackle and solve those issues. Due to the recent advancement in the observation sensor technique and the data processing technique, the satellite observation has been showing rapid progress, and the time is changing from examining the accuracy of the observation sensor data to the advancement of the data application, leading to broaden potential users. In these days application became synergetic, so we comprehensively pick up this topic in the Atmospheric and Hydrospheric Sciences Session of this Union Meeting that enables to comprise the atmospheric, oceanic and land sciences; by combining the intelligence and the knowledge of the party, we propose a session that aims to prompt further studies towards the issues on earth environmental change, the advancement in the data application and future plans of Earth Observation missions.

[ACG51-13] An Overview of NASA's Aerosols and Clouds-Convection-Precipitation (A-CCP) Pre-formulation Study

★Invited Papers

*Arlindo da SIlva[1] (1.NASA Goddard Space Flight Center)

[ACG51-14] **Cloud liquid water database derived from a global cloud-system resolving model for precipitation retrievals of GPM/DPR observations**

*Takuji Kubota[1], Masaki Satoh[2], Shinta Seto[3], Toshio Iguchi[4], Takeshi Masaki[5], Tomoe Nasuno[6], Riko Oki[1] (1.Earth Observation Research Center,Japan Aerospace Exploration Agency, 2.Atmosphere and Ocean Research Institute, University of Tokyo, 3.Graduate School of Engineering, Nagasaki University, 4.Earth System Science Interdisciplinary Center, University of Maryland, 5.Remote Sensing Technology Center of Japan, 6.Research Institute for Global Change, Japan Agency for Marine-Earth Science and Technology)

[ACG51-15] Validation of DPR products by using MP-PAWR data - thunder storm case on August 27, 2018 –

*Nobuhiro Takahashi[1], Takeharu Kouketsu[1] (1.Institute for Space-Earth Environmental Research, Nagoya University)

[ACG51-16] Near-global three-dimensional hail signals detected by using GPM-DPR observations

*Tatsuya Seiki[1] (1.Japan Agency for Marine-Earth Science and Technology)

[ACG51-17] Precipitation and latent heating distribution in extratropical cyclones observed by the Global Precipitation Measurement Dual-frequency Precipitation Radar

*Hiroki Tsuji[1], Yukari Takayabu[1], Eigo Tochimoto[1] (1.Atmosphere and Ocean Research Institute, The University of Tokyo)

[ACG51-18] Ensemble-Based Data Assimilation of GPM/DPR Reflectivity into the Nonhydrostatic Icosahedral Atmospheric Model NICAM

*Shunji Kotsuki[1], Koji Terasaki[2], Masaki Satoh[3], Takemasa Miyoshi[2] (1.Center for Environmental Remote Sensing, Chiba University, 2.RIKEN Center for Computational Science, 3.Atmosphere and Ocean Research Institute, The University of Tokyo)

An Overview of NASA's Aerosols and Clouds-Convection-Precipitation (A-CCP) Pre-formulation Study

*Arlindo da SIlva[1]

1. NASA Goddard Space Flight Center

The 2017 Decadal Survey (DS) highlighted Earth System Science themes, science and application questions, and several high priority objectives that have led to the inclusion of Aerosols (A) and Clouds-Convection-Precipitation (CCP) as *Designated Observables* (DOs). On July 17, 2018, several NASA centers (GSFC, LaRC, JPL, MSFC, GRC and ARC) submitted a joint Study Plan to the NASA Earth Science Division for the Aerosol (A) and Cloud, Convection, and Precipitation (CCP) Pre-formulation Study (A-CCP). The DS and the A-CCP team recognized the science merit in combining the A and CCP DOs for both enhancing the ability to address a number of science objectives and also to provide an expanded capability to address additional objectives beyond those addressed by individual DOs.

A critical element of the A-CCP observing strategy is to make extensive use of new passive and active sensors as well as of the so-called Program-of-Record (PoR), complemented by a fully integrated sub-orbital component. Central to this observing system design is the adoption of a *Value Framework* in which quantitative assessment of the science benefits of space- and air-borne assets is a key element. Given pre-defined A-CCP science objectives and geophysical variables with desired accuracies, A-CCP relies on a spectrum of Observing System Simulation Experiments (OSSEs) aimed at addressing pixel level retrieval uncertainties and sampling trade-offs.

In this talk we present an overview of the ACCP study. Starting with its roots at the 2017 Decadal Survey, we will outline the main goals and science objectives of ACCP, followed by a brief description of the study approach, value framework and architectures being considered. We will then highlight *OSSEs* activities being conducted, namely, synergistic retrievals involving passive/active sensors of particular relevance for the A-CCP science objectives and the key architectures being considered.

Keywords: aerosol, clouds, convection, precipitation, satellite

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Cloud liquid water database derived from a global cloud-system resolving model for precipitation retrievals of GPM/DPR observations

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The Dual-frequency Precipitation Radar (DPR) onboard the Global Precipitation Measurement (GPM) Core Observatory was launched on February 2014. The DPR expands the coverage of observations to include higher latitudes than those that are obtained by the Precipitation Radar (PR) onboard the Tropical Rainfall Measuring Mission (TRMM). The DPR measures precipitation via higher-sensitivity observations than those of the TRMM/PR and provides drop size distribution (DSD) information based on the differential scattering properties at the two frequencies. The DPR consists of Ku-band (13.6 GHz) precipitation radar (KuPR) and Ka-band (35.5 GHz) pre-cipitation radar.

In generating precipitation datasets, it is necessary to develop computationally efficient, fast-processing DPR Level-2 (L2) algorithms that can provide estimated precipitation rates, radar reflectivity factors, and precipitation information, such as the DSD and precipitation type. In the L2 algorithms, an assumption related to Cloud Liquid Water (CLW) is one of uncertain factors; the algorithm assumes the liquid water profiles in precipitating clouds. Attenuation by CLW is larger in the Ka-band than in the Ku-band, as shown in previous works . Therefore, estimating precipitation intensity with high accuracy from KaPR observations requires developing a method to estimate the attenuation due to CLW and incorporate it into the algorithm.

As the CLW assumption in precipitation retrievals for the spaceborne radar, regional atmospheric simulations and observational data were utilized in previous works. Recently, high-resolution global atmospheric simulations have been done using a global cloud-system resolving model (GCRM) (Stevens et al. 2019). The GCRM explicitly calculates moisture convection using a microphysical cloud scheme. The development of the GCRM was pioneered by the Nonhydrostatic ICosahedral Atmospheric Model (NICAM).

The DPR-L2 algorithm uses a correction method for attenuation by CLW that was developed using 3.5km-mesh NICAM simulation data. In the algorithm, the CLW value is assumed using the database with inputs of the surface precipitation rate, precipitation type (convective or stratiform), temperature, latitude, and surface type.

By comparing the one-month experiment of CLW with 0 mg/m^3, the impact of current CLW assumptions for surface precipitation estimates were evaluated using the Normalized Mean Absolute Error by 1.8% for the Ku, 14.0% for the Ka, and 8.0% for the Dual-Frequency algorithms in global averages.

Effects of the precipitation estimates from the CLW assumption were examined further for correction of the radar reflectivity by path-integrated attenuation (PIA) due to CLW and consideration of the PIA due to CLW in estimating the PIA due to precipitation. While the experiments confirmed the offsets between both

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effects and therefore reduced residual errors related to the CLW assumption, this paper emphasizes higher impacts of the consideration in estimating the PIA by the precipitation to precipitation retrievals.

Keywords: Global Precipitation Measurement, Dual-frequency Precipitation Radar , Cloud Liquid Water

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Validation of DPR products by using MP-PAWR data - thunder storm case on August 27, 2018 –

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Validation of dual-frequency precipitation radar (DPR) onboard Global Precipitation Measurement (GPM) core observatory is aimed to evaluate not only the surface precipitation ratio and corresponding Z value but also three-dimensional structure of precipitation including cloud physical properties. Because of dual-frequency observation, GPM/DPR can estimate drop size distribution and rain/snow classification. Recently, GPM/DPR product added the information of the hail/graupel existence. These values are hard to be evaluated because of lack of the observation. A ground-based multi-parameter phased array weather radar (MP-PAWR) has advantages on the simultaneous three-dimensional observation and estimation of cloud physical properties. Since the MP-PAWR operates electrical scan in elevation and mechanical scan in azimuth, it completes the three-dimensional observation within 30 seconds. In addition, by using dual-polarization observation, cloud physical properties such as particle type classification can be achieved.

This study aims to evaluate the cloud physical properties estimated by GPM/DPR are evaluated ground-based multi-parameter weather radar. This study shows a case on August 27, 2018 when the GPM flew over Kanto area at 18:20 JST. Unfortunately, MP-PAWR was not operated because of power shutdown in this time frame (17:40-19:35). The X-band MP radar network (XRAIN) data are used for analysis. Even XRAIN consists of conventional multi-parameter radar, there are 5 radars over Kanto area and therefore the three-dimensional structure of precipitation system is retrieved by combining multiple radar. Three-dimensional wind field is estimated by the dual-Doppler analysis by using all combinations of radars.
The flagHeavyIcePrecipitation in GPM/DPR product, which indicates the existence of large particles above -10-degree Celsius height, were observed at the target area. The ground-based radar also caught the signature of mixed-phase precipitation indicating the existence both rain and ice particles. The precipitation system is sustained by the updraft less than 4 km in height. Note that hail storm was reported 30 to 20 minutes before the GPM observation. At that time, the precipitation system is characterized by the strong updraft above melting level (> 5 km) and mixture of rain and ice particles even above the melting layer.

Keywords: Precipitation, hail and grapple, multi-parameter radar

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Near-global three-dimensional hail signals detected by using GPM-DPR observations

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A hailstone is a large, dense ice particle, and its particle size often reaches more than 1 cm. Hail is known to be associated with intense storms and causes severe damage to cars, buildings, and croplands. In general, hail has been observed by weather radar systems or reported from visual checks on the ground. Such observations are limited to developed countries and populated regions, and hence, the global three-dimensional structure of hail has not yet been analyzed.
This study proposes a method to detect three-dimensional hail distribution by using the GPM (Global Precipitation Measurement) DPR (Dual-frequency Precipitation Radar) products in combination with the atmospheric temperature from a reanalysis product. The ZKu (radar reflectivity at the Ku-band) and DFR (dual-frequency ratio) values are examined for hydrometeor classification at the five atmospheric temperature ranges by comparison to the ground radar product in a test hail storm case. The hail signals lie along the collisional growth curves on the scatter plot of ZKu and DFR. The five-year dataset of the GPM-DPR observations illustrates that hail is widely distributed over the ocean and is frequently observed near the freezing level. Most oceanic hail layers are found to be thin (i.e., less than 1500 m) and, hence, have been potentially missed by ground observations.

Keywords: hail, severe storm, extreme weather events

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Precipitation and latent heating distribution in extratropical cyclones observed by the Global Precipitation Measurement Dual-frequency Precipitation Radar

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Extratropical cyclones (ETCs) contribute to more than 90% of precipitation climatology in some area of midlatitude in winter (Hawcroft et al. 2012). Latent heating associated with precipitation affects structure and development of ETCs through diabatic potential vorticity production. However, almost no statistical studies about precipitation and latent heating distribution in ETCs have performed. In this study, horizontal distribution and vertical profiles of precipitation and latent heating in extratropical cyclones are statistically investigated using four years of the Global Precipitation Measurement (GPM) satellite radar observation data. Over 1200 ETCs in both hemispheres occurred in winter are used in this study.

The results of composite analyses aligning ETC centers show that precipitation distribution during developing stage of the northern hemisphere ETCs are similar to that in the idealized ETC shown in previous studies. Convective precipitation is dominant in a cold front, whereas stratiform precipitation is dominant in a warm front. The convective precipitation in the cold front is unclear in the southern hemisphere ETCs. The fronts are not observed in composites for ETCs in decaying stage for both hemispheres, in which shallow and isolated precipitation is dominant.

The maximum latent heating is observed at an altitude of 3.5 km. Cooling is observed below 750 m. These characteristics are maintained during the life cycle of the ETCs in both hemispheres. Maximum heating is observed at 24 hours before the time when the ETCs reach its minimum pressure. After reaching the maximum heating, the peak values of heating decreases with time, whereas change of the low-level cooling is small. The maximum heating value for the southern hemisphere ETCs is a half of that for the northern hemisphere ETCs.

We also performed analyses dividing ETCs into explosively developing cyclones and non-explosively developing cyclones. In the northern hemisphere, composites of the explosively developing cyclones show clear warm and cold fronts in developing stage. In contrast, the cold front in the composite of the non-explosively developing cyclones is unclear. The cold front is unclear in the composite of southern hemisphere explosively developing cyclones.

Acknowledgments
This study is supported by the Japan Aerospace Exploration Agency (JAXA) Precipitation Measuring Mission science.

Keywords: extratropical cyclones, precipitation, latent heating, GPM

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Ensemble-Based Data Assimilation of GPM/DPR Reflectivity into the Nonhydrostatic Icosahedral Atmospheric Model NICAM

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This study aims to improve the precipitation forecasts from numerical weather prediction models through effective assimilation of satellite-observed precipitation data. The assimilation of precipitation data is known to be difficult mainly due to highly non-Gaussian statistics of precipitation-related variables. We have been developing a global atmospheric data assimilation system NICAM-LETKF, which comprises the Nonhydrostatic ICosahedral Atmospheric Model (NICAM) and Local Ensemble Transform Kalman Filter (LETKF). Using the NICAM-LETKF system, Kotsuki et al. (2017, JGR) successfully improved the weather forecasts by assimilating the Japan Aerospace eXploration Agency (JAXA)' s Global Satellite Mapping of Precipitation (GSMaP) data into the NICAM at 112-km horizontal resolution. However, assimilating space-borne precipitation radar data remains to be a challenging issue.
This study pioneers to assimilate radar reflectivity measured by the Dual-frequency Precipitation Radar (DPR) onboard the Global Precipitation Measurement (GPM) core satellite into the NICAM. We conduct the NICAM-LETKF experiments at 28-km horizontal resolution with explicit cloud microphysics of a single-moment 6-class bulk microphysics scheme. To simulate GPM/DPR reflectivity from NICAM model outputs, the Joint-Simulator (Hashino et al. 2013; JGR) is used. Our initial tests showed a better match with the observed reflectivity by assimilating GPM/DPR reflectivity into NICAM forecasts. However, the results from a 1-month data assimilation cycle experiment showed general degradation by assimilating GPM/DPR reflectivity. For better use of GPM/DPR reflectivity data, we are exploring to estimate model cloud physics parameters for terminal velocity by data assimilation. Parameter sensitivity experiments revealed that using a parameter of slower snowfall made contoured frequency by altitude diagrams (CFADs) closer to GPM/DPR observations. The parameter of slower snowfall also improved temperature and humidity fields in the mid- to lower troposphere. This presentation will include the most recent progress up to the time of the conference.

Keywords: GPM DPR, NICAM-LETKF, Data Assimilation, Cloud Microphysics

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG51] Satellite Earth Environment Observation

convener:Riko Oki(Japan Aerospace Exploration Agency), Yoshiaki HONDA(Center for Environmental Remote Sensing, Chiba University), Yukari Takayabu(Atmosphere and Ocean Research Institute, the University of Tokyo), Tsuneo Matsunaga(Center for Global Environmental Research and Satellite Observation Center, National Institute for Environmental Studies)

In recent years, we cannot avoid facing issues on global environmental changes that occur in various spatiotemporal scales. The earth environmental observation data by satellites became the necessary basic data to tackle and solve those issues. Due to the recent advancement in the observation sensor technique and the data processing technique, the satellite observation has been showing rapid progress, and the time is changing from examining the accuracy of the observation sensor data to the advancement of the data application, leading to broaden potential users. In these days application became synergetic, so we comprehensively pick up this topic in the Atmospheric and Hydrospheric Sciences Session of this Union Meeting that enables to comprise the atmospheric, oceanic and land sciences; by combining the intelligence and the knowledge of the party, we propose a session that aims to prompt further studies towards the issues on earth environmental change, the advancement in the data application and future plans of Earth Observation missions.

[ACG51-19] Improvement and Evaluation of 1-moment Cloud Microphysics using GPM Satellite Data

*Yasutaka Ikuta[1] (1.Japan Meteorological Agency)

[ACG51-20] Satellite-based Data Assimilation Systems by Using Microwave Radiometers

★Invited Papers

*Toshio Koike[1] (1.International Centre for Water Hazard and Risk Management)

[ACG51-21] How much is the accuracy of land emissivity representation necessary for adequate cloud water content estimation over land using satellite-based passive microwave remote sensing?

*Rie Seto[1], Kentaro Aida[2], Toshio Koike[2], Shinjiro Kanae[1] (1.Tokyo Institute of Technology, 2.The International Centre for Water Hazard and Risk Management under the auspices of UNESCO)

[ACG51-22] Detectability of Heavy Rainfall and Drought in East Asia and Western Pacific Region using GSMaP

*Tashima Tomoko[1], Takuji Kubota[1], Riko Oki[1] (1.Japan Aerospace Exploration Agency)

[ACG51-23] Identifying Gaps Between Satellite Measurement Capability and Decision-making in Water Resource Management – A Case Study from Australia

*Maki Kikuchi[1,2], Anthony S. Kiem[2], Andrew D. Magee[2], Matthew Armstrong[2] (1.Japan Aerospace Exploration Agency (JAXA), 2.The University of Newcastle)

[ACG51-24] Rice planted area mapping using ALOS-2 ScanSAR data with Machine Learning Algorithm

*Kei Oyoshi[1], Shinichi Sobue[1] (1.JAXA Japan Aerospace Exploration Agency)

Improvement and Evaluation of 1-moment Cloud Microphysics using GPM Satellite Data

*Yasutaka Ikuta[1]

1. Japan Meteorological Agency

A radar simulator as observation operators has been developed for GPM/DPR data assimilation in JMA. A function to simulate the melting layer and an artificial noise-filter to reproduce the detection limit of radar were implemented into the simulator. Using the radar-simulator and RTTOV, we verified the predictions of the operational Meso-Scale Model (MSM) against GPM satellite observation data. Compared to DPR, the amount of rain in the lower troposphere was underestimated, and compared to GMI using RTTOV-SCATT, the amount of cloud ice was further underestimated. We found that the reasons for the underestimation were due to the large evaporation rate of rain and the large conversion rate of cloud ice into snow. These errors were successfully reduced by revision to the PSD for rain, the terminal velocity of cloud-ice and the conversion methods between water species. This improvement has a large impact for precipitation and atmospheric profiles in the forecast of MSM. In this presentation, I would like to show the improvement of 1-moment cloud microphysics in our operational system.

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Satellite-based Data Assimilation Systems by Using Microwave Radiometers

*Toshio Koike[1]

1. International Centre for Water Hazard and Risk Management

Various types of data assimilation systems for monitoring and prediction water cycle have been developed based on the information derived from satellite-based passive microwave radiometers boarded on satellites. By coupling a land data assimilation by using satellite-based passive microwave sensors with an atmospheric model, Land Data Assimilation System coupled with Atmospheric model (LDAS-A) physically input land surface hydrological conditions into a land-atmosphere coupled model. By merging the land surface information obtained ranging from the lower frequencies to the higher frequency, Coupled Atmosphere and Land Data Assimilation System (CALDAS) assimilate soil moisture, vertically integrated cloud water content over land, and heat and moisture within clouds simultaneously. By using high sensitivity of microwave to water included in surface soil and terrestrial vegetation, Coupled Land and Vegetation Data Assimilation System (CLVDAS) can provides better estimates of vegetation growth as we as soil moisture.

Keywords: Microwave, Data Assimilation, Water Cycle

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How much is the accuracy of land emissivity representation necessary for adequate cloud water content estimation over land using satellite-based passive microwave remote sensing?

*Rie Seto[1], Kentaro Aida[2], Toshio Koike[2], Shinjiro Kanae[1]

1. Tokyo Institute of Technology, 2. The International Centre for Water Hazard and Risk Management under the auspices of UNESCO

The utilization of satellite-based passive microwave remote sensing (PMW) is an essential technique to grasp the long-term and extensive distribution of cloud water content (CWC). However, in particular, over highly heterogeneous land, detailed MW radiative transfer characteristics between land and atmosphere including clouds are not adequately elucidated. Therefore, most of CWC estimation methods are not implemented over land. This study aims to elucidate these characteristics and to reveal for adequate estimation of CWC over land using satellite-based PMW, how much accuracy of representation of land emissivity is needed. For this purpose, at first, the important parameters related to MW radiative transfer at CWC-sensitive frequencies (89 and 36 GHz) between land and atmosphere under the existence of clouds are clarified based on the radiative transfer equations. Also, the relationship between errors in representation of these parameters and brightness temperatures used for CWC estimation is specified through theoretical consideration. Then, ground-based passive MW radiometer observations and numerical simulations are utilized to reveal real features of these important parameters, physical variables of land which have large radiative impacts, and their relationships. Finally, it is found that there are threshold values of liquid water path with which we can reasonably neglect the heterogeneity of emissivity and radiation of land surface in CWC estimation over land. Furthermore, for the case of LWP less than the thresholds, we show the desirable accuracy in representation of land emissivity and volumetric soil moisture content for both frequencies.

Keywords: Satellite-based microwave remote sensing, Estimation of cloud water content over land, radiation of land

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Detectability of Heavy Rainfall and Drought in East Asia and Western Pacific Region using GSMaP

*Tashima Tomoko[1], Takuji Kubota[1], Riko Oki[1]

1. Japan Aerospace Exploration Agency

To demonstrate a usefulness for precipitation extremes monitoring in East Asia and Western Pacific region using satellite-based precipitation products, case analysis and statistical analysis for both heavy rainfall and drought are investigated. As one of satellite-based precipitation products, the focus here is on the Global Satellite Mapping of Precipitation (GSMaP) provided by the Japan Aerospace Exploration Agency (JAXA). GSMaP is a product of the Global Precipitation Measurement (GPM) mission, which provides a global hourly rain rate with a 0.1 x 0.1 degree resolution. Though there are various products in GSMaP, we use Near-real-time Gauge-adjusted Rainfall Product (GSMaP GNRT) that is the most suitable for monitoring.

Heavy rainfall for daily and weekly precipitation is defined by threshold of 90th percentile or more over periods from April 2000 to March 2019. From comparison between GSMaP GNRT and CPC GAG, it is indicated that a threat score increases as total precipitation increases. In results by three thresholds (90th, 95th and 99th percentile), the higher the percentiles, the lower the detectability. If the forecast is wrong, the number of “false alarm” tends to be higher than “Misses”. Furthermore, it is suggested that a threat score varies greatly from region to region. In Australia where is dry area, the detection rate for a threshold of 90th or 95th percentiles is relatively high. On the other hand, in Indonesia where is a rainy island country, the detection rate for even a threshold of 90th percentile is low. Such low detectability in snowfall areas, mountains and rainy island nations may be caused by characteristics of GSMaP products of algorithm version 6 used in this study such as are the non-implementation of the snowfall estimation method, the limitation of Orographic/non-orographic rainfall classification scheme and difficulty of coastal estimation.

Short-term drought from one-month to three-month are defined by Standardized Precipitation Index (SPI) calculated by GSMaP GNRT since April 2000. From comparison of SPIs between GSMaP GNRT and CPC GAG, correlation coefficients in East Asia and Western Pacific region are 0.712 in 1-month SPI, 0.728 in 2-month SPI, and 0.735 in 3-month SPI, that is, the longer the accumulation period of precipitation, the higher the detection rate. Especially, correlation coefficients in Australia, which has experienced numerous droughts in recent years, are higher; 0.763, 0.786, and 0.794. Moreover, it seems that GSMaP GNRT tends to detect drought intensity somewhat weakly.

Keywords: GSMaP, heavy rainfall, drought, monitoring

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Identifying Gaps Between Satellite Measurement Capability and Decision-making in Water Resource Management –A Case Study from Australia

*Maki Kikuchi[1,2], Anthony S. Kiem[2], Andrew D. Magee[2], Matthew Armstrong[2]

1. Japan Aerospace Exploration Agency (JAXA), 2. The University of Newcastle

Over the past 50-years, satellite observing systems have become more stable and satellite sensors have become fundamental tools for observing, understanding and managing the Earth’ s environment. While attempts to improve data accuracy continue, expectations of satellite missions have been shifting from achieving stable measurements to exploring more complex scientific questions and wider areas of operational applications. One such area is water resource management, since the monitoring of water at both the local and global scales is essential in enabling improved decision-making. As such, the aim of this study is to investigate the needs of decision-makers in water resource management and identify the gaps between these needs and the capability of current satellites. To better understand this, we investigated to what extent satellite data is used within national and local government organisations responsible for establishing water policies and how those policies are implemented by water authorities. Australia was chosen as a case study as it is widely known as a country that is influenced significantly by climate variability and has experienced severe drought, cyclones, flooding and bushfires. The needs of the decision-makers were collected through online surveys and interviews from national and state water resource management sectors across New South Wales, Victoria, Queensland and the Australian Capital Territory, where 80% of the Australian population are governed. For each satellite measurement related to water management, the following five satellite specifications were investigated in particular: (1) *spatial resolution*; (2) *temporal resolution*; (3) *latency*; (4) *continuity*; and (5) *accuracy*. The response data collected was evaluated to understand and quantify the gaps between end-user needs and the capability of current satellites to identify specific areas of improvements in satellite development. For example, whether improvements require in sensors and algorithm development for resolution improvements, or in the ground-based facilities for prompt distribution, or even in national satellite planning to secure observation continuity. The quantitative evaluation and recommendations proposed in this study offer insights for future satellite development and planning in order to bridge the gaps between decision-makers and the products obtained from satellite missions.

Keywords: Satellite, Water Resource Management, Decision-making

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Rice planted area mapping using ALOS-2 ScanSAR data with Machine Learning Algorithm

*Kei Oyoshi[1], Shinichi Sobue[1]

1. JAXA Japan Aerospace Exploration Agency

Rapid population and economic growth, and the increase in extreme weather events, are destabilizing global food security. Rice is a staple cereal crop in Asia, and the continent accounts for about 90% of global rice production and consumption. Rice is mainly cultivated in the rainy season, and the high density of cloud cover during that season limits the observations that can be made from space using only optical sensors. In contrast, Synthetic Aperture Radar (SAR) is a robust tool because it penetrates cloud cover. And also, machine learning technology has been dramatically developed recent years and this technology was used in a lot of land cover related research and distinct results were reported. In this research, machine learning algorithm was applied to ALOS-2 PALSAR-2 ScanSAR data (dual pol. HH and HV) to identify rice planted area in South Asia. However, crop calendar of rice in the region is complicated because adequate temperature allows to plant rice every time if water resource and labor are available. In order to compensate crop calendar difference, time-series metrics such as min/max/range of HH or HV, correlation coefficient of HH and HV etc. were calculated during the determined cropping cycle. These metrics were used as input data to develop random forest classifier for four countries including Cambodia, Laos PDR, Thailand, and Vietnam. Test accuracies of the model for each country were evaluated using the half of training data and the results showed high accuracy. In addition, the resulted rice-planted are map were compared with existing rice maps developed by other satellite such as Sentinel-, Radarsat-2, Landsat and some differences were observed between the maps, but high consistency was confirmed. Rice planted area is fundamental information for national agricultural related policy, our result would improve our ability to estimate rice crop production, and also quantify the carbon, water balance or methane emission via paddy fields.

Keywords: ALOS-2, Machine Learning, Rice planted area, Lower Mekon River countries

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG52] Large Ensemble Modeling Approaches as Tools for Climate and Impacts Research

convener:Rodgers Keith Bradley(IBS Center for Climate Physics), Shoshiro Minobe(Graduate School of Science, Hokkaido University), Hideo Shiogama(Center for Global Environmental Research, National Institute for Environmental Studies), Ryo Mizuta(Meteorological Research Institute)

Large ensemble model simulations are now integral tools for evaluating climate variability, climate change, and associated impacts. The range of tools applied encompasses Earth System Models (ESMs), Coupled General Circulation Models (CGCMs), Atmospheric General Circulation Models (AGCMs), Ocean General Circulation Models (OGCMs), and Regional Climate Models (RCMs), with the number of ensemble members typically spanning ten to several tens to one hundred. In addition to their utility in identifying emergent forced trends, they are also proving to be of great value in the study of extreme events and how extreme events evolve under anthropogenic perturbations. Furthermore, large ensembles of AGCMs nd OGCMs can prove invaluable as complements to fully coupled models in providing insights into scales and drivers of variability and trends, as well as climate feedbacks.
This session welcomes studies using the full range of large ensemble modeling tools. This includes studies of emergent trends and extreme events, and more generally studies that facilitate interpretation of observations as well as projections of future changes. Abstracts are particularly welcomed that address novel and emergent topics, including but not limited to compound events, biogeochemistry, and observing system design.

[ACG52-01] Evaluating ocean physical biogeochemical interactions in ESM large ensembles

★Invited Papers

*Takamitsu Ito[1], Filippos Tagklis[1], Yohei Takano[2] (1.Georgia Institute of Technolog, 2.Los Alamos National Laboratory)

[ACG52-02] Event attribution using large ensemble model simulations by MIROC5-AGCM, MRI-AGCM, and NHRCM

★Invited Papers

*Yukiko Imada[1], Hiroaki Kawase[1], Hideo Shiogama[3], Masato Mori[4], Chiharu Takahashi[2], Miki Arai[5], Masahiro Watanabe[2], Izuru Takayabu[1] (1.Meteorological Research Institute, Japan Meteorological Agency, 2.Atmosphere and Ocean Research Institute, the University of Tokyo, 3.National Institute for Environmental Studies, 4.Research Center for Advanced Science and Technology, the University of Tokyo, 5.Japan Agency for Marine-Earth Science and Technology)

[ACG52-03] Changes in global terrestrial ecosystem respiration with future warming: a probabilistic approach

*Irina Melnikova[1], Takahiro Sasai[1] (1.Tohoku University)

[ACG52-04] Global warming changes tropical cyclone translation speed

*Munehiko Yamaguchi[1], Johnny C. L. Chan[2], Il-Ju Moon[3], Kohei Yoshida[1], Ryo Mizuta[1] (1.Meteorological Research Institute, Japan Meteorological Agency, 2.City University of Hong Kong, 3.Jeju National University)

[ACG52-05] Nonlinear forced change implies nonergodicity and vice-versa: The case of ENSO teleconnections

*Tamas Bodai[1,2], Axel Timmermann[1,2], Gabor Drotos[3], Timea Haszpra[4] (1.Pusan National University, 2.Center for Climate Physics, Institute for Basic Science, South Korea, 3.Instituto de Física Interdisciplinar y Sistemas Complejos, CSIC-UIB, Palma de Mallorca, Spain, 4.Institute for Theoretical Physics, Eötvös Loránd University, Budapest, Hungary)

[ACG52-06] Parallel Analog Ensemble: The Power of Weather Analogs

*Weiming Hu[1], Guido Cervone[1], Martina Calovi[1], Laura Clemente-Harding[2] (1.Pennsylvania State University Main Campus, 2.Engineer Research and Development Center)

Evaluating ocean physical biogeochemical interactions in ESM large ensembles

*Takamitsu Ito[1], Filippos Tagklis[1], Yohei Takano[2]

1. Georgia Institute of Technolog, 2. Los Alamos National Laboratory

State-of-the-art Earth System Models (ESMs) disagree in the sign of dissolved oxygen changes in the tropical oceans under global warming. Unlike heat or carbon dioxide, atmospheric oxygen has a very weak anthropogenic trend, thus the long-term change of oceanic oxygen reflects ocean circulation and biochemical changes induced by the warming and stratification increase. These model disagreements imply fundamental differences in the sensitivity of physical and biogeochemical processes that impact not only oxygen cycling but also other important elements such as nitrogen, phosphorus and carbon with implications to ecosystem health. The growing collection of historical datasets is finally allowing the direct comparison of simulated and observed dissolved oxygen over the last several decades. On one hand, natural climate variability influences oxygen changes as recorded in historical datasets, and on the other a correct diagnosis of anthropogenic trends requires an understanding of background natural climate variability. ESM simulations offer a powerful tool to examine underlying mechanisms of observed biogeochemical changes. We examine the simulated physical and biogeochemical changes under the Representative Concentration Pathway (RCP) 8.5 scenario in two large ensembles of ESMs; 34 member CESM-LENS and 100 member MPI-GE, exhibiting significantly different patterns of ocean deoxygenation. The results are interpreted in terms of the relationship between the ocean oxygen inventory and the heat content, and linking the physical climate modes to the pattern of biogeochemical variability. Water mass displacement often results in positive relationship between oxygen and heat. In contrast ocean stratification and ventilation changes typically result in negative relationship. The representation of physical climate modes and atmospheric teleconnections are essential for reproducing the biogeochemical properties and their spatio-temporal patterns.

Keywords: physical biogeochemical interaction, earth system model

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Event attribution using large ensemble model simulations by MIROC5-AGCM, MRI-AGCM, and NHRCM

*Yukiko Imada[1], Hiroaki Kawase[1], Hideo Shiogama[3], Masato Mori[4], Chiharu Takahashi[2], Miki Arai[5], Masahiro Watanabe[2], Izuru Takayabu[1]

1. Meteorological Research Institute, Japan Meteorological Agency, 2. Atmosphere and Ocean Research Institute, the University of Tokyo, 3. National Institute for Environmental Studies, 4. Research Center for Advanced Science and Technology, the University of Tokyo, 5. Japan Agency for Marine-Earth Science and Technology

There are many evidences of connections between long-term trends of extreme events and the human influence. However, specific extreme events can not totally be blamed on the past human activity, because extreme events can be happened only due to the natural variability. In this study, we examine whether human influence has largely affected the probability of extreme events by comparing large-ensemble climate model simulations under the "factual" conditions and the "counterfactual" ones in which influences of anthropogenic climate drivers were omitted. Such an attempt is called "Event Attribution" (EA).
We conducted large ensemble simulations for the factual and counterfactual experiments using two atmospheric general circulation models: MIROC5-AGCM and MRI-AGCM3.2. The MIROC5 dataset is superior for consideration of the range of uncertainty, whereas the MRI-AGCM3.2 dataset, so called d4PDF (the Database for Policy Decision making for Future climate change), focuses on high-resolution simulations with ~60 km horizontal resolution along with downscaled products produced by a regional climate model NHRCM with ~20km horizontal resolution which covers the East Asian region.
Here, I will introduce our recent works using the large ensemble simulations focusing on how much anthropogenic global warming contributed to increased occurrence of recent extreme events around the globe when compared to the inter-annual and decadal variability.

Keywords: Event Attribution, Large ensemble simulation, Extreme event

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Changes in global terrestrial ecosystem respiration with future warming: a probabilistic approach

*Irina Melnikova[1], Takahiro Sasai[1]

1. Tohoku University

The atmospheric increase in CO_2 concentration and consequent climate change rendered the terrestrial biosphere as an increasing carbon sink. Although several studies have warned that the land sink may slow down or reverse in a future warmer world, no study projected the future changes in the carbon fluxes by using statistical methods. Here we combined a biosphere model BEAMS and a large-ensemble warming climate simulations of d4PDF data set in order to investigate the changes in the frequency distributions of global terrestrial ecosystem respiration (TER) in 1960–2010 and future +2K and +4K warmer than pre-industrial climate simulations. This is a pioneer study that performs a probabilistic approach to analyze the future changes in TER. The biosphere model outputs indicate that both magnitude and interannual variability of TER increase with climate warming, with larger relative increase in the high latitudes. The increase in TER variability exhibits bipolarity and corresponds to higher TER in the tropics and northern high latitudes. The TER increase in the present climate is attributed to the CO2 fertilization effect-driven increase in plant biomass. However, in future +2K and +4K climates, temperature contribution to the anthropogenic TER effect is projected to increase exponentially according to Q10 function. The disproportional increase in TER with warming towards high latitudes that are a massive reservoir of soil carbon highlight the need in the urgent action for stronger mitigation policies. The estimation of unaccounted land carbon fluxes, e.g. permafrost thawing and subsequent decomposition of organic matter, fires, etc. would further contrite to deepening the understanding of the impact of anthropogenic activities on the terrestrial carbon fluxes.

Keywords: d4PDF, biosphere model, TER

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Global warming changes tropical cyclone translation speed

*Munehiko Yamaguchi[1], Johnny C. L. Chan[2], Il-Ju Moon[3], Kohei Yoshida[1], Ryo Mizuta[1]

1. Meteorological Research Institute, Japan Meteorological Agency, 2. City University of Hong Kong, 3. Jeju National University

Slow-moving tropical cyclones (TCs) can cause heavy rain because of their duration of influence. Combined with the expected increase in rain rates associated with TCs in a warmer climate, there is growing interest in TC translation speed in the past and future. Observational data since the mid-twentieth century indicate a slowdown of the TC translation speed due to the weakening of the general atmosphere circulation. However, it has also been pointed out that the slowdown may not be a real climate signal and could be due to inhomogeneities in the observational data used. As it is difficult to ascertain the extent of such inhomogeneities, we propose to examine large ensemble numerical simulations from a high-resolution atmospheric general circulation model that is able to simulate the present-day TC frequency and distribution. Here we show that a slowdown trend is not simulated for the period 1951-2011, based on the model historical simulations using specified interannually-varying observed sea-surface temperatures together with observed greenhouse gas concentrations. We also find that the annual-mean translation speed could increase in a future warmer climate. Although previous studies show a large uncertainty in the projections of changes in TC characteristics including its tracks, results from the model used in this study show that the average TC translation speed at higher latitudes becomes smaller in the warmer climate, but the relative frequency of TCs at higher latitudes also increases. Since the translation speed is much larger in the extratropics, the increase in the relative frequency of TCs at higher latitudes compensates the reduction of the translation speed there, leading to a global mean increase in TC translation speed.

Keywords: Global warming, Tropical cyclone, Translation speed

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Nonlinear forced change implies nonergodicity and vice-versa: The case of ENSO teleconnections

*Tamas Bodai[1,2], Axel Timmermann[1,2], Gabor Drotos[3], Timea Haszpra[4]

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We study the forced response of the teleconnection between the El Niño–Southern Oscillation (ENSO) and global precipitation in general and the Indian summer monsoon (IM) in particular in the Max Planck Institute Grand Ensemble. The forced response of the teleconnection is defined as the time-dependence of a correlation coefficient evaluated over the ensemble. The ensemble-wise variability is taken either wrt. spatial averages or dominant spatial modes in the sense of Maximal Covariance Analysis or Canonical Correlation Analysis or EOF analysis. We find that the strengthening of the ENSO-IM teleconnection is robustly featured in view of all four teleconnection representations, and both in the historical period and under the RCP8.5 forcing scenario. We also find that this forced change is typically nonlinear by formally rejecting the hypothesis that ergodicity holds, i.e., that expected values of temporal correlation coefficients with respect to the ensemble equal the ensemble-wise correlation coefficient itself. We also provide global maps of the degree of nonlinearity of the forced change of the teleconnection between local precipitation and ENSO.

Keywords: ENSO, Indian summer monsoon, teleconnection, global precipitation, ergodicity, Maximum Covariance Analaysis

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Parallel Analog Ensemble: The Power of Weather Analogs

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1. Pennsylvania State University Main Campus, 2. Engineer Research and Development Center

We present the newest release of a parallel, scalable, and extensible implementation of the Analog Ensemble technique, called PAnEn. Forecast ensembles are usually generated using multi-model or multi-initialization approaches. These approaches become computationally expensive rapidly when the spatial and temporal resolution increases. On another hand, Analog Ensemble generates forecast ensembles relying on a single deterministic model simulation and the corresponding observations or model analysis.

Weather analogs are defined using a multi-variate linear distance function. According to the calculated distance metric, the most similar past forecasts to the current forecasts are identified, and the observations associated with the most similar past forecasts are selected as analog ensemble members. Analog Ensemble has been successfully applied to various projects across the fields including weather forecasting, air quality control, and renewable energy forecasting.

PAnEn implements the complete framework of data pre-processing, analog generation, post-processing, and data visualization. It also ships with a set of command-line utilities to generate and evaluate analogs. The core libraries are implemented in C++ for performance and the programming interfaces are available both in C++ and R. The package is opensource and documented. To harness the power of high-performance computing, PAnEn can be deployed with RADICAL EnTK and run on supercomputers such as XSEDE Summit and NCAR Cheyenne. The implementation achieves 92% overall parallelization.

PAnEn is a well-suited solution for problems where calibrated forecast ensembles are needed but computation remains a constraint. It can also be applied to uncertainty quantification and model downscaling. We hope to present these use cases and support collaborations.

Keywords: Analog Ensemble, Ensemble Modelling, HPC

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[E] Oral | A (Atmospheric and Hydrospheric Sciences)：A-CG Complex & General

[A-CG53] Terrestrial monitoring using new-generation geostationary satellites

convener:Yuhei Yamamoto(Center for Environmental Remote Sensing, Chiba University), Yunyue Yu(NOAA National Environmental Satellite, Data, and Information Service), Tomoaki Miura(Univ Hawaii), Kazuhito Ichii(Chiba University)

The third-generation geostationary satellites, such as Himawari 8/9, GOES-16/17, Fengyun-4, and GeoKompsat-2A are recently launched, and earth observation is in a new phase. These sensors are equipped with new spectral bands suitable for terrestrial monitoring used in polar-orbiting satellite sensors, enabling detailed land observations such as land surface temperature, surface albedo, and land cover and vegetation dynamics. Furthermore, by utilizing the advantages of hypertemporal (e.g. 10 min) and moderate spatial resolution, various new land dynamics can be observable. By combining these satellites and polar-orbiting satellites/sensors such as Terra/MODIS and GCOM-C/SGLI, a new generation monitoring data covering Asia, Oceania and North and South America will become possible. This would allow for a consistent comparison of a variety of phenomena across continents. To this end, there are many issues to be discussed, such as the standardization of the estimation algorithms of physical quantities, calibration and verification using GEO-(LEO)-GEO satellites, and application of these new datasets to various phenomena.
In this session, we will discuss the retrieval algorithms of land surface parameters, inter-satellite calibration, validation efforts using in-situ data, and novel applications to various phenomena. Studies on atmospheric parameters in relation to land surface phenomena, such as cloud cover are aerosol, are highly welcomed.

[ACG53-01] GeoNEX: Earth observations from operational geostationary satellite systems
★Invited Papers

*Ramakrishna R Nemani[1] (1.NASA Ames Research Center)

[ACG53-02] Preliminary research on validation for the atmospheric correction of HIMAWARI-8 AHI data using SKYNET data

*Hirokazu YAMAMOTO[1], Satoshi Tsuchida[1] (1.Geological Survey of Japan, AIST)

[ACG53-03] An analysis of land surface temperature during summer clear-sky days focusing on the diurnal change characteristics using Himawari-8 data

*Yuhei Yamamoto[1], Kazuhito Ichii[1] (1.Center for Environmental Remote Sensing, Chiba University)

[ACG53-04] An Enterprise Land Surface Temperature (LST) Algorithm for the GOES-R and Himawari Satellites

*Yunyue Yu[1], Jaime Daniels[1], Satya Kalluri[1], Peng Yu[1] (1.NOAA National Environmental Satellite, Data, and Information Service)

[ACG53-05] Analysis of differences between NDVI-based indices of Himawari 8 AHI and Aqua MODIS using Rayleigh-corrected reflectances

*Kenta Obata[1], Hiroki Yoshioka[1] (1.Aichi Prefectural University)

[ACG53-06] Functional grassland phenology discrimination and analyses with Himawari-8 geostationary data
★Invited Papers

*Alfredo R Huete[1], Ngoc Nguyen Tran[1], Qiaoyun Xie[1], Tomoaki Miura[2] (1.University of Technology Sydney, 2.University of Hawaii)

GeoNEX: Earth observations from operational geostationary satellite systems

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1. NASA Ames Research Center

The latest generation of geostationary satellites (Himawari 8/9, GOES-16/17, FY-4, GK-2A) carries sensors that closely mimic the spatial and spectral characteristics of widely used polar-orbiting, global monitoring sensors such as MODIS and VIIRS. When combined, data from various currently operating/planned geostationary platforms provide a geo-ring of hyper-temporal (5-10 minutes), multispectral observations at spatial resolutions as high as 500 m. These high frequency observations offer exciting new possibilities for monitoring our planet, including better retrievals of geophysical variables by overcoming cloud cover, enabling studies of diurnally varying phenomena in the atmosphere, land, and the oceans, and support operational decision-making in agriculture, hydrology and disaster management. The NASA Earth Exchange (NEX) team, in collaboration with scientists from JAXA, KARI, NOAA and other international institutions, created the GeoNEX (www.nasa.gov/geonex) pipeline to integrate data from all available geostationary platforms and produce and distribute spatially, temporally, and radiometrically consistent data for the earth science community. To facilitate collaborative work among the partners, we have established the OpenNEX platform on the public cloud. OpenNEX provides researchers, developers, educators, and ordinary users with easy access to an integrated Earth science computational and data platform, enabling citizen scientists and application developers to realize the full value of GeoNEX data assets and software tools.

Keywords: geostationary, vegetation, atmosphere

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Preliminary research on validation for the atmospheric correction of HIMAWARI-8 AHI data using SKYNET data

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Himawari-8 was developed by the Japan Meteorological Agency (JMA) and launched on October 7, 2014, and the official operation started on July 7, 2015, and data has also been distributed by the National Institute of Information and Communications Technology (NICT) and Center for Environmental Remote Sensing (CEReS) at Chiba University. Himawari-8 has a multispectral sensor, Advanced Himawari Imager (AHI) that can observe the visible and near infrared (VNIR), short wavelength infrared (SWIR), and thermal infrared (TIR). Although the spatial resolution of AHI sensor is 0.5 km to 2 km, it is possible to observe the hemisphere at a high frequency every 10 minutes. In recent years, there are many researches on vegetation monitoring using geostationary satellite data that can be frequently observed. Biophysical parameters can be derived from satellite sensors data, and the atmospherically corrected surface reflectance product is a key role dataset. We already develop simple atmospheric correction algorithm for Himawari-8 AHI sensor data, and it is needed validation process for generated products. We have three validation sites for ground-based measurement of atmospheric parameters in Japan. Skyradiometer POM02 manufactured by PREDE Co., Ltd. are installed to measure the atmospheric parameters over the above 3 sites. POM02 can measure various parameters of the aerosol optical properties, which are transferred to SKYNET (http://atmos3.cr.chiba-u.jp/skynet/). SKYNET is a ground-based radiation observation network for aerosol/cloud researches, and provides many kinds of aerosol properties, which are accessible freely via internet. Each site has upward view sky images, and we selected ground-based aerosol data under completely clear sky conditions. This research show our simple atmospheric correction algorithm and the example results of validation using the atmospheric aerosol optical characteristics obtained by the POM02 installed over 3 validation sites.

Keywords: Himawari-8 AHI, Atmospheric Correction, Validation, POM02, SKYNET

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An analysis of land surface temperature during summer clear-sky days focusing on the diurnal change characteristics using Himawari-8 data

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Land surface temperature (LST) is a physical quantity related to the surface heat/water budgets, and plays an important role in various fields, such as the land-atmosphere interactions, vegetation dynamics, and urban climate. A new generation of Japanese geostationary satellite, Himawari-8, can estimate the LST with high frequency (10 min) and a moderate spatial resolution (2–3 km) by improving observation functions.
However, the retrieval of LST from Himawari-8 data is basically limited to clear-sky conditions. In East and Southeast Asia, clouds are frequently generated due to the wet and hot environments, so that there are many outliers and missing values due to the clouds. Therefore, it is difficult to capture the temporal change characteristics of LST.
In order to fill the gaps due to a brief cloud cover, we attempt to use a diurnal temperature cycle (DTC) model, and show the limitations of the DTC model for various missing/outlier cases. Moreover, we investigate the thermodynamic implication of diurnal change characteristics represented by the DTC model in coastal/inland areas or various land cover types such as urban, cropland and forest areas.

Keywords: Himawari-8, Land surface temperature

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An Enterprise Land Surface Temperature (LST) Algorithm for the GOES-R and Himawari Satellites

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As one of the essential climate variables defined by the Global Climate Observing System of the World Meteorological Organization, land surface temperature (LST) is a fundamental parameter in the physics of land surface processes from regional to global scales. LST products have been widely applied in and closely linked to radiative, latent and sensible heat fluxes at the surfaceatmosphere interface. Satellite platforms provide an excellent opportunity of measuring LSTs continuously at such scales. Among satellites with different types of orbits, geostationary satellites uniquely provide LST measurements with very high temporal resolution, which are critical for many LST applications.

An enterprise LST algorithm has been developed and applied to the U.S. Geostationary Environmental Observation Satellite (GOES) R series (GOES-R) at the U.S. National Environmental Satellite Data Information Service (NESDIS), which currently consists of GOES-16 and GOES-17. The algorithm is based on a traditional linear regression split-window LST retrieval technique in the thermal infrared spectrum, with a mitigation package to reduce risks from abnormal Focal Plane Module (FPM) performance found on the Advanced Baseline Imager (ABI) onboard GOES-17. The enterprise algorithm was evaluated using in-situ measurements and compared with the baseline algorithm that has been used for operational GOES-16 LST production since it was launched. Polar-orbiting satellite data such as JPSS LST products have also been used for the comparison analyses. Furthermore, the algorithm has been applied to Advanced Himawari Imager (AHI) data to extend the spatial coverage of the geostationary satellite LST product, since the AHI sensor is mostly similar to the ABI sensor. This presentation will provide scientific details of the enterprise LST algorithm and its performance on GOES-16 and -17 satellite data, as well as some samples based on Himawari satellite data.

Keywords: Land Surface Temperature, Geostationary Satellites, Algorithm

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Analysis of differences between NDVI-based indices of Himawari 8 AHI and Aqua MODIS using Rayleigh-corrected reflectances

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A new generation of geostationary (GEO) satellite sensors, including the Himawari 8 Advanced Himawari Imager (AHI), has been launched in past five years. These sensors have been widely used for monitoring spatial and temporal changes of terrestrial vegetation with high temporal resolution. Data from polar-orbiting, low earth orbit (LEO) satellite sensors such as the Moderate Imaging Spectroradiometer (MODIS) can be used to complement observations made using the new-generation GEO sensors; for example, LEO data obtained prior to the launch of GEO sensors can be used to create long-term data sets. Evaluation of the consistency of GEO and LEO products is thus crucial for the integrated application of GEO and LEO sensors.
A major issue in comparing GEO and LEO products is that the ray-matched condition, in which the illumination and viewing angle condition is nearly identical, does not appear in middle to high latitude regions. The mismatch of the angular condition and effects of surface anisotropy, i.e., bidirectional reflectance distribution function (BRDF), cause biases in reflectances of sensors that propagate into downstream products such as the Normalized Difference Vegetation Index (NDVI). In addition, NDVI data may differ between sensors due to differences in their spectral response functions.
In this study, we scrutinize an index related to greenness, specifically, the fraction of vegetation cover (FVC), and examine its consistency between AHI and Aqua MODIS (near-nadir viewing) for land surfaces in mid-latitude regions. The FVC is referred to as an “NDVI-based index” as it is a function of NDVI and can be less than 0 or greater than 1. Previously, we developed an algorithm that, using top-of-atmosphere (TOA) reflectances as input data, makes the output (NDVI-based index) consistent between sensors in order to mitigate effects of viewing zenith angle (nadir and off-nadir) and spectral response functions. However, the spatial heterogeneity of the atmospheric layer arising from Rayleigh scattering, aerosol loading, ozone and water vapor contents added uncertainties when comparing NDVI-based indices.
Here, as the next step in our studies, we use Rayleigh-corrected (RAC) reflectances to evaluate differences between NDVI-based indices from AHI and Aqua MODIS. Results indicate that NDVI-based indices using RAC reflectances show more consistent results relative to NDVI using RAC reflectances. Additionally, absolute differences between RAC NDVI-based indices of two sensors are similar to or slightly smaller than that between TOA NDVI-based indices. Finally, the benefit of NDVI-based index for transforming NDVIs between sensors is introduced for comparing/integrating observation data obtained using AHI and MODIS for monitoring terrestrial vegetation.

Keywords: Himawari 8, MODIS, NDVI, FVC

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Functional grassland phenology discrimination and analyses with Himawari-8 geostationary data

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1. University of Technology Sydney, 2. University of Hawaii

Climate change and extreme events are altering the functioning and composition of ecosystems with consequences for ecological processes, food security, and human health. Australia’s highly productive dry grassland ecosystems with biodiverse native flora are particularly vulnerable, yet there is very little knowledge of their health, functioning, and changes in response to climate change. A key bio-indicator of climate change is phenology (the study of recurrent life cycle events), and much progress has been made in Northern Hemisphere ecosystems in which many studies have documented advancing biological spring seasons with climate warming. By contrast less progress has been made in Southern Hemisphere ecosystems, due to the lack of long term phenology datasets, a high species diversity, and the absence of a marked dormant season. Satellite time series data enable repetitive and consistent measures of green-leaf phenology, however at coarse, nominal temporal resolutions of 8- and 16-day.

In this study we investigated the potential of geostationary satellite 'greenness' data to discriminate, characterize and retrieve key functional phenological information over a 3,000 km continental-scale grassland area encompassing subtropical C4 grasses to cool temperate C3 grasses, with an extensive areas of mixed, cool- and warm season grasses. Our aim was to assess whether C3 and C4 grass phenologies, as well as mixed phenology, can be identified and mapped for the purpose of monitoring grassland changes over time. There are few studies on characterizing phenology patterns of spatially mixed C3, C4 functional grassland ecosystems which have year round grass cover, and currently there are only meteorology estimates of C3 and C4 grassland areas.

We computed 10 minute vegetation indices (NDVI, EVI) from MAIAC-corrected surface reflectances and composited the data to daily values using solar noon and fixed view angle geometries. We found the resulting green-leaf phenology profiles, at daily timesteps, revealed important structural detail related to varying C3 and C4 grass composition and functional phenologies. C3 grassland phenologies were dominat in the spring season, while C4 grass areas exhibited summer- autumn phenologies. For the most part, mixed areas exhibited two distinct growing season profiles related to grass functional composition. Using the per-pixel geostationary data phenology profiles we mapped the grassland study area into C3, C4 and mixed C3-C4 grasslands. Lastly we verified the structural nature of the phenology profiles by comparison with in situ phenocams (time lapse cameras) which generated green-leaf phenology profiles using green chromatic coordinate (Gcc) values. Our results confirm the unique and valuable additional information available from daily resolution geostationary data for improved phenology assessments. With projected climate changes and extreme events showing continued warming and more intense droughts, the geostationary information will become increasingly important as early warning indicators of ecosystem change.

Keywords: Phenology, Grassland, Geostationary, Himawari-8, C3-C4 grass

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[E] Oral | H (Human Geosciences)：H-GM Geomorphology

[H-GM02] Geomorphology

convener:Tsuyoshi Hattanji(Faculty of Life and Environmental Sciences, University of Tsukuba), Masayuki Seto(Fukushima Future Center for Regional Revitalization, Fukushima University)

The main subject of this session is interdisciplinary discussion on the whole range of themes relating to geomorphology, especially geomorphic processes, landform development and its relation to environmental changes, geomorphological hazards and their mitigation, relationships among geomorphic processes, other natural phenomena and human activities, and various techniques of geomorphological measurements and landform classification. All presentations and discussion of this session are made in English.

[HGM02-01] Detecting geomorphic and sedimentary effects of modern climate change: how much do we know?

*Amy E East[1], Joel B Sankey[2] (1.U.S. Geological Survey, Santa Cruz, California, U.S.A., 2.U.S. Geological Survey, Flagstaff, Arizona, U.S.A.)

[HGM02-02] Effects of different controlling factors on the experimental landform development

*Shunji Ouchi

[HGM02-03] Measurement of landslide surface deformation along Kali Gandaki River, Nepal using time-series Sentinel-1 InSAR images

*Hiroshi, P. Sato[1], Masahiro Chigira[2], Ching-Ying Tsou[3] (1.College of Humanities and Sciences, Nihon University, 2.Disaster Prevention Research Institute, Kyoto University, 3.Faculty of Agriculture and Life Science, Hirosaki University)

[HGM02-04] UAV SfM monitoring of coastal morphology on Kujukuri beach

*Mergen Kungaa[1], Toshihiko Sugai[1], Natsuki Sasaki[1], Tatsuki Miyamoto[1], Tatsuya Terada[1] (1.Tokyo University, Graduate School of Frontier Sciences, Department of Natural Environmental Studies)

[HGM02-05] Evaluating soil physical properties and their spatial variability in a headwater catchment

*Ingrid Lima[1], Takashi GOMI[1], Taro UCHIDA[2], Takao YAMAKOSHI[3], Yohei ARATA[1], Kenta Koyanagi[1] (1.Tokyo University of Agriculture and Technology , 2.University of Tsukuba , 3.National Institute for Land and Infrastructure)

[HGM02-06] Four major geomorphological debates in Japan

*Takashi Oguchi[1] (1.Center for Spatial Information Science, The University of Tokyo)

Detecting geomorphic and sedimentary effects of modern climate change: how much do we know?

*Amy E East[1], Joel B Sankey[2]

1. U.S. Geological Survey, Santa Cruz, California, U.S.A., 2. U.S. Geological Survey, Flagstaff, Arizona, U.S.A.

Hydroclimatic changes associated with global warming have been documented widely over the past 50 years, but associated physical landscape responses are poorly understood thus far. Detecting sedimentary and geomorphic signals of modern climate change presents challenges owing to short record lengths, difficulty resolving signals in stochastic natural systems, influences of land use and tectonic activity, long-lasting effects of individual extreme events, and variable connectivity in sediment-routing systems. However, being able to resolve and constrain geomorphic and sedimentary response to rapidly progressing climate change has widespread implications for ecosystem resilience, human health and safety, infrastructure, water security, and economics. We have reviewed and synthesized existing literature to investigate the nature and extent of sedimentary and geomorphic responses to modern climate change, focusing on the western United States, a region with generally steep relief and high sediment yield likely to be sensitive to climate variability. We test four hypotheses: that recent climate-driven changes will have caused (1) greater watershed sediment yields, (2) changes in slope stability, (3) more dynamic fluvial morphology, and (4) more aeolian sediment mobilization. We examine the extent to which these hypotheses are currently testable given the state of the science, and identify knowledge gaps that limit robust testing. Each hypothesis is supported to some degree, by small numbers of studies with limited geographic scope; none can be refuted with the currently available literature. To detect ongoing and future responses to climate change will require better understanding how landscape response scales with disturbance, how lag times and hysteresis operate within sedimentary systems, and how to distinguish relative influence of superimposed disturbances, including some that are unrelated to climate. We are in need of abundant data from many more places globally, at greater spatial and temporal resolution, to determine the nature and extent of landscape response to ongoing climate change. Where applicable, this should include thorough reporting of negative results; well constrained tests for a lack of sedimentary and geomorphic responses—and studies capable of rejecting hypotheses such as ours—are just as necessary as data that indicate support for the hypotheses we have posed.

Keywords: landscape change, climate change, geomorphology

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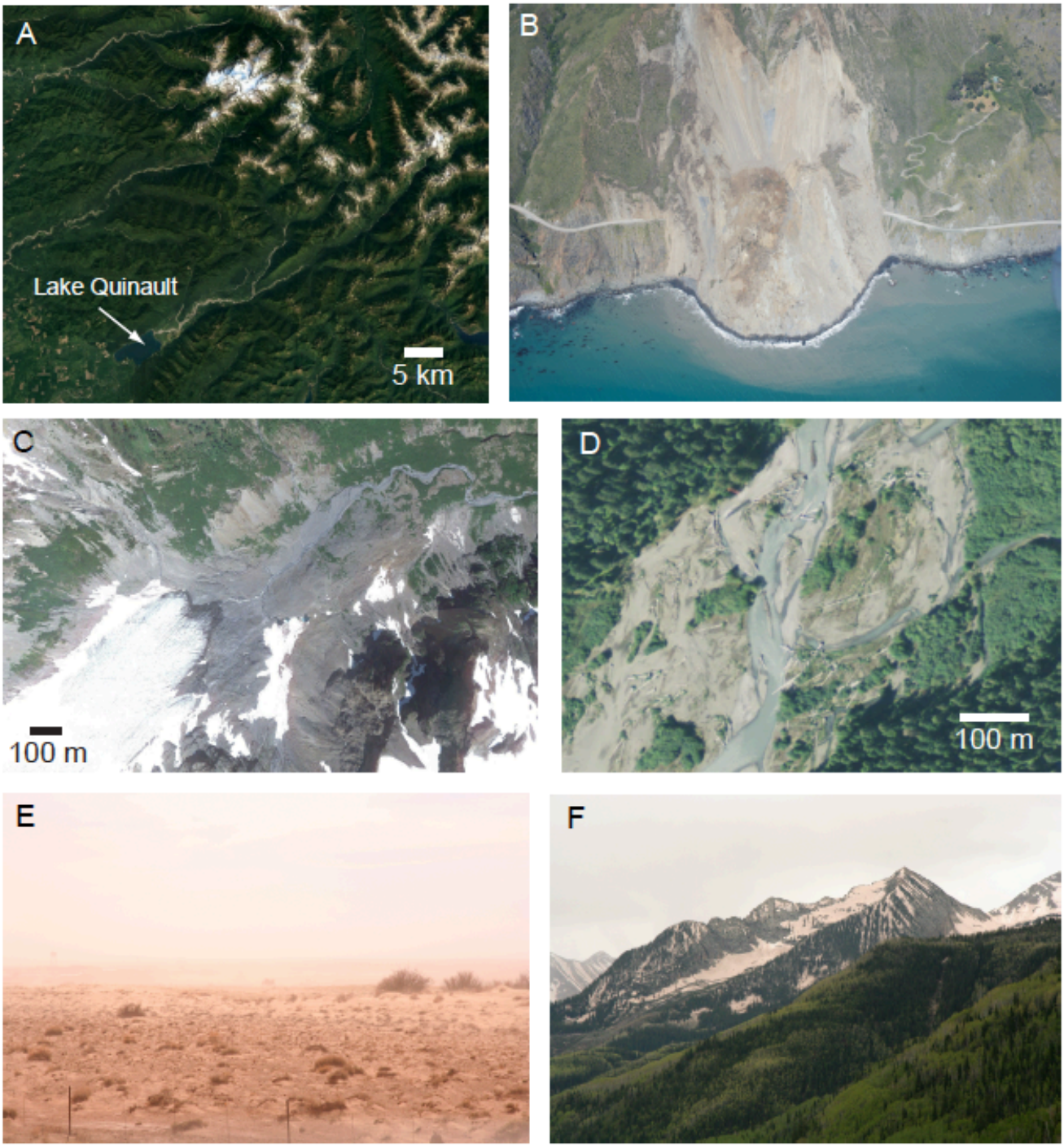

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Effects of different controlling factors on the experimental landform development

*Shunji Ouchi

Geomorphic experiments with uplift and rainfall erosion cannot be a scale model of real landform development; however, I believe that it can provide some useful ideas to help interpreting the real landform development, which left only scarce and sporadic evidence. I have been conducting this type of experiments for years, and now as I finished the series of experiments, I would like to explain what those experiments indicated. A mixture of fine sand, kaolinite and water (ca. 10 : 1 : 0.7 by weight) compacted in a square prism-shaped stainless container (ca. 60 ×60 ×40 cm) is pushed up by an uplift-generating device set under the bottom plate. Mist-type rainfall is generated by a pump through spray nozzles set at four corners. The duration of experiments was rather long (ca. 200 - 1800 hours) to accommodate slow uplift. The results of experiments suggested the existence of two threshold uplift rates. Below the lower threshold (ca. 0.05 mm/h), fluvial erosion alone can offset the uplift, and gentle landforms reflecting the mound erodibility appear (Characteristic relief phase). Above the upper threshold (ca. 5.0 mm/h), uplift overwhelms and a massive mountain grows until it hits the limit determined by the experimental setting (Mountain building phase). When the uplift rate is between these thresholds, average surface height stops increasing after valleys fully develop and slopes grow enough to cause landslides, and then changes around the certain equilibrium height depending on the uplift rate (Steady state phase). This phase is the most common condition throughout the series of experiments. The experimental landform in this phase develop through 3 stages. **Stage 1:** The surface erosion starts with the formation of small grooves at all sides of uplifted area. One groove in the middle at each side soon grows larger with capturing smaller ones and develops into a valley system. The average height of uplifted area increases linearly with uplift at a little lower rate. **Stage 2:** As the uplift and valley incision continue, slopes grow and slope failures start to occur on valley side slopes and on fault scarps. The frequency and size of slope failures increases with relief, and the increase rate of average height goes on declining. **Stage 3**: The average surface height stops its continuous increase and repeats ups and downs around a certain height (equilibrium height) determined by the uplift rate. Landslides dominate the erosion process, and channels of stable profiles become conduits for transporting sediments yielded by slope failures. The occurrence of landslides (followed by fluvial transport) tends to concentrate periodically and reduces the surface height on a certain cycle, while the surface slowly rises with uplift at a lower rate between the times of landslide concentration. Rainfall intensity is another important factor controlling the rate of fluvial erosion. Low rainfall generates less overland flow and makes the surface rise higher with less fluvial erosion. However, in runs with higher permeability, less rainfall caused more intensive erosion. The higher permeability of the same material acquired by the lower degree of compaction associates with lower shear strength, which is considered to promote slope failures by infiltrated water. More rainfall generates more overland flow. This provably promotes the development of grooves in the early stage and accelerates the development of valley systems. Efficient water drainage through valleys of high density may reduce water infiltration and retard slope failures. This possibly resulted in the higher surface under heavier rainfall. Even in the simplified experimental condition, a little difference in one controlling factor apparently cause complex effects among factors and then on the development of landform. We have to be very careful and try not to rush into a clear conclusion when we study the development of landform.

Keywords: geomorphic experiment, uplift rate, rainfall intensity, permeability, fluvial erosion, landslide

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Measurement of landslide surface deformation along Kali Gandaki River, Nepal using time-series Sentinel-1 InSAR images

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This study aims to detect landslide surface deformation along Kali Gandaki River, Nepal. Surface landslides was causatively related with a large deep-seated gravitational slope deformation (DGSD) in a hilly region of the southwestern Alps (Tibaldi et al. 2004). Tibaldi et al. (2004) also mentioned that post-glacial and active surface landslides developed on the convex lower part of the slope, suggesting that they resulted from instability due to the new profile assumed by the slopes during the deep-seated deformation. Sato (2019) has already interpreted images of synthetic aperture radar interferometry (InSAR) and pointed out occurrence of the deformation in the study area where Kali Gandaki River incises the mountains between Tal Bagar and Lete, Nepal. To detect landslide deformation, we used time-series Sentinel-1 InSAR and unwrapped InSAR images and measured the velocity of the deformation along line of sight (LoS) using the tool of LiCSBAS. This tools was developed and provided by an open-source InSAR time series analysis package that integrates with the automated Sentinel-1 InSAR processor (LiCSAR) (Morishita et al. 2020). We downloaded 81 products of the data observed from 11 Sep 2016 to 04 May 2018 in the Frame ID of 158A_06249_131313 which covers the study area. An SBAS (Small Baseline Subset algorithm) analysis of the products gave us the resulting velocity of the deformation for about two years (Fig.1), overlain on the landslide landform classification map (Chigira et al. 2019). In Fig.1, red and orange point indicates the location of the knick point of the river around Tal Bagar and Lete, respectively. We set two measurement lines (Fig.1) on the slope near Tal Bagar and Lete. As shown in Fig.2, the line 1 (near Lete) showed −10mm/yr to −30mm/yr (downward and/or easting) deformation along LoS, and this remarkable deformation is illustrated between 600m and 1200m in distance; where is interpreted as the depression and the scar of the old landslide in the landslide landform classification map (Chigira et al., 2019). As shown in Fig.3, the line 2 (near Tal Bagar) showed −15mm/yr to 0mm/yr (downward and/or easting) deformation along LoS, and the deformation recorded at a velocity greater on and near the ridge than on the convex lower part of the slope, where is interpreted as DGSD (Chigira et al. 2019). The velocity shown in Figs 2 and 3 may include some noise and more calculation is needed. Its signal is estimated as more or less than ±15mm/yr; however, the measured velocity shown in the figures was found to be harmonized with the interpreted landslide landform classification map. This study was supported by KAKEN 17H02973; Principal Researcher, Prof. Masahiro Chigira, DPRI, Kyoto Univ.

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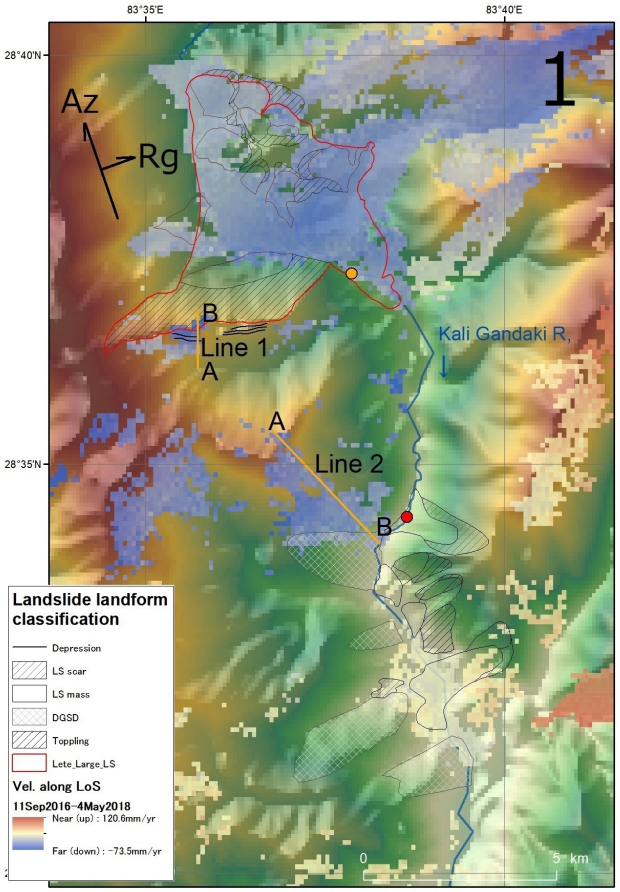
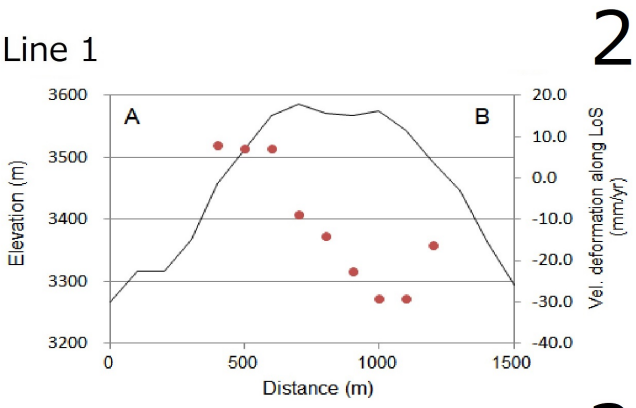
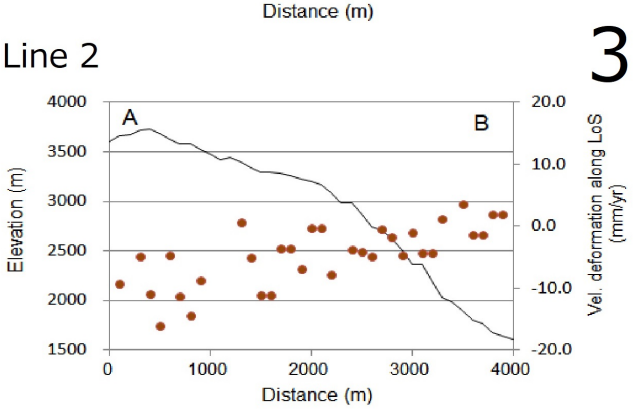
Keywords: Landslide, Deep-seated gravitational deformation, Sentinel-1, SAR, LiCSAR, Kali Gandaki







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UAV SfM monitoring of coastal morphology on Kujukuri beach

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During 2018-2020 we conducted several UAV SfM surveys on the 3.2 km long stretch of Kujukuri beach between Nabakigawa and Horikawa rivers, Chiba Prefecture. These 2 rivers separate the research area from the rest of the 60-km long Kujukuri beach, forming separate morpho- and lithodynamical unit. The results of the research were high-resolution digital elevation models (DEM) and orthomosaics representing 2 years of change. Based on DEM and orhomosaics we were able to evaluate that from February 2018 to September 2018 we recorded active accumulation along the entire length of the beach. But accumulation intensity varied in different zones of the beach as if foreshore, backshore or dunes. Also, the accumulation processes did not occur evenly for 7 months but mostly intensified in the summer. From September 2018 to February 2019 erosional processes were not observed, respectively, summer profile at the survey area remained stable. Thus, during winter season 2018-2019 we were not able to record the process of transition back to winter profile from summer profile. In June 2019 we again observe summer profile. But autumn 2019 was marked by 2 typhoons hitting Japan: Faxai (#15, Sep 2019) and Hagibis (#19, Oct 2019). In the case of Kujukuri beach most impactful was Faxai, hence we conducted a survey on the 28th of September 2019. But we were not able to fix any erosion due to Faxai typhoon. Re-survey was conducted on December 6, 2019. At that moment, we are already seeing a complete transition to winter profile. Is it delayed reaction to more impactful Faxai typhoon, or Hagibis also might be a reason for transition to winter profile?

Keywords: UAV SfM, coastal geomorphology, Kujukuri beach

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Evaluating soil physical properties and their spatial variability in a headwater catchment

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1. Tokyo University of Agriculture and Technology , 2. University of Tsukuba , 3. National Institute for Land and Infrastructure

Soil-bedrock interface is a Critical Zone for various hydrogeomorphic processes such as flow paths, developing groundwater, and slope stability. Soil-bedrock is an important parameter which it is in contact with the hydrosphere, is composed of chemically and physically altered or weathered rocks. The soil-bedrock interface is hard to be measured and estimated in hydrogeomorphic and pedological studies, even for small catchment areas. The processes that control the formation and thus the present-day depth to the bedrock are, however, poorly quantified and few predictive model exists. Our estimates of soil depth geometry are based on very sparse measurements and mostly rely on empirical relationships or correlations. Nowadays, there is a scarcity in the methodologies to define the spatial distribution and soil properties of this parameter on the slopes. Several direct and indirect measurement methods have been used to estimate depth to bedrock. Examples of direct measurement methods include rod penetrometers, excavated pits and Knocking Cone Penetration Test (KCPT). This last measurement device is particularly promising as it can help delineate soil stratigraphy and layers with contrasting hydraulic properties. In recent years, efforts have been made in order to understand the mechanisms/processes leading to the initiation and propagation of landslides and debris flows and to develop new approaches for soil depth estimation model. In particular, the 2009 landslide and debris flow disasters, in which rapid flows of rock boulders, soil and organic material sweeping down the narrow channels of Hofu city, Yamaguchi prefecture - Japan, caused loss of life and innumerous damages have been the focus of the studies. In this work, we present a detailed field investigation of a small catchment area in natural forested region of the Hofu city, Japan. We developed methods for analyzing depth of soil-bedrock interface and soil physical properties using the Knocking Cone Penetration Test (KCPT). Our findings show, the high spatial variability for the formation of soils vertical profiles possibly relate to recurrences of landslides and subsequences of formation of soil by weathering granite.

Keywords: Soil Depth , Soil Properties , Field investigation, Knocking Cone Penetration Test (KCPT)

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Four major geomorphological debates in Japan

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Debates contribute to the development of science including geomorphology. This presentation introduces four major geomorphological debates in the history of Japanese geomorphology. Three of them are long-term scientific debates on the effects of glaciers versus mass movements and running water, the effects of periglacial processes versus mass movements and running water, and the effects of tectonics versus climates. These debates are still ongoing. Another debate is on research principles, i.e., descriptive/historical geomorphology versus process geomorphology. This debate was heated in the past, but had almost ceased by now. The influence of international geomorphology on the four debates is also described.

Keywords: History of geomorphology , Scientific debate, Japan

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[E] Oral | H (Human Geosciences)：H-QR Quaternary research

[H-QR04] Innovative Applications of Trapped-Charge Dating to Quaternary Geochronology

convener:Toru Tamura(Institute of Geology and Geoinformation Geological Survey of Japan, AIST), Shin Toyoda(Department of Applied Physics, Faculty of Science, Okayama University of Science), Yuji Ishii(National Institute of Advanced Industrial Science and Technology), Sumiko Tsukamoto(Leibniz Institute for Applied Geophysics)

Trapped-Charge Dating (TCD) is a general term for absolute dating methods that use trapped electrons in crystal lattice, such as optically-stimulated luminescence (OSL) and electron spin resonance (ESR) dating. TCD presented one of the most successful progresses in geoscience and archaeology over the last 20 years, and still has a great potential in innovative applications. Technical progresses in optical dating of quartz and feldspar grains enables determination of depositional ages in a broad range from 10 to 500,000 years. Rock surface dating provides a way to determine surface exposure ages as well as burial ages of gravels. Thermochronometry with TCD is a state of the art method to determine the degradation and uplift rates on high temporal resolution. Further efforts have been made on TCD for extracting chronological information of past seismic activities. Innovative IRPL (infrared photoluminescence) method has also recently been invented. This session covers a wide range of TCD applications to problems in Quaternary geochronology as well as its technical advances. Comprehensive reviews on successful TCD applications and contributions of unestablished, challenging researches are also welcome.

[HQR04-01] East Asian summer monsoon dynamics over the last interglacial-glacial cycle inferred from fluctuations of Lake Daihai in northern China

★Invited Papers

*Hao Long[1], Yandong Hou[1], Lei Gao[1], Qian Liu[2] (1.NIGLAS, 2.Nanjing Normal Univ.)

[HQR04-02] Fine-grained quartz OSL dating for reconstructing the Holocene evolution of the Mekong River floodplain

*Yuji Ishii[1,2], Toru Tamura[2], Ben Bunnarin[3] (1.Research Fellow of the Japan Society for the Promotion of Science, 2.Geological Survey of Japan, AIST, 3.Department of Geology, GDMR, MIME, Cambodia)

[HQR04-03] Feldspar pIRIR dating for defining glacial-interglacial depositional sequences in the Kanto Plain, eastern Japan

*Toru Tamura[1,4], Hiroko Okazaki[2], Hiroomi Nakazato[3], Tomonori Naya[1], Rei Nakashima[1] (1.Institute of Geology and Geoinformation Geological Survey of Japan, AIST, 2.Natural Hisory Museum and Institute, Chiba, 3.The National Agriculture and Food Research Organization, 4.Graduate School of Frontier Sciences, The University of Tokyo)

[HQR04-04] Testing the reliability of the fading correction near saturation for the Infrared stimulated luminescence dating

★Invited Papers

*Yan Li[1,2], Sumiko Tsukamoto[2], Hao Long[3], Jingran Zhang[4], Linhai Yang[5], Manfred Frechen[2] (1.China Univ. of Geosci., 2.LIAG, 3.NIGLAS, 4.Nanjing Normal Univ., 5.Shaanxi Normal Univ.)

[HQR04-05] The production mechanism of the E_1' center by low-velocity friction based on the particle characteristics

*Kiriha Tanaka[1], Jun Muto[1], Yasuo Yabe[2], Toshitaka Oka[3], Hiroyuki Nagahama[1] (1.Earth Science, Graduate School of Science, Tohoku University, 2.Research Center for Prediction of Earthquakes and Volcanic Eruptions, Graduate School of Science, Tohoku University, 3.Japan Atomic Energy Agency)

[HQR04-06] ESR dating of quartz: issues on sediment dating and on thermochronometry

*Shin Toyoda[1] (1.Department of Applied Physics, Faculty of Science, Okayama University of Science)

East Asian summer monsoon dynamics over the last interglacial-glacial cycle inferred from fluctuations of Lake Daihai in northern China

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Palaeolake archives, including both core sedimentary sequences and palaeoshorelines, from northern China have been extensively used to reconstruct the lake evolution and regional moisture history during the latest Pleistocene and Holocene. Such studies have played important roles in understanding the intensity variations of East Asian summer monsoon (EASM) and the underlying drivers on the sub-orbital timescales. However, the reconstructions of lake evolution in the time period beyond late glacial is substantially limited, and as a result, the picture and forcing of the EASM variations on the glacial-interglacial timescale have not been well revealed from lake archives yet.
In this study, we applied a combined quartz and K-feldspar luminescence dating to a fluvial-lacustrine sedimentary sequence (section DH17-1) from Lake Daihai in semiarid northern China to reconstruct its lake level fluctuation. The comprehensive investigations based on sedimentology, stratigraphy, and luminescence chronology demonstrate two highstands periods of Lake Daihai from ~130 ka to 110 ka and from ~90 ka to 70 ka, respectively, interrupted by a relatively low lake level period in between. Afterward, the lake level might have experienced a gradual decrease from ~70 ka to ~50 ka, suggested by less and less offshore components upward shown in grain-size end-member analysis of sediments. The reconstructed lake fluctuation history of Lake Dai infers a humid condition at the last interglacial owing to strengthened EASM intensity but deteriorated regional moisture condition through the last glacial. The overall correspondence of lake-level fluctuations to marine isotope record implies a dominant ice-volume forcing of the EASM variations on the glacial-interglacial timescale. It appears to be incompatible with the standpoint of the insolation regulation of monsoon intensity documented by the stalagmite oxygen isotope records on the orbital timescale.

Keywords: Lake level fluctuation, Glacial-interglacial, OSL dating, Humid condition, Monsoon

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Fine-grained quartz OSL dating for reconstructing the Holocene evolution of the Mekong River floodplain

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The Holocene evolution of coastal floodplains and delta plains is influenced by sea-level and climate changes. Two well-known examples from Mississippi and Rhine-Meuse rivers demonstrate that sea-level changes mainly controlled the style of fluvial deposition. However, evolution of Asian large river systems is yet to be fully understood partly because of problems in chronology. OSL dating of fluvial deposits is challenging because of the incomplete bleaching of sediment grains during transport that potentially causes age overestimate. Sand-sized quartz grains are generally used because measurements of the small number of grains or a single grain are considered to allow separation of incompletely bleached grains. However, the Mekong River floodplain is mud-dominated and the sediment load does not contain enough amount of sand grains for OSL dating. Our previous comparison between fine-grained and sand-sized quartz OSL ages from the Holocene and modern deposits indicate that the fine grains are better bleached and thus considered suitable for constraining the chronology of the fluvial deposits. Here we present the chronology of the Mekong River floodplain based on fine-grained quartz OSL ages determined for sediment succession in 12 boreholes.

Progradational avulsion and crevasse splay deposition promoted rapid aggradation before 7 ka. The abrupt cessation of aggradation is correlated to the lowering rate of eustatic sea-level rise. After 7 ka, fluvial deposition was limited near the river courses, and a hiatus between 7 and 4 ka was observed at one site. Ages obtained at the upstream end of an abandoned large distributary channel suggest that it was fully or partially abandoned at 3.5 ka. A previous study also indicated that another channel was abandoned at 4 ka. The relative sea-level fall since the middle to late Holocene in the area would have lowered the river bed and stabilized the distributary channels. A sharp precipitation decrease associated with the weakening of the EASM at 4 ka may have reduced the discharge of the Mekong River, promoting the channel abandonment. Upstream of Phnom Penh, the river actively migrated and a series of abandoned inner bank levees were preserved. The OSL ages obtained from the levee deposits are < 0.5 ka, which demonstrates rapid migration at least after 0.5 ka. The Digital Surface Model indicates that there are no older levees around the area. A human-induced increase in sediment discharge possibly promoted the rapid channel migration or older series of levees may have been eroded by recent channel migration.

Keywords: OSL dating, floodplain, Mekong River, Holocene

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Feldspar pIRIR dating for defining glacial-interglacial depositional sequences in the Kanto Plain, eastern Japan

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Feldspar post-IR IRSL (pIRIR) protocol is virtually an exclusive method for constraining absolute chronology of siliciclastic depositional records from the Middle to Late Pleistocene. Nevertheless, since its advocacy in 2008, the potential of pIRIR application has not been explored much. pIRIR dating is expected effective for constraining coastal sequence stratigraphy in relation to the Pleistocene glacial sea-level changes, in which sea-level highstand marine deposits are bounded by unconformity and lowstand terrigenous deposits. We applied $pIRIR_{50/290}$ dating to a 35-m-long sediment core (GS-HKT-1) obtained from the northeastern Kanto Plain, eastern Japan, to examine its efficacy for defining depositional sequences after Marine Isotope Stage (MIS) 9. The core GS-HKT-1 in ascending order consists of shallow-marine deposits not younger than MIS7, terrigenous and brackish deposits, and MIS 5e coastal regressive succession overlain by aeolian sand and loess. Sixteen fading-uncorrected $pIRIR_{50/290}$ ages clearly underestimated the shallow marine deposits. The fading rate determined for individual sample is characterized by a broad scatter, and, if used for the fading correction, leads to an inconsistent age sequence with the stratigraphy. In contrast the average fading rate corrects ages consistently with the stratigraphy and correlation of the coastal and shallow-marine deposits with the interglacial stages. The fading rate is generally associated with large errors and its accurate determination requires a large number of replications. Therefore as practiced here unless there are significant changes in sediment provenance the average fading rate is consider to better represent the value for the fading correction. Further application of pIRIR dating is expected to clarify the stratigraphic structure and thus tectonic history of the Kanto Plain, the largest Quaternary basin nearby the triple junction of the plate boundaries.

Keywords: Sedimentology, OSL dating, tectonics, glacial sea-level change, sequence stratigraphy

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Testing the reliability of the fading correction near saturation for the Infrared stimulated luminescence dating

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The infrared stimulated luminescence (IRSL) signal of K-feldspar/polymineral has a more extended dating range than that of the quartz optically stimulated luminescence (OSL) signal. However, the athermal signal loss, known as anomalous fading, holds back the application of K-feldspar IRSL dating for relatively old sediments. Although the post-IR IRSL (pIRIR) signals without fading were proposed, such athermally stable signals tend to be more difficult to bleach. For dating sediments from difficult-to-bleach environments, one has to choose a signal which still fades and the age has to be corrected for fading. Specifically, for old samples close to or in field saturation, a fading correction model was proposed by Kars et al. (2008) to construct the simulated natural dose response curve and determine the saturation level on the basis of quantum mechanical tunnelling model. However, ~10% underestimation of field saturation level was observed, suggesting a potential age over-correction.

The loess-palaeosol sequences on the Chinese Loess Plateau contain homogenous and quasi-continuous wind-blown dusts with independent age control for the entire Quaternary. Therefore, these loess-palaeosol sequences provide an ideal material to test the reliability of the fading correction model mentioned above, and determine the upper dating limit of multiple IRSL signals from K-feldspar.

In this study, loess samples collected from the Luochuan Potou loess profile are used for the coarse-grained K-feldspar / fine-grained polymineral pIRIR and pulsed IRSL measurements. The natural dose response curve (DRC) is constructed using the natural luminescence intensities from all samples and the corresponding independent ages. After the construction of the simulated natural DRCs following the fading correction model, the natural and simulated natural DRCs are compared to evaluate the reliability of the fading correction near field saturation, and to determine the upper dating limit for the pIRIR and pulsed IRSL signals using the D_0s from both DRCs. We also compared the fading corrected ages following Huntley and Lamothe (2001) and Lamothe et al. (2003) with independent age and evaluate where the methods start to be inapplicable.

Keywords: Luminescence dating, Anomalous fading, Fading correction model, pIRIR dating, Pulsed IR dating, Grain size

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The production mechanism of the E_1' center by low-velocity friction based on the particle characteristics

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Electron spin resonance (ESR) dating is a method to determine an age of a fault movement using the unpaired electrons trapped in defects in fault materials. It is based on a premise that the ESR intensity, which means the number of unpaired electrons, accumulates by natural radiation and set to zero by the cataclastic deformation and/or frictional heating of a seismic slip [1]. The premise called as zero-setting, however, has not been demonstrated in the laboratory and its physical mechanism is still obscure. We have performed low-velocity friction experiments for the simulated-quartz gouges with different displacements or normal stresses [2]. The result indicates that the E_1' center (an unpaired electron trapped at oxygen vacancy) increases mainly by cataclastic deformation of low-velocity and low-pressure friction. However, the production mechanism has not been clarified. In this study, we analyze the particle characterization of gouges before and after friction tests. We will discuss the production mechanism of the E_1' centers related to the cataclastic deformation of frictional slip at the shallow depth.
Starting simulated-quartz gouge was commercial natural quartz sand which mainly consists of SiO_2. Low-velocity friction tests were performed for the gouges using a rotary shear apparatus. The inner diameter, outer diameter, and thickness without compaction of gouges were 20 mm, 30 mm and 1.5 mm, respectively. Slip rate and displacement were calculated at a diameter of 25 mm. Friction experiments were performed under two experimental conditions. Experiments to study the effect of displacements on the E_1' center (Experiment 1) were performed with a slip rate of 0.76 mm/s, a normal stress of 1.0 MPa and displacements from 0.28 to 1.4 m. Experiments to study the effect of normal stresses on the E_1' center (Experiment 2) were performed with a slip rate of 0.76 mm/s, normal stresses from 1.0 to 15 MPa and a displacement of 0.57 m. ESR measurements were conducted for gouges (see [2] for detail). Particle characterizations were carried out for gouges using Morphologi G3 (Malvern Instruments Ltd.). We estimated the specific surface area from particle size distribution obtained from the particle characteristics and formula [3].
In experiment 1, ESR intensity increased with displacements and reached about 120 % at a displacement of 0.85 m. The intensity was kept constant about 120 % (average) with further increases in displacements upto 1.4 m. Specific surface area also increased with displacements and reached about 540 % at a displacement of 0.85 m. The surface area was kept constant about 470 % (average) with the further increases in normal stresses from upto 1.4 m. In experiment 2, ESR intensity increased with normal stresses and reached about 140 % at a normal stress of 2.9 MPa. The intensity was kept constant about 120 % (average) with further increases in normal stresses upto 15 MPa. Specific surface area increased with the normal stresses and reached 510 % at a normal stress of 2.9 MPa. The surface area was kept constant about 370 % (average) with the further increases in normal stresses from upt 15 MPa. This clear correlation between specific surface area and the ESR intensity indicate that the E_1' centers are produced on the newly formed surfaces depending on the degree of cataclastic deformation. According to this study, cataclastic deformation of frictional slip at the shallow depth can not cause zero-setting of the ESR intensity of quartz grains. In order to prove the zero-setting of ESR intensity, we should consider the other effects (e.g., frictional heat, deformations without grain reduction) .

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Keywords: Electron Spin Resonance (ESR), Low velocity friction, Particle characteristics

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ESR dating of quartz: issues on sediment dating and on thermochronometry

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Electron spin resonance (ESR) detects unpaired electrons in materials. The principle of ESR dating is the same as luminescence dating that the “signals” (unpaired electrons in ESR) created by natural radiation are accumulated with geological time scale. As quartz is one of the minerals most abundant on the surface of the earth, there are many applications using quartz ESR signals, such as fault movements, tephra, sediments, and heating of flints. Another advantage of using quartz is that it has several paramagnetic centers (ESR signals such as Al, Ti-Li and Ti-H centers) to be used for dating so that “multiple center” approach is possible where ages can be obtained with several signals independently to check the reliability.

One of the most important issues of ESR dating of quartz is how to be sure that the signal has been completely erased at the time of dating events. Among the above materials, tephra would most surely be zeroed at the time of the dating event, which is volcanic eruption. However, ESR dating of tephra would still be the subject of methodological investigation where Toyoda et al. (2006) showed that the problem is determination of D_E.
Probably, fundamentals on ESR dating of quartz should be again investigated where the key issues would be the dose recovery and preheating. It is possible that paramagnetic defects in quartz exchange electrons and holes with thermal activation processes that would modify the original amount of the signals formed just by radiation. Possible sample and age range dependence should be a factor that makes things more complicated. The protocols developed for luminescence dating should be adopted to establish the method of ESR dating of quartz.

Keywords: ESR, dating, quartz

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[E] Oral | H (Human Geosciences)：H-DS Disaster geosciences

[H-DS08] Tsunami and tsunami forecast

convener:Hiroaki Tsushima(Meteorological Research Institute, Japan Meteorological Agency), Tatsuya Kubota(National Research Institute for Earth Science and Disaster Resilience)

This session discusses issues related to improving real-time and long-term prediction accuracy of tsunami from earthquakes, landslides, and volcanoes, which include such as a better understanding of tsunami dynamics, new real-time tsunami observing systems deployed in the open ocean and coastal waters, methodologies of more rapid and accurate prediction during tsunami emergencies, more extensive and accurate inundation maps, and long-term tsunami potential forecast.

[HDS08-01] N-net: Nankai Trough Seafloor Observation Network for Earthquakes and Tsunamis

*Shin Aoi[1], Tetsuya Takeda[1], Takashi Kunugi[1], Kenji Uehira[1], Masanao Shinohara[1], Toshikazu Tanada[1], Shigeru Nagata[1], Takayuki Miyoshi[1], Narumi Takahashi[1] (1.National Research Institute for Earth Science and Disaster Resilience)

[HDS08-02] Probabilistic Tsunami Hazard Assessment for next Nankai Earthquake sequence

*Kenji Hirata[1], Hiroyuki Fujiwara[1], Hiromitsu Nakamura[1], Tsuneo Ohsumi[1], Nobuyuki Morikawa[1], Shinichi Kawai[1], Takahiro Maeda[1], DOHI YUJI1[1], Hisanori Matsuyama[2], Nobuhiko Toyama[2], Tadashi Kito[2], Kenshi Ohshima[2], Xuelei Zhang[2], Yasuhiro Murata[3], Ryu Saito[3], Tomoyuki Shibuki[3], Shin'ichi Akiyama[4], Mariko Korenaga[4], Yuta Abe[4], Teppei Ono[4] (1.National Research Institue for Earth Science and Diaster resilience, 2.OYO corporation, 3.KKC, 4.CTC)

[HDS08-03] **J-THIS** - a Public System for Sharing Information on Nationwide Probabilistic Tsunami Hazard Assessment in Japan -

*DOHI YUJI[1], Hiromitsu Nakamura[1], Hiroyuki Fujiwara[1], Tsuneo Ohsumi[1], Kenji Hirata[1], Shinichi Kawai[1], Nobuyuki Morikawa[1], Takahiro Maeda[1] (1.National Research Institute for Earth Science and Disaster Resilience)

[HDS08-04] Tsunami height variations due to stochastic self-similar slip distributions on a non-planar fault for megathrust earthquakes

*Masaru Nakano[1], Shane Murphy[2], Ryoichiro Agata[1], Yasuhiko Igarashi[3], Masato Okada[3], Takane Hori[1] (1.Japan Agency for Marine-Earth Science and Technology, 2.Ifremer, France, 3.Graduate School of Frontier Sciences, The University of Tokyo)

[HDS08-05] Tsunami synthetics using mechanic-based earthquake rupture scenarios

*Tatsuhiko Saito[1], Akemi Noda[1] (1.National Research Institute for Earth Science and Disaster Resilience)

[HDS08-06] Probabilistic tsunami hazard assessment for the Japan Sea region

*Iyan E. Mulia[1], Takeo Ishibe[2], Kenji Satake[1], Aditya Riadi Gusman[3] (1.Earthquake Research Institute, The University of Tokyo, 2.Association for the Development of Earthquake Prediction, 3.GNS Science)

N-net: Nankai Trough Seafloor Observation Network for Earthquakes and Tsunamis

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Based on the fundamental observation plan of the Headquarters of Earthquake Research Promotion (HERP) that established after the Great Hanshin-Awaji Earthquake Disaster, fundamental seismic observation networks in land were constructed in early 2000s by NIED. As for the Great Eastern Japan Earthquake and Tsunami, observation in seafloor is insufficient, and cased underestimates of magnitude, and resulted in underestimates tsunami and earthquake early warning. To enrich seafloor observations, S-net was constructed off the Pacific Coast of eastern Japan, and the construction of DONET from the Kumano-Nada to the Kii Channel water was promoted. These observation networks are integrally operated as MOWLAS, and provide dense spacing and high-quality data. However, the blank of seismic and tsunami observation exists from off Kochi to the Hyuga-nada that is western half of the anticipating Nankai Trough earthquakes. To fill in the blank, NIED starts to construct N-net (Nankai Trough Seafloor Observation Network for Earthquakes and Tsunami) as a subsided project sponsored by MEXT. N-net observes tsunami and ground motion just above the source region, and is capable to accelerate the detection of tsunami and earthquake early warning with accuracy. The objectives of N-net are to understand and simulate the source phenomena such as coupling and spatial and temporal change of the slip on the plate boundary by monitoring of the offshore seismicity, to promote utilization of observations and related information toward the feedback to the society, and to mitigate disaster of giant earthquakes. N-net consists of the two systems of inshore and offshore to link landing stations in Kochi and Miyazaki Prefectures. Each system holds 18 stations that connect to the fiber optic cable with about 700 -800 km long, and 36 stations will be installed in total. In the inline system adopted in S-net, each observation equipment is broke in the main cable, and cable ships can install in the wider region with relatively low cost. On the other hand, in the node system with expandability adopted in DONET, the observation node is installed by ROV (Remotely Operated Vehicle) as the extended branch that is branched from the main cable equipped by cable ships via the branching unit. N-net is basically designed as the inline system but to adopt the hybrid system to node system. Each observation system is equipped by a pair of pressure gauges to detect tsunamis and a pair of the acceleration and short-period velocity sensors are installed to keep redundancy. The construction of N-net is expected to shorten 20 min and 20 sec at maximum to detect tsunamis and earthquakes. The observed data is planned to transmit to the JMA in realtime, and to use for the tsunami and earthquake early warning. In this presentation, we introduce N-net that NIED is newly constructing along the Nankai Trough.

Keywords: N-net, Nankai Trough earthquake, earthquake observation, tsunami observation, seafloor observation network for earthquakes and tsunamis, early warning

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Probabilistic Tsunami Hazard Assessment for next Nankai Earthquake sequence

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Earthquake Research Committee (ERC)/HERP, Japanese government assessed next Nankai earthquake could be M8 to M9 class(ERC, 2013) andits occurrence probability(P30) that next event will occur within next 30 years(from Jan. 1, 2020) is 70% to 80%(ERC,2020a) in long-term evaluation reports. They expected that next Nankai event sequence could occur as one of a variety of occurrence patterns with a variety of earthquake source regions(ESRs), and considered that such varieties could be represented by a variety of combinations of 18 segments on subducting plate geometry(ERC, 2013). Based on the long-term evaluation reports, ERC(2020b) announced a probabilistic tsunami hazard assessment(PTHA) for the next Nankai event sequence in January 2020, although they excluded possible maximum-sized ruptures over M9, etc. from their PTHA. In this study, we make another PTHA for the next Nankai event sequence by adding tsunamis from possible maximum-sized ruptures over M9, etc. to the PTHA of ERC(2020b).

We first review methodology of ERC(2020b); (1) they constructed 79 earthquake source regions(ESR) that are expressed by a variety of combo of 18 segments and 2,720 characterized earthquake fault models(CEFMs) which yields 176 combo of ESRs and 348,345 combo of CEFMs for next event sequence based on Tsunami Recipe (ERC, 2017). (2) They divided 176 combo of ESRs(hence 348,345 combo of CEFMs) into Groups I and II; Group I consists of combo of the ESRs(CEFMs) whose largest ESR(CEFM) spans three or less segments along the trough, representing cases where Tonankai and Nankai regions are ruptured individually(e.g.,1944 and 1946 sequence). Group II consists of combo of the ESRs(CEFMs) whose largest ESR(CEFM) spans four or more segments along the trough, representing cases where both the Tonankai and Nankai regions are simultaneously ruptured (e.g.,1707 Hoei). (3) From occurrence pattern history, they assigned weight ratios (ratios of relative occurrence probability) 2/3 vs 1/3 to Group I vs Group II.

The present study follows the methodology of ERC(2020b) principally, but newly adds (i) CEFMs in Group III that consists of maximum-sized ruptures over M9 and (ii) CEFMs with a super large slip(4 times amount of average slip) that ERC(2020b) excluded to the original CEFMs in Groups I and II, in which (ii) is allowed to exist when earthquake ruptures reach the trough axis as the 2011 Tohoku rupture reached the trench axis. Consequently, we construct 83 ESRs and 3,480CEFMs which yields 180 combo of ESRs and 916,669 combo of CEFMs for next event sequence (Kito et al., this meeting).For initial water surface distribution caused by CEFM each(Okada,1992;Tanioka&Satake,1996), we compute tsunami by solving nonlinear long wave equations, using finite difference method, including runup calculation, over a nesting grid system with a minimum grid size of 50 meters to obtain 3,480coastal tsunami height distribution patterns(Saito et al., this meeting). We assign an weight ratio 1/21 vs 20/21 to Group III vs Groups I &II by accepting an idea regarding the weight ratio in “National Seismic Hazard Maps for Japan in 2014 “(ERC,2014). Other frameworks to estimate hazard curves will be explained in Abe et al. (this meeting).

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PTHA in the present study shows that distribution of exceedance probability(P30) that coastal tsunami height becomes over 3 meters in next 30 years shows similarities to those of ERC(2020b). But P30s in this study become ~1% and ~2% on average (~3% and ~4% at maximum) larger than those of ERC(2020b) in several coasts facing the Pacific between Kyushu and Boso Peninsula, and in Izu-Bonin islands, respectively(Abe et al., this meeting). However, the scientific evidence to the weight ratio to Group III vs Groups I &II is not so strong. A case study shows epistemic uncertainty to the weight ratio affects PTHA largely not to ignore, which implies further researches to the weight ratio regarding Group III, that is maximum-sized ruptures over M9, are needed.

Keywords: Tsunami, PTHA, exceedance probability, Nankai Trough, Nankai earthquake

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J-THIS - a Public System for Sharing Information on Nationwide Probabilistic Tsunami Hazard Assessment in Japan -

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The National Research Institute for Earth Science and Disaster Resilience (NIED) has been conducting nationwide Probabilistic Tsunami Hazard Assessment (PTHA) in Japan. For the better usage of tsunami hazard information based on PTHA, NIED set up the committee for Usage Application of Tsunami Hazard Information (2013-2016) and the committee for Advanced Usage of Tsunami Hazard and Risk Information (2017-). The former committee emphasized the importance of public system for sharing information on various tsunami hazards. Following in it, the latter committee has been discussing the specifications and the needs in tsunami hazard information and risk at an advanced level with using the system.

Based on the above, we have been developing Japan Tsunami Hazard Information Station (J-THIS) to construct such a public browsing system. J-THIS is available on the web and has five main functions. It enables general users to view (1) distributions of the exceedance probability of tsunami heights higher than 3m, 5m, and 10m within 30 years at every 50m mesh on the coastlines on Geospatial Information Authority of Japan (GSI) Maps, (2) tsunami hazard curves for 30 years at every 50m mesh on the coastlines, (3) earthquake fault models used for tsunami simulation on GSI Maps and earthquake fault parameters, (4) distributions of tsunami heights, for each earthquake fault model, at every 50m mesh on the coastlines on GSI Maps, and (5) bathymetric charts of 1350m, 450m, 150m, and 50m mesh on GSI Maps.

In the first step of sharing information on nationwide PTHA in Japan, J-THIS is providing PTHA along the Nankai Trough, which focused on inter-plate earthquakes (Mw7.6-9.0) excluded possible maximum-sized ruptures, by Headquarters for Earthquake Research Promotion (HERP) of Japanese Government (2020). HERP (2020) announced distributions of the exceedance probability of tsunami heights higher than 3m, 5m, and 10m within 30 years at each city, ward, town, and village. J-THIS provides not only information announced by HERP (2020) but also detailed information of it and related information, in terms of five points as described above.

We have been developing J-THIS as a part of the research project on “Research on Evaluation of Hazard and Risk” of NIED. Some contents in J-THIS are equal to the PTHA along the Nankai Trough announced by HERP (2020).

Keywords: Japan Tsunami Hazard Information Station (J-THIS), tsunami, Probabilistic Tsunami Hazard Assessment (PTHA), Nankai Trough

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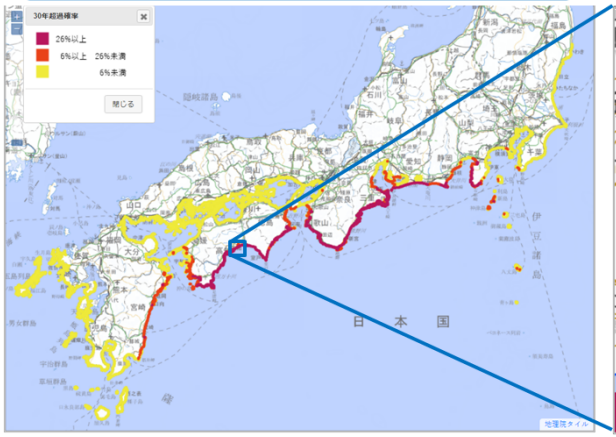
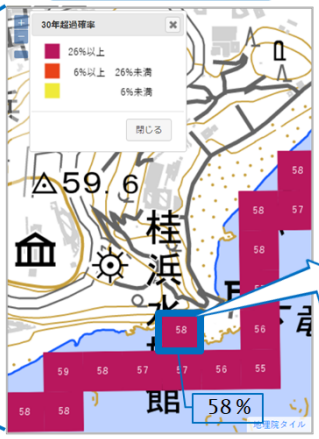
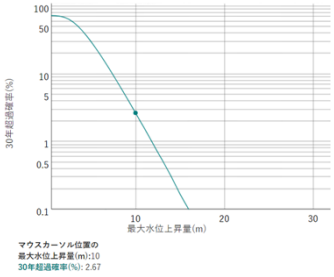
Distribution of the exceedance probability of tsunami heights higher than 3m within 30 years



Enlarged view of each 50m mesh



Tsunami hazard curves for 30 years



マウスカーソル位置の
最大水位上昇量(m):10
30年超過確率(%): 2.67

Top five tsunami heights of tsunami simulation results using 2,720 earthquake fault models

当該ハザード評価点における最大水位上昇量上位５位までの波源断層モデル
モデル名をクリックすると波源断層モデル・津波伝播遡上計算を表示します。

主要波源断層モデル	最大水位上昇量(m)
NK_ZEsm_TYPE2Eh_30L1_m2_02	10.1
NK_ZDsm_TYPE2Eh_30L1_m2_02	10.1
NK_ZEsm_TYPE2Eh_30L2_m2_m3_02	9.8
NK_ZEsm_TYPE2Eh_30L2_m2_s3_02	9.8
NK_ZEsm_TYPE2Eh_30L2_m2_m2_02	9.8

10.1m

9.8m

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Tsunami height variations due to stochastic self-similar slip distributions on a non-planar fault for megathrust earthquakes

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Megathrust earthquakes along the Nankai trough in southwest Japan, such as the 1944 Tonankai and 1946 Nankai events, have caused severe damage due to strong ground motion and the generation of large tsunamis. Since such devastating earthquakes have repeatedly occurred throughout history in this region, we should prepare for future large earthquakes. Tsunami early warning systems have been developed to mitigate such tsunami disasters. Two types of systems exist: (1) based on early estimations of earthquake and/or tsunami sources (e.g. Tatehata 1997; Tsushima et al. 2009), and (2) based on correlations of coastal tsunami heights from scenario earthquakes and offshore tsunami observations (e.g. Baba et al. 2014; Igarashi et al. 2016; Yamamoto et al. 2016). While the computation cost for early warning is relatively low in the latter method, its accuracy may depend on the variations of scenario earthquakes. To date, studies adopting method (2) compute the theoretical tsunamis using thousands of earthquake scenarios of various magnitude earthquakes with uniform slip distributions. However, actual earthquakes have heterogeneous slip distributions which affect coastal tsunami heights and distributions. One possible solution to resolve this issue is to create a set of scenario earthquakes based on a slip probability density function (SPDF, Murphy et al., 2016), in which heterogeneous slip distributions on the source fault are stochastically generated based on a given probability density function. The generated earthquake slip distributions differ from event to event, but their average over a large ensemble of models converges to a predefined SPDF.

In this study, we create a set of scenario earthquakes that contain self-similar slip distributions based on the composite source model (Herrero and Murphy, 2018) on the Nankai trough. In this set of scenario earthquakes fault slip is not tapered to zero at the free surface (i.e. surface rupture is considered). We assume the SPDF is similar to the slip deficit rate (SDR) obtained by Yokota et al. (2016), which may represent long-term average of slip on the target fault. Using this technique, 200 scenario earthquakes were generated for the expected Tonankai earthquake (Mw=8.2) and the ensuing tsunamis were computed using the JAGURS code (Baba et al. 2014). We then compared the peak nearshore tsunami amplitudes generated using these scenario earthquakes that incorporate slip heterogeneity with those from uniform slip distribution on the same fault area.

We found that the peak tsunami amplitudes along the coast facing the source region varies by as much as 3 to 10 times depending on the slip distribution of the scenario earthquakes. The peak tsunami amplitude distributions are well fitted by Gauss distribution with a mean and standard deviation depending on each site. Largest and/or smallest peak amplitudes are caused by a few extreme cases, and locations showing large variations might depend on the scenarios generated in this study. Increasing the number of scenario earthquakes might increase variations of peak tsunami amplitudes, especially locations showing relatively small variations obtained in this study.

Next, we compared the median heterogeneous-slip amplitudes with that due to an earthquake of uniform slip distribution. The median heterogeneous-slip amplitudes are larger compared with that from uniform

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slip at most sites. This result indicates that consideration of heterogeneous slip for scenario earthquakes is crucial to accurately estimate peak tsunami amplitudes consequently improving the accuracy of tsunami early warning based on scenario earthquakes.

Acknowledgments: This work is supported by CREST project “Establishing the most advanced disaster reduction management system by fusion of real-time disaster simulation and big data assimilation” from the Japan Science and Technology Agency.

Keywords: Nankai trough, Tsunami early warning, Scenario earthquakes

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Tsunami synthetics using mechanic-based earthquake rupture scenarios

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The present study theoretically assesses the tsunami height along the coasts excited by possible great earthquakes that will occur in the Nankai Trough subduction zone and simulates observable records for ocean-bottom pressure gauges. First, by surveying energy balance, we constructed multi-segment rupture scenarios using the GNSS observations and the earthquake mechanics. We estimated a shear-stress distribution along the plate boundary from the GNSS data analyses (Noda et al. 2018 JGR) and calculated coseismic slip distributions to release the accumulated stress. Then, employing an idea of the energy conservation of the earthquake faulting, we evaluated the possibility of each multi-segment rupture. The released strain energy by shear faulting should be larger than the energy dissipated on the fault. However, for some scenarios, the released strain energy was smaller than the dissipated energy calculated from assumed slip weakening friction laws. Such rupture scenarios cannot occur in the viewpoint of earthquake mechanics.
We then theoretically synthesize ocean-bottom pressure changes of the earthquake rupture scenarios caused by both seismic waves and tsunamis using a simulation method based on elastic and fluid dynamics (Saito and Tsushima 2016 JGR; Saito et al. 2019 Tectonophysics). Seismic-wave contributions to ocean-bottom pressure changes are critically important for the synthetics in near-field or inside rupture areas because the seismic waves overlap with tsunami signals and work as noise for real-time tsunami monitoring. The records simulated in this study can be used to examine the monitoring ability of a deep-ocean observation network for megathrust earthquakes and tsunamis in this region.

Keywords: Tsunami hazard, Earthquake mechanics, Wave theory

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Probabilistic tsunami hazard assessment for the Japan Sea region

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While our attention is drawn to the east coast of Japan due to the occurrence of mega tsunamis in the subduction zones, such as the Japan Trench and Nankai Trough, its counterpart in the west coast possesses non-negligible tsunami hazards. The west coast of Japan is situated in the eastern margin of the Japan Sea, which is known to host large tsunami events generated by earthquakes (M>7) on several active fault systems in the region: The 1993 South-west Hokkaido (M 7.8), 1983 Japan Sea (M 7.7), 1964 Niigata (M 7.5), 1940 Shakotan-oki (M7.5), and 1833 Shonai-oki (M 7.5). Each earthquake causes considerable coastal tsunami impacts, with the highest observed tsunami of approximately 30 m at Okushiri Island associated with the 1993 event. These historical records highlight the necessity to assess the tsunami hazard levels along the west coast of Japan as part of mitigation efforts, particularly in relation with the coastal development strategy.

To that end, we conducted a probabilistic tsunami hazard assessment (PTHA) study around the Japan Sea in accordance with 60 submarine active faults identified by the Ministry of Land, Infrastructure, Transport and Tourism of Japan (MLIT, 2014). The faults correspond to estimated moment magnitudes ranging from 6.8 to 7.9. We generated multiple stochastic non-uniform slip models on each fault system to develop a regional synthetic earthquake catalog, while the earthquake recurrence rate was determined using real data from the Japan Meteorological Agency earthquake catalog within a period of 1997-2017. The PTHA was derived based on a Green’ s function approach, in which maximum coastal tsunami heights were resulted from a superposition of precalculated tsunami scenarios weighted by slips. In this study, we considered 156 coastal points in the analysis representing municipalities along the west coast of Japan.

In general, the hazard level increases from southwest to northeast. This is consistent with the limited number of identified faults in the southwestern part, as well as the types of fault that are mainly characterized by strike-slip faults. However, the southwestern part could also be subjected to significant tsunamis, especially at locations situated very close to the fault system. Deaggregation analysis further confirmed the profound effect of local faults to the coastal tsunami heights indicating the main characteristic of tsunamis in the Japan Sea.

Such near-field events are very difficult to deal with as they can produce a very large tsunami with an extremely short lead time. Our study shows the potential of near-field tsunamis that may cause severe damage in the Japan Sea region. Thus, specific precautionary measures for near-field events should be implemented to protect coastal areas at risk.

Keywords: Japan Sea, Probabilistic tsunami hazard assessment, Earthquake

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[E] Oral | H (Human Geosciences)：H-DS Disaster geosciences

[H-DS08] Tsunami and tsunami forecast

convener:Hiroaki Tsushima(Meteorological Research Institute, Japan Meteorological Agency), Tatsuya Kubota(National Research Institute for Earth Science and Disaster Resilience)

This session discusses issues related to improving real-time and long-term prediction accuracy of tsunami from earthquakes, landslides, and volcanoes, which include such as a better understanding of tsunami dynamics, new real-time tsunami observing systems deployed in the open ocean and coastal waters, methodologies of more rapid and accurate prediction during tsunami emergencies, more extensive and accurate inundation maps, and long-term tsunami potential forecast.

[HDS08-07] Numerical simulation of debris avalanche and tsunami caused by the 2018 sector collapse of Anak Krakatau

*Hideaki Yanagisawa[1], Tatok Yatimantoro[2] (1.Department of regional Management, Faculty of Liberal Arts, Tohoku Gakuin University, 2.Indonesian Agency for Meteorology, Climatology and Geophysics)

[HDS08-08] **Tsunami hazards in East Indonesia: the case of 14 November 2019 Mw7.1 earthquake and tsunami in Molucca Sea, Indonesia**

*Mohammad Heidarzadeh[1], Takeo Ishibe[2], Tomoya Harada[3], Bayu Triyogo Widyantoro[4] (1.Brunel Univ. London, UK, 2.Association for the Development of Earthquake Prediction, Japan, 3.Univ. of Tokyo, Japan, 4.Indonesian Geospatial Information Agency, Indonesia)

[HDS08-09] *Augmenting GNSS and Teleseismic networks for improved tsunami early warning*

*Y Tony Song[1] (1.Jet Propulsion Laboratory)

[HDS08-10] Determination of Appropriate Source Models for Tsunami Forecasting: Application to Large Earthquakes in Central Sumatra, Indonesia

*Yuichiro Tanioka[1], Rinda Nita Ratnasari[1] (1.Hokkaido University, Institute of Seismology and Volcanology)

[HDS08-11] Tsunami analysis using the S-net pressure gauge records during the Mw 7.0 Off-Fukushima earthquake on 22 Novenver 2016 to reduce the effects of tsunami-irrelevant pressure components

*Tatsuya Kubota[1], Naotaka Yamamoto Chikasada[1], Hiroaki Tsushima[2], Wataru Suzuki[1], Takeshi Nakamura[1] (1.National Research Institute for Earth Science and Disaster Resilience, 2.Meteorological Research Institute)

[HDS08-12] Operational use of tsunami source inversion in near-field tsunami warning by JMA

*Hiroaki Tsushima[1], Takeyasu Yamamoto[2] (1.Japan Meteorological Agency, 2.Meteorological Research Institute, Japan Meteorological Agency)

Numerical simulation of debris avalanche and tsunami caused by the 2018 sector collapse of Anak Krakatau

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1. Department of regional Management, Faculty of Liberal Arts, Tohoku Gakuin University, 2. Indonesian Agency for Meteorology, Climatology and Geophysics

On 22 December 2018, a sector collapse was occurred by volcanic activity of the Anak Krakatau in Sunda Strait. The debris of sector collapse rushed into sea area and caused large tsunami that killed more than 400 people. After the collapse, some of Indonesian institutes such as Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG) measured tsunami heights and found more than 10 m heights. In this event, many of data is collected and the data is very important to clarify the physical processes of sector collapse and resulting tsunami. In this study, we simulate the event to clarify the physical processes of collapse and resulting tsunami. We use two-layer model with nonlinear long wave/dispersive wave model for tsunami waves induced by debris avalanche. For the bottom layer of soil mass, manning model/coulomb model are used to compare the effect of constitutive law of models. We assume volume of collapse as 0.2, 0.25 and 0.3 km^3. As results of numerical simulations, we found that coulomb and nonlinear dispersive model with 0.25 km^3 volume are required to reproduce all evidences of distribution of debris deposit, wave gauges and tsunami heights that observed in this event.

Keywords: Anak Krakatau, Tsunami, Sector collapse, Numerical simulation, Sunda Strait

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Tsunami hazards in East Indonesia: the case of 14 November 2019 Mw7.1 earthquake and tsunami in Molucca Sea, Indonesia

*Mohammad Heidarzadeh[1], Takeo Ishibe[2], Tomoya Harada[3], Bayu Triyogo Widyantoro[4]

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East Indonesia is characterized by an extremely complicated tectonic setting where a combination of curved subduction zones, submarine and land faults transformed the region to be among seismically active areas of the world. Although the region has experienced a number of deadly tsunamis such as those in 1629, 1674, 1852, and 1899, the tsunami hazard on east Indonesia is not well understood. Very few tsunami researches have been conducted for east Indonesia. Given the high tsunami risks associated with east Indonesia, it is essential that more researches to be conducted on tsunami hazards of this region. In this work, we study the earthquake (Mw 7.1) and tsunami of 14 November 2019 in the Molucca Sea in east Indonesia. Although the tsunami was small, its study helps to understand the characteristics of tsunami propagation in the region and predict potential high-risk areas. Here we obtained teleseismic waveforms of the earthquake and the tide gauge records of the tsunami and performed seismicity analysis to shed light on the magnitude and mechanisms of earthquakes in this area. The source model of the earthquake is extracted using teleseismic records. Tide gauge records showed that tsunami height was a few centimeters along the coastal areas. Tsunami simulations were conducted using our source model, which showed fairly good agreement with observed tide gauge data. We applied the validated tsunami model to study tsunami propagation patterns in the Molucca Sea and identified high-risk areas in terms of tsunami hazards. The results of this study contribute to a better understanding of tsunami risks in east Indonesia.

Keywords: Earthquake, Tsunami, Subduction Zone, East Indonesia, Tsunami simulations

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Augmenting GNSS and Teleseismic networks for improved tsunami early warning

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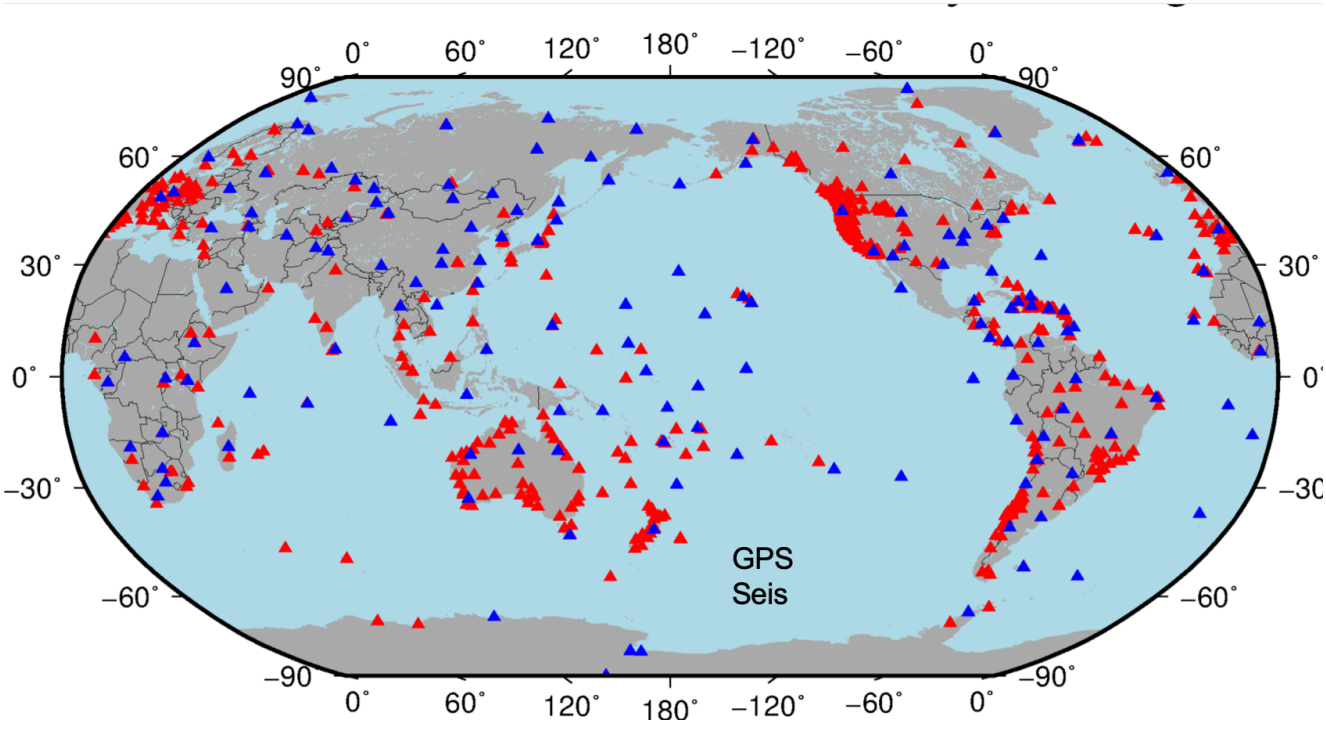
1. Jet Propulsion Laboratory

For the last 10 years, we have been developing both theories and algorithms to detect tsunami source energy and scales directly from real-time Global Navigation Satellite System (GNSS) for tsunami early warning [Song 2007; Xu and Song 2013]. However, Real-time GNSS stations are sparse along most of the active faults and unreliable for tsunami early warnings in those regions.

Recently, we have further developed an automatic earthquake finite source inversion (AutoQuake Inversion) algorithm jointly using near-field GNSS data and mid-range teleseismic P displacement waveforms. Neither the near-field GNSS nor the mid-range teleseismic data clip or saturate during large earthquakes, while the fast-traveling P-waves are still essential to constrain the source in regions where very few or no GNSS stations are available [Chen et al, 2019].
The new algorithm has been implemented in JPL’s GNSS-Aided Tsunami Early-detection System (https://gates.jpl.nasa.gov) for real-time events in the last three years. Here we present results and evaluate the performance of the global real-time earthquake and tsunami detection system. Detailed results on particular events, including the 2018 Indonesia Palu M7.5 earthquake and tsunami, as well as the more recent 2019 California Ridgecrest M7.1 earthquake, will also be discussed.



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Determination of Appropriate Source Models for Tsunami Forecasting: Application to Large Earthquakes in Central Sumatra, Indonesia

*Yuichiro Tanioka[1], Rinda Nita Ratnasari[1]

1. Hokkaido University, Institute of Seismology and Volcanology

The subduction of the Indo-Australian plate beneath the Eurasian plate off the west coast of Sumatra has often resulted in large tsunamigenic earthquakes. Great earthquakes have occurred along this plate boundary such as the 2004 Sumatra–Andaman earthquake (Mw 9.1) and the 2005 Nias earthquake (Mw 8.6). On September 12, 2007, a great earthquake (Mw 8.4) occurred offshore of the Bengkulu province of Sumatra. According to the US Geological Survey, the mainshock at 18:10 local time (11:10 UTC) was followed by two large aftershocks (Mw 7.9 and Mw 7.1) at 23:49 UTC and 03:35 UTC, respectively. The mainshock generated a large tsunami along the Bengkulu coastline and caused damage at several locations along the Bengkulu coastal area. A few years later, another large earthquake (Mw 7.8) occurred on October 25, 2010, off the west coast of Mentawai Islands at 21:42 local time (14:42 UTC). This earthquake also generated a large tsunami and caused more than 400 casualties around the Mentawai Islands. Although the moment magnitude of the 2010 earthquake is much smaller than that of the 2007 earthquake, the tsunami heights resulting from the former 2010 earthquake were higher than those resulting from the latter 2007 earthquake, indicating that tsunami heights are difficult to forecast.

An advanced method to determine appropriate source models that can explain the tsunami heights along coastal areas is needed for tsunami warning purposes. In this study, fault parameters were estimated from the W-phase inversion and fault length and width were calculated from suitable scaling relations between those and magnitude for the 2007 and 2010 earthquakes. Tsunami numerical simulations were conducted using various slip amounts or corresponding rigidities. The best slip amount or corresponding rigidity was selected by comparing the measured and computed tsunami heights.

The 2007 great Bengkulu earthquake (Mw 8.4) was a typical interplate earthquake that occurred at the subducted plate interface. The measured tsunami heights along the coast of Sumatra Island were well explained by the computed tsunami from the source model estimated by our method using the rigidity of 3.0×10^{10} Nm^{-2} (7.59-m slip amount). This rigidity is consistent with the depth dependent rigidity curve estimated by Tanioka et al. (2017) at an estimated depth of 30 km (Figure). The 2010 Mentawai tsunami earthquake (Mw 7.8) occurred at the plate interface near the trench. The measured tsunami heights along the coast of Mentawai Islands were also explained well by the computed tsunami from the source model estimated using the method with a rigidity of 1.5×10^{10} Nm^{-2} (8.17 m slip amount). This rigidity is slightly larger than the depth dependent rigidity curve estimated by Tanioka et al. (2017) at an estimated depth of 17 km (Figure). These results indicate that the rigidity differences along the plate interface as suggested by Bilek and Lay (1999) have a considerable impact on tsunami height estimation as also suggested by Tanioka et al. (2017). These results also suggested that a blue dashed line in Figure should be used for the rigidity estimate along the plate interface off Sumatra in Indonesia. Therefore, appropriate slip amounts of source models for tsunami forecast in this region can be estimated rapidly using the results of W-phase inversion and this depth dependent rigidity (a blue line in Figure).

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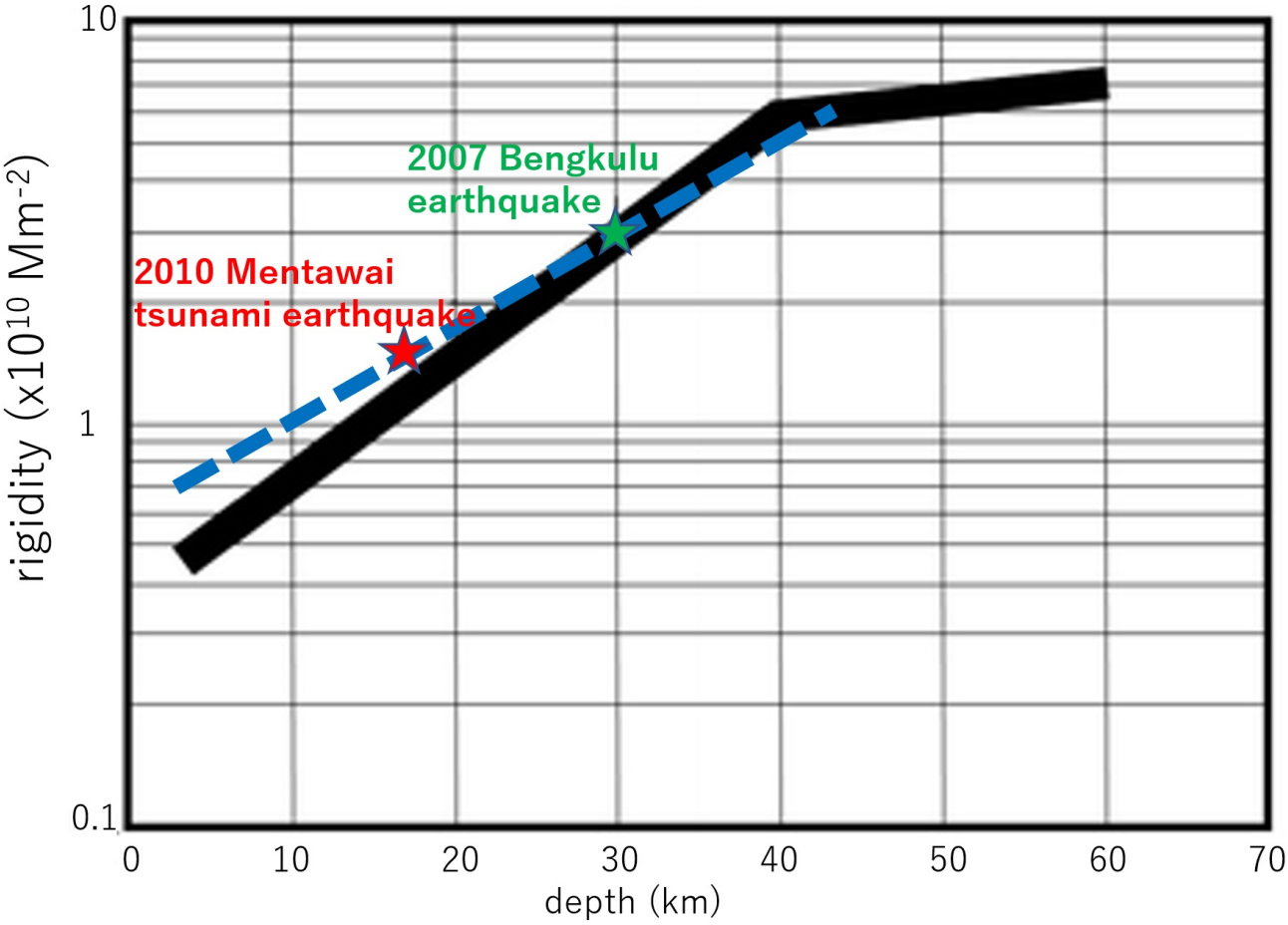
Keywords: Tsunami forecast, Tsunami numerical simulation, Central Sumatra



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Tsunami analysis using the S-net pressure gauge records during the Mw 7.0 Off-Fukushima earthquake on 22 Novenver 2016 to reduce the effects of tsunami-irrelevant pressure components

*Tatsuya Kubota[1], Naotaka Yamamoto Chikasada[1], Hiroaki Tsushima[2], Wataru Suzuki[1], Takeshi Nakamura[1]

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Following the 2011 Tohoku-Oki earthquake, the seafloor observation network for earthquakes and tsunamis along the Japan Trench (S-net) was developed by the National Research Institute for Earth Science and Disaster Resilience (NIED, Kanazawa et al. 2016). This network employs a Digiquartz Series 8B pressure sensor (8B7000 or 8B8000) manufactured by Paroscieitific, Inc. Each of the observatories equips two pressure sensors for redundancy, which were not directly exposed to seawater but put in an oil-filled metal housing. Since this network was constructed, several tsunami events have been observed; the largest one is the Mw 7.0 Fukushima-Oki earthquake on November 22, 2016 (Gusman et al. 2017; Suppasri et al. 2017; Nakata et al. 2019). In this presentation, we examine the features of the S-net pressure records during this event.

We first removed the tidal component from the S-net pressure record. We confirmed tsunami-related pressure changes with amplitudes up to 40 cm. Some stations also included drifts with rates of a few hPa/hour, which were much larger than the long-term drift observed in the Paroscientific sensors (~8.8 hPa/year, Polster et al. 2009). In addition, at stations near the epicenter, step-like pressure offset changes were recorded just after the earthquake. For example, at the station S2N15, located ~60 km from the epicenter, an abrupt pressure offset increase of ~30 hPa was recorded. Pressure offset changes are often recognized as a result of seafloor vertical crustal deformation; however it was quite unlikely that such a large crustal deformation occurred at ~60 km away from the epicenter and thus these offset changes are not related to the crustal deformation.

We then compared the pressure waveform with those of the other pressure sensor at the sites where large pressure steps were observed. At the observatories, which were revealed to have significantly rotated during the earthquake based on the analysis of the co-located accelerometer (Takagi et al. 2019), the offsets of two sensors were not coincided with each other, whereas at the other sites where the rotation was insignificant, the offsets coincided well. For example, at the observatory S2N15, where a sensor rotation of 5.88° was observed (Takagi et al. 2019), one had an offset increase of ~30 hPa and ~37 hPa for another. Chadwick et al. (2006) pointed out that the offset of the Paroscientific pressure sensors has strong dependency of the sensor rotation angle. The rotation angle of ~10° corresponds to the pressure offset change of ~5 hPa at maximum. The differences in the offsets between two sensors might be related to differences in the sensors' sensitivity to the rotation angle. In addition, because it is unlikely that the offsets are identical to each other considering the differences in the sensitivity to the rotation, the pressure steps should be related to the observation system including the housing in addition to the pressure sensor itself.

We finally estimated the initial sea height distribution by the waveform inversion to evaluate how useful the S-net pressure data are. We applied the bandpass filter with passbands of 100-3600 s to avoid the drift and used the method of Kubota et al. (2018), which uses time-differentiated pressure waveforms to

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reduce the effect of the step. The time window for the inversion was determined by visual inspection. The distribution was consistent well with this event’ s normal-faulting mechanism, which shows that the S-net tsunami records are very useful even if they are contaminated by the tsunami-irelevant signals. The distribution extended about 30 km along the strike direction and was slightly smaller than that expected from the scaling law (~40 km, Wells and Coppersmith 1991). This suggests that the fault dimension of this event was smaller than that of typical earthquakes.

[Acknowledgments] The peak ground acceleration and rotation angle data are provided by Ryota Takagi, Tohoku University.

Keywords: S-net, Tsunami, Ocean bottom pressure gauge, Noise

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Operational use of tsunami source inversion in near-field tsunami warning by JMA

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In Japan, Japan Meteorological Agency (JMA) has responsibility for operational tsunami forecast and warning. When a tsunamigenic earthquake occurs around Japan, JMA issues tsunami warning within three min after the earthquake using seismic-wave data, and then the warning is often updated based on tsunami measurements. For the rapid and reliable update, offshore tsunami data take an important role, because tsunamis can be detected at offshore stations earlier than at coastal sites, and the data provide direct information about the impending tsunamis. After the 2011 off the Pacific coast of Tohoku Earthquake (Mw 9.0) (hereafter, 2011 Tohoku earthquake), dense seafloor observation network were deployed by NIED (S-net system) and JAMSTEC (DONET system). These systems equips ocean-bottom pressure gauge (OBPG) that enable us to greatly enhance our ability of real-time tsunami monitoring. Actually, these data are already used in JMA's tsunami-warning operation since 2016. On 26 March, 2019, JMA started operation of a new tsunami-forecasting method in which offshore tsunami data are used more effectively, in order to realize more reliable update of near-field tsunami warnings. In this paper, we present the tsunami forecasting method and its forecasting performance.

In our tsunami-forecasting method (tFISH: Tsushima et al., 2009, JGR), offshore tsunami-waveform data are used to estimate spatial distribution of initial sea-surface displacement in tsunami source area. Then linear combination of the estimated source and the precomputed tsunami-waveforms from sea-surface elements (i.e. Green's functions) are calculated to forecast tsunami waveforms at coastal sites of interest. Actual OBPG data contain pressure variations not only due to tsunami, but also due to other natural phenomena such as permanent seafloor deformation (coseismic offset) and seismic waves (short-period pressure fluctuation). To reduce effect of these non-tsunami components we applied revision of tsunami Green's functions (Tsushima et al., 2012, JGR) and real-time noise reduction such as recursive digital filter (Saito 1978). The retrospective application to the 2003 Tokachi-oki earthquake (Mw 8.3) and the 2011 Tohoku earthquake (Mw 9.0) (e.g. Tsushima et al., 2011, EPS) showed its good tsunami-forecasting ability.

The forecasting accuracy by tFISH depends on station coverage (Tsushima et al., 2009, JGR). Since the present offshore tsunami network, especially S-net, is distributed widely, densely and homogeneously, tFISH expected works well. In the actual pressure records, however, coseismic offset and long-wave-period variations that cannot be interpreted as seafloor deformations and tsunamis are sometimes measured (Wallace et al., 2016, JGR; Kubota et al. 2020, GRL). For example, when the 2016 off Fukushima earthquake (Mw 6.9) occurred, coseismic step appeared in the records of the OBPGs around source area, but the step amount is too large to be explained as coseismic seafloor deformation (Kubota et al., 2020, this meeting). The application of tFISH to these data showed significant tsunami-source artifact, resulting in degrading accuracy of tsunami forecast (overestimation of coastal tsunami height). The source artifact can be decreased substantially by applying the revised tFISH inversion that is proposed by Tsushima and Yamamoto (2017, SSJ Meeting). In the observation equation of the revised inversion, we put assumption that observed waveform at OBPGs can be represented by not only tsunami and seafloor deformation, but also coseismic step function and liner trend function. The reason why we chose these functions is that actual waveforms of non-tsunami signal resembles these

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functions: i.e. we do not have physical image. We applied the revised method to the S-net OBPG data of the 2016 Fukushima earthquake and succeeded in improving source model and coastal tsunami forecasts.

Keywords: Tsunami, Real-time forecast, Tsunami warning

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[E] Oral | H (Human Geosciences)：H-DS Disaster geosciences

[H-DS08] Tsunami and tsunami forecast

convener:Hiroaki Tsushima(Meteorological Research Institute, Japan Meteorological Agency), Tatsuya Kubota(National Research Institute for Earth Science and Disaster Resilience)

This session discusses issues related to improving real-time and long-term prediction accuracy of tsunami from earthquakes, landslides, and volcanoes, which include such as a better understanding of tsunami dynamics, new real-time tsunami observing systems deployed in the open ocean and coastal waters, methodologies of more rapid and accurate prediction during tsunami emergencies, more extensive and accurate inundation maps, and long-term tsunami potential forecast.

[HDS08-13] Point-to-point Tsunami Ray Tracing Method

*Tungcheng Ho[1,2], Shingo Watada[2], Kenji Satake[2] (1.Disaster Prevention Research Institute, Kyoto University, 2.Earthquake Research Institute, the University of Tokyo)

[HDS08-15] Derivation of Time Difference Equation using Continuous Expression in Nonlinear Long Wave Equation and Evaluation of its Discretization Error

*Masaaki MINAMI[1], Takeyasu Yamamoto[1] (1.Meteorological Research Institute)

[HDS08-16] Estimating tsunami currents from shipborne Automatic Identification System data

*Daisuke Inazu[1], Tsuyoshi Ikeya[1], Toshio Iseki[1], Takuji Waseda[2] (1.Tokyo University of Marine Science and Technology, 2.The University of Tokyo)

[HDS08-18] Hydraulic experiments to investigate how vegetation coverage affects sediment transport during a tsunami

*Ako YAMAMOTO[1], Yuki Kanemaru[2], Ryunosuke Matsunaga[3], Takayuki Minamino[3], Tsuyoshi Tada[2], yo Fukutani[3], Yoshinori Shigihara[2] (1.Forest of Research and Management Organization Forestry and Forest Products Research Institute, 2.National Defense Academy, 3.Kanto Gakuin University)

Point-to-point Tsunami Ray Tracing Method

*Tungcheng Ho[1,2], Shingo Watada[2], Kenji Satake[2]

1. Disaster Prevention Research Institute, Kyoto University, 2. Earthquake Research Institute, the University of Tokyo

Wave ray tracing is a commonly used tool for researches in seismology which provides important information for wave propagation, ray path, and arrival time prediction. There are two kinds of ray tracing methods: the initial value problem, and the boundary value problem. In terms of tsunami research, ray tracing is a useful method to assess the tsunami travel path and arrival time and gives us essential information for hazard prevention and mitigation.
Initial value ray tracing has been applied to tsunami researches since 1980s. Woods and Okal (1987) applied the ray tracing to tsunami propagation in an ocean to reconstruct the tsunami wavefield from the 1960 Chile earthquake. Sansanbata et al. (2018) applied the ray tracing method to dispersive tsunamis and demonstrated that the ray path of the dispersive tsunami wave is frequency-dependent.
In this study, we perform a boundary value tsunami ray tracing with the long wave assumption, where a tsunami traveltime program (TTT, Geoware) is applied in our study. Our ray tracing method (hereafter, LW method) calculates the ray path by minimizing the tsunami travel time between the source and the receiver. The LW method exhibits an explicit and efficient approach with an ignorable expected error of 0.05%. We compare the LW method to the bending method (Um and Thurber, 1987; Koketsu and Sekine, 1998) which is commonly used in seismic wave research. Two almost identical ray paths are expected by the two methods. Our result shows that the LW method utilizes a noniterative scheme and exhibits a more efficient way to an expected result. The advantage of the LW method can be obvious in transoceanic tsunami events.

Keywords: ray tracing, bending method, tsunami, long wave, travel time

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Derivation of Time Difference Equation using Continuous Expression in Nonlinear Long Wave Equation and Evaluation of its Discretization Error

*Masaaki MINAMI[1], Takeyasu Yamamoto[1]

1. Meteorological Research Institute

We are working on the improvement of the finite difference formula of the nonlinear long-wave equation to improve the accuracy of the tsunami numerical calculation, especially its decay process. In the tsunami field, the method of [Imamura et al., 2006] is widely used for the finite difference formulas of the nonlinear long wave equation. Fluid simulations using nonlinear long-wave equations are performed in various fields, such as river engineering, oceanography and hydrology. In each field, the same method is used in many cases as in the tsunami field. However, the existing method has weak points that tsunami decay is weak, and the cause has not been elucidated yet. Therefore, we focused on the friction term of the nonlinear long-wave equation, which greatly affects the tsunami decay. At [Minami, 2019, JpGU], we showed that the accuracy of the tsunami decay process can be improved by improving the difference equation of friction term. In this process, it was shown in Fig.1 that the friction term can be solved analytically by the time difference. It was shown that the accuracy of the decay process of increased. In this paper, this form is called Simple-Implicit, following [Imamura et al., 2006]. In addition, Fig.2-2, the method widely used in tsunami numerical calculation, is called Combined-Implicit. Note that Fig.2-3 is Explicit method. Furthermore, at [Minami, 2019, the 9th Meeting of the Huge Tsunami Research Group], we compared analytical solution, Simple-Implicit, and Combined-Implicit for the process in which the gravity term and advection term did not work and the overall flow gradually weakened only with the bottom friction. We have shown that Simple-Implicit agrees with the analytic solution though it is discrete (Fig.3) and, Combined-Implicit also showed that there is a numerical oscillation reported in [Imamura et al., 2006].
Next, these computational stability in the local inertial equation has already been evaluated in previous studies [Tanaka et al., 2017], suggesting that Simple-Implicit is more stable.
Therefore, in this paper, we evaluated time discretization error between Simple-Implicit and Combined-Implicit about under various conditions. For this purpose, we have created a new tsunami calculation code. It is a 1D nonlinear long-wave equation that can calculate Simple-Implicit and Combined-Implicit at the same time, and can handle virtual terrain and virtual initial waveform. We did not perform run-up calculations to eliminate errors due to run-up calculation conditions, and using radiation boundary condition by characteristic curve.
In order to evaluate the errors of these methods, a value that serves as a criterion is necessary, but no analytical solution has yet been found for the nonlinear long-wave equation. Also, it cannot be evaluated with observation values because it contains various other errors. For that reason, we use a characteristic that regardless of the time difference method, if the integration time dt is shortened as much as possible, each method will produce the same result. We determined that dt was short enough if the value was below a certain criterion, and then set the waveform as a tentative true value. Then, we evaluated the discretization errors of the time difference by comparing with the calculation results at dt which is much larger than its tentative value. dt used in the calculation is usually in the range used in the tsunami numerical calculation. In this case, we compared dt with $1/128$ from the original dt.
In this comparison, there are time discretization errors of the gravity term and the advection term, and these errors are often larger than the time discretization error of the friction term. Therefore, it was

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impossible to compare the results of Simple-Implicit and Combined-Implicit. For that reason, the calculation was performed with the original dt and dt reduced to 1/128, excluding the friction term, and by taking the difference between them, the time discretization error of the advection term and the gravity term was estimated. By subtracting them from the calculation results of Simple-Implicit and Combined-Implicit, only the differences between Simple-Implicit and Combined-Implicit were extracted. The result is Fig.4. In all the calculated cases, it was shown that the error of Simple-Implicit was always small.

In summary, when solved analytical, the form of Simple-Implicit is obtained, and Simple-Implicit has better computational stability than Combined-Implicit and has less discretization error. In other words, this paper showed that Simple-Implicit is a more suitable calculation method for real-time simulations performed for disaster prevention.

Keywords: Tsunami numerical simulation, Nonlinear long wave equation, Finite difference formula

Existing difference equation of friction term is

$$gn^2\left(\frac{D^k_{i,j}+D^k_{i+1,j}}{2}\right)^{-7/3}\frac{M^{k+1/2}_{i+1/2,j}+M^{k-1/2}_{i+1/2,j}}{2}\sqrt{(M^{k-1/2}_{i+1/2,j})^2+(N^{k-1/2}_{i+1/2,j})^2}$$

For convenience, putting

$$M' = M_k - (\text{gravity term}) - (\text{advection term})$$

$$\text{fric} = dt * g * n^2 * D^{-\frac{7}{3}} * \sqrt{M_k{}^2 + N_k{}^2}$$

we obtained

$$M_{k+1} = M' - \text{fric} * \frac{(M_k + M_{k+1})}{2}$$

Next, when putting $N = \alpha \cdot M$, we have fric'$= g * n^2 * D^{-\frac{7}{3}} \cdot \sqrt{1+\alpha^2}$

The partial differential equation due to friction term is

$$\frac{\partial M}{\partial t} = -fric' * M^2$$

using separation of variables

$$\int_{M(k)}^{M(k+dt)} \frac{\partial M}{M^2} = -fric' * \int_k^{k+dt} \partial t$$

$$\frac{1}{M(k)} - \frac{1}{M(k+dt)} = -fric' * dt$$

$$M(k+dt) = \frac{M(k)}{1 + fric' * dt * M(k)}$$

$$M(k+dt) = \frac{M(k)}{1 + fric}$$

namely, $$M_{k+1} = \frac{M'}{1+fric} \rightarrow M_{k+1} = M' - \text{fric} * M_{k+1}$$

Fig.1 Analytically solve the friction term in time difference

$M_{k+1} = M' - \text{fric} * M_{k+1}$ 2-1.Simple-Implicit

$M_{k+1} = M' - \text{fric} * \frac{(M_k + M_{k+1})}{2}$ 2-2.Combined-Implicit

$M_{k+1} = M' - \text{fric} * M_k$ 2-3.Explicit

Fig.2 equations of Simple-Implicit, Combined-Implicit, Explicit

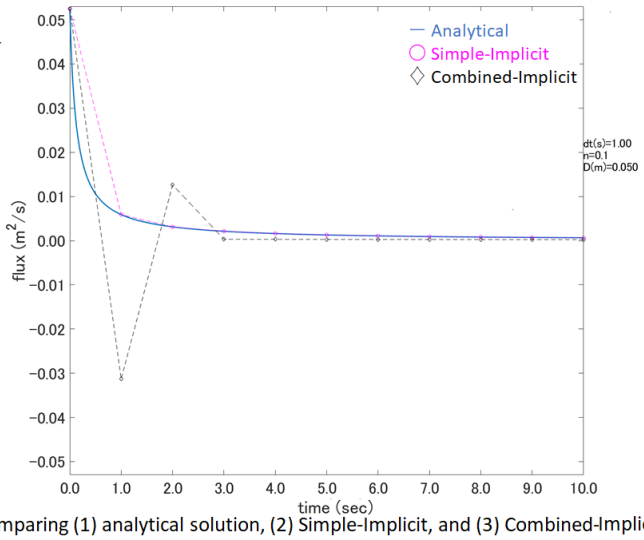

Fig.3 comparing (1) analytical solution, (2) Simple-Implicit, and (3) Combined-Implicit

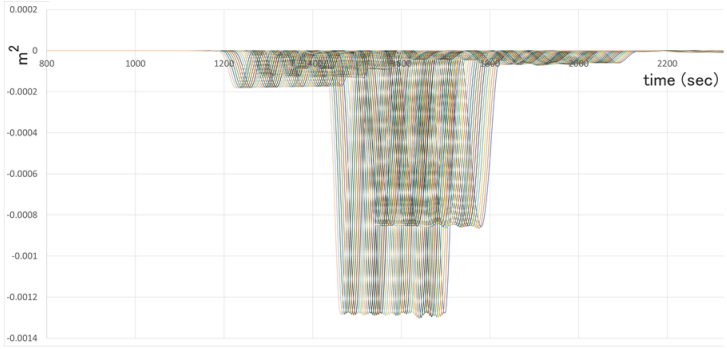

Fig.4 Timelines of discretization error of (Simple-Implicit)^2 - (Combined-Implicit)^2

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Estimating tsunami currents from shipborne Automatic Identification System data

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1. Tokyo University of Marine Science and Technology, 2. The University of Tokyo

We explored tsunami signals in maritime Automatic Identification System (AIS) data during the 2011 Tohoku, Japan, tsunami. The AIS data include latitude/longitude in horizontal location, ship heading, and so on. We employed the horizontal locations and the heading of each ship from AIS data to calculate ship velocity components in two directions in terms of the ship heading: heading-normal and heading-parallel directions. The heading-normal velocity showed good agreement with the simulated tsunami current. However, the heading-normal velocity was contaminated by non-tsunami noises that were mostly related to the ship yaw motion around the pivot point. The noise due to the yaw motion was reasonably corrected in the heading-normal velocity. The corrected heading-normal velocity clearly showed better agreement with the simulated tsunami current. The corrected heading-normal velocity was still a ship response to the tsunami current. Based on an equation of a ship response to tsunami currents, we numerically estimated tsunami current from the corrected heading-normal velocity. We could find very slight improvements in estimating the tsunami currents, which indicated that this operation possibly worked as a secondary correction. Although the heading-parallel velocity is basically the navigation speed, and is mostly controlled by ships' captain, we could find the heading-parallel velocity was also drifted by tsunami currents.

Keywords: Automatic Identification System, Tsunami current, Ship heading

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Hydraulic experiments to investigate how vegetation coverage affects sediment transport during a tsunami

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During a tsunami, coastal forests can trap sediment and reduce the water level and velocity of the tsunami wave. The coastal forest in Tohoku, Japan, was severely damaged by the tsunami that was triggered by the earthquake on 11 March 2011. The forests were redeveloped on a coastal embankment. So that the roots could penetrate, the soil on the embankment was dug and softened. However, while this was necessary for the plants to grow, it was also important that the softened embankment could still resist the tsunami and prevent the generation of flood wood by scouring. Softness and scour can be prevented by implementing countermeasures on the surface of the embankment—for example, by covering the surface with vegetation. To date however, there is no method for evaluating how vegetation coverage affects sediment transport.

In this study, hydraulic experiments were carried out to determine how vegetation cover affects the amount of sediment transported. The experiments were carried out in a two-dimensional water channel that comprised a water tank (5 m^3), a water channel (30 m), and a tank that drained water from the upstream. The experiments comprised two parts. In the first, the bed was fixed and hydraulic data were measured at various points. The second involved a fixed sand bed, a box that contained sand and vegetation, that moved when there was flow in the channel. Changes in the amount of sediment trapped by vegetation cover were measured. A wave that imitated a tsunami was generated in the water tank by opening the gate rapidly. The slope, sand bed section, and flat section were installed downstream of the channel. In the sand bed section, sand (d_{50}=0.287 mm) and vegetation were installed with different proportions, namely 0% (sand only), 30%, 50%, and 100%. When the sand covers were 30% and 50%, the amount of deposition in the sand bed section changed. The net amount of sand deposited by the plankton downstream of the flat section and the dry weight of sand deposited on the flat section were measured. The results showed that the amount of sediment transport decreased and the ability of the vegetation to capture sediment increased as the coverage increased. When we considered where the vegetation was planted, we found that more sediment was transported when vegetation was planted upstream of the sand bed section than when it was planted downstream. Additionally, the scouring was deeper when the vegetation was planted upstream rather than downstream. These results highlight the importance of both the deposition and the degree of vegetation cover.

Keywords: Vegetation coverage, Hydraulic experiments, Tsunami

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[E] Oral | H (Human Geosciences)：H-DS Disaster geosciences

[H-DS09] Landslides and related phenomena

convener:Masahiro Chigira(Disaster Prevention Research Institute, Kyoto University), Fumitoshi Imaizumi(Faculty of Agriculture, Shizuoka University), Gonghui Wang(Disaster Prevention Research Institute, Kyoto University)

Mass movements, such as landslides, rockfalls, and debris flows, have been occurring extensively in a large number of countries, causing heavy damage. In order to understand them and mitigate induced disasters, we invite contributions that report and discuss on mass movements and related phenomena, focusing on improved understanding of their characteristics; new insights into landslide mechanisms; the development of new approaches to monitoring; novel approaches to behavior forecasting and prediction; studies of successful landslide management; and the development of methods for hazard and risk evaluation. In particular, papers about recent landslide hazards, such as those induced by 2015 Kundasang earthquake in Malaysia, 2018 western Japan rainstorm, and 2018 Hokkaido earthquake are welcome.

[HDS09-01] **Examining the mobility of earthquake-induced landslides materials using small flume apparatus**

*Rozaqqa Noviandi[1], Hefryan Sukma Kharismalatri[2], Takashi Gomi[3], Yoshiharu Ishikawa[3], Rasis Putra Ritonga[4] (1.Department of International Environmental and Agricultural Science, Tokyo University of Agriculture and Technology, Japan, 2.Institute of Global Innovation Research, Tokyo University of Agriculture and Technology, Japan, 3.Graduate School of Agriculture, Tokyo University of Agriculture and Technology, Japan, 4.United Graduate School of Agricultural Science, Tokyo University of Agriculture and Technology, Japan)

[HDS09-02] Seismic signal analysis of the 2011 landslide in Misakubo, Shizuoka prefecture and the potential for the real-time landslide detection

*Masumi Yamada[1], Ryo Okuwaki[2], Hikaru Osawa[2] (1.Disaster Prevention Research Institute, Kyoto University, 2.Mountain Science Center, Univ. of Tsukuba)

[HDS09-03] **Steady-state shear resistance and viscosity of brittle dense grain flows appear to be independent of grain material and normal stress**

★Invited Papers

*wei hu[1], Mauri McSaveney[2] (1.Chegndu University of Technology, 2.GNS Science, New Zealand)

[HDS09-04] **A discussion on the characteristics of seismic signals of different landslide movement types by coupling PFC and FLAC codes**

*Rui-Jia Zhuang[1], Zheng-yi Feng[1] (1.National Chung Hsing University Department of Soil and Water Conservation)

[HDS09-05] Tertiary Creep Behavior of Soils and Corresponding Power Law Singularity

*Chengrui Chang[1], Gonghui Wang[2] (1.Graduate School of Science, Kyoto University, 2.Disaster Prevention Research Institute, Kyoto University)

Examining the mobility of earthquake-induced landslides materials using small flume apparatus

*Rozaqqa Noviandi[1], Hefryan Sukma Kharismalatri[2], Takashi Gomi[3], Yoshiharu Ishikawa[3], Rasis Putra Ritonga[4]

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The 2018 6.7 Mw Eastern Iburi Earthquake triggered more than 6,000 landslides on over 400 km^2 area in Hokkaido, Japan. Most landslides evolved into high mobility debris flow damaging infrastructures and agriculture lands. Because landslide mobility is one key factor for disaster risk reduction, we developed a two-segment flume apparatus representing hillslope and in-channel transport zones with 1/300 of geometric scale to quantify such mobility. Materials used in flume experiment were obtained from landslide deposits that mainly consists of less cohesive pyroclastic fall deposits derived from Mt. Tarumae (9 ka) and Mt. Eniwa (20 ka). The mobility of landslide materials was examined by combinations of various saturation (S=0-1.0) and soil types (andosol, pumice, and mixed materials). Velocity was measured from a high-speed camera with 0.2 s of shooting interval. Such a low cohesiveness caused the material to be progressively deposited during the motion. Hence, the kinetic friction coefficient was estimated based on the conservation of mechanical energy by considering progressive mass loss. The apparent friction coefficient, representing block movement, was measured by dividing total fall height over the run-out distance (H/L). Laboratory test characterized the material as coarse-grained or granular soils (D_{50} =0.5-5.4 mm). A threshold exists at under saturated condition altering the movement from low to high (hereinafter referred to as turning point, T_p), associated with inner-particle water absorption on pumice (S =0.56) and liquid limit on andosol (S=0.49). $S \leqq T_p$ inhibits the movement (e.g., velocity and run-out distance), and in contrast, enhances the movement when $S > T_p$. The apparent friction coefficient (0.26-1.0) that always lower than the kinetic friction coefficient (0.31-1.1) signifies that landslides with progressive mass loss have lower energy dissipation than those move as a block. Progressive mass loss on granular soils may allow the energy to be not thoroughly dissipated by friction. When some parts of kinetic energy are dissipated by friction resulting in deposition, the other parts are used for the movement. It causes the spread landslide mass to move further downslope. Moreover, variability in particle size distribution on mixed materials causes segregation, in which the finer and heavier particles segregate underneath the landslide mass, acting as a lubricant that enhances the movement. We found that soil characteristics are the most important factor for controlling the mobility of landslide materials by the Eastern Iburi Earthquake, followed by water content. We suggest that the variability in mobility might be associated with the variability of soil depth (stratigraphy) and initial water contents in sliding layers.

Keywords: earthquake-induced landslide, landslide mobility, flume experiment, granular volcanic soils

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Seismic signal analysis of the 2011 landslide in Misakubo, Shizuoka prefecture and the potential for the real-time landslide detection

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When Typhoon Talas moved through western Japan on September 3-4, 2011, there were heavy rainfalls across a wide region in central and western Japan. There were extensive slope failures in the Kii peninsula, which killed 97 people. In Shizuoka prefecture, the total rainfall during the week exceeded 1000 mm. Although the damage is less severe than the Kii peninsula, the heavy rainfall triggered a large landslide in Misakubo-town, Tenryu-ward, Hamamatsu city, Shizuoka prefecture. The landslide was detected by the Japan Air Self-Defense Force on September 7, 2011. The field survey to analyze the landslide dam was performed on the next day.

We applied the triad array method (Fan et al., 2018, GJI) to detect and locate seismic sources using F-net and TW arrays (Okuwaki and Fan, 2019, AGU). The signal from the Misakubo landslide was recorded at 6:07 PM, September 4, 2011. The location error between the estimation and field survey is about 6 km. We also performed the long-period seismic waveform inversion with the same dataset. The result shows the estimated volume is about 2 million (m^3) and the movement of the landslide is from east to west. These movement mechanisms are consistent with the field survey result.

Seismic signals from landslides are generated less efficiently than from earthquakes. Due to their small amplitude, the signal is difficult to be observed in the period range of microseisms (5-20 s). Therefore, the signals tend to be observed clearly in the short period range (a few Hz), or long period range (20-50 s). The short-period signals are more sensitive to smaller events, but signal attenuates faster than long-period signals. Therefore, near-source stations within the limited distance range can record the signals. They will be useful to locate an event with higher precision. The long-period signals have little influence from a velocity structure, so the signals are more coherent over the longer distance. In general, landslides larger than 1 million (m^3) are recorded by the seismic network in Japan. The combination of these short-period and long-period seismic signals will be useful for the real-time detection of landslide events.

Keywords: landslide, seismic waveform, Misakubo-town

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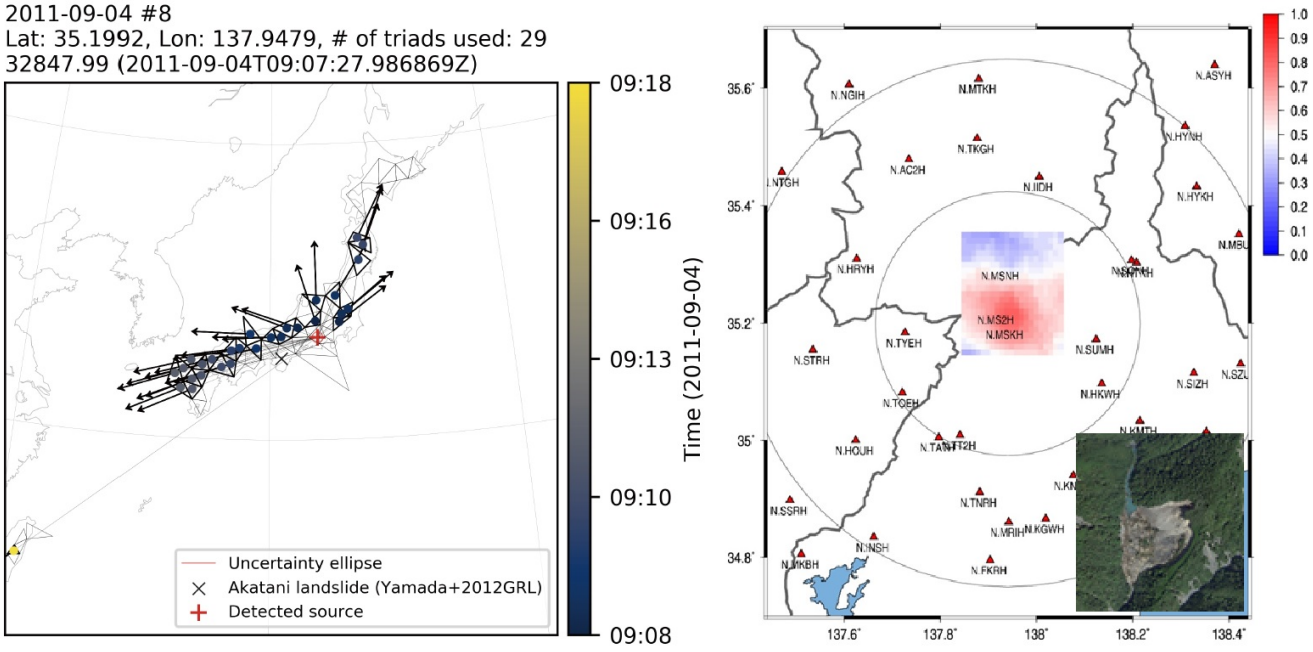

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Steady-state shear resistance and viscosity of brittle dense grain flows appear to be independent of grain material and normal stress

*wei hu[1], Mauri McSaveney[2]

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Despite their importance in planetary-surface processes there has been little experimental research on high-stress grain flows in which grain breakage is widespread, such as occurs in rock avalanches, fault rupture and post-impact-crater evolution. In this study, eight different brittle materials were subjected to high-speed rotary shear at fast shear strain rates and normal stresses between 0.3 and 1 MPa while shear resistance and thickness of the shearing layer were monitored. We report variation of shear resistance and viscosity of these grain flows during very large strains. Shear resistance of all the materials reached a similar steady-state value independent of applied normal stress and material composition. Viscosity for all the materials also reached similar steady-state values at all applied normal stresses but was inversely proportional to shear speed . When initial values of shear resistance and viscosity were above the steady state values, the materials weakened to the steady state, but when the initial values were less than the steady state, the materials strengthened with increasing shear strain to reach the same steady state.

Keywords: granular material, rock avalanches, grains flow

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A discussion on the characteristics of seismic signals of different landslide movement types by coupling PFC and FLAC codes

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1. National Chung Hsing University Department of Soil and Water Conservation

This study discussed the characteristics of seismic signals for different types of landslide movement, including rock fall, translational slide and flow. In this study, PFC (Particle Flow Code) and FLAC (Fast Lagrangian Analysis of Continua) codes were coupled to simulate the seismic signals generated by the three types of landslide movement. The landslide mass was simulated by PFC particles, and the seismic signals were recorded by FLAC. The analyses of the seismic signals includes the empirical mode decomposition (EMD) to obtain IMFs (Intrinsic Mode Functions), and to obtain the energy ratio and vibrational frequencies of the IMFs and Hilbert-Huang Transform (HHT) to obtain a time-frequency spectrum. The parameters, Arias intensity, significant duration and vibrational frequency in the signals of the three movement types were also calculated. For further discussion, this study simulated the seismic signals generated by flow and translational slide in different volume of moving masses, in order to find the relationship between the volume and Arias intensity. Furthermore, in order to evaluate the correctness of the coupling simulation method of PFC and FLAC, the authors constructed a model slope at Huisun Forest Farm in Nantou County, Taiwan to conduct a field test. The seismic signals generated by falling of rocks and rock-debris mixture were monitored. The process of this field test was also simulated by coupling PFC and FLAC codes. The parameters, including Arias intensity, significant duration and vibrational frequency were compared and evaluated.

Keywords: Seismic signals, Landslide, Numerical modeling, PFC, FLAC

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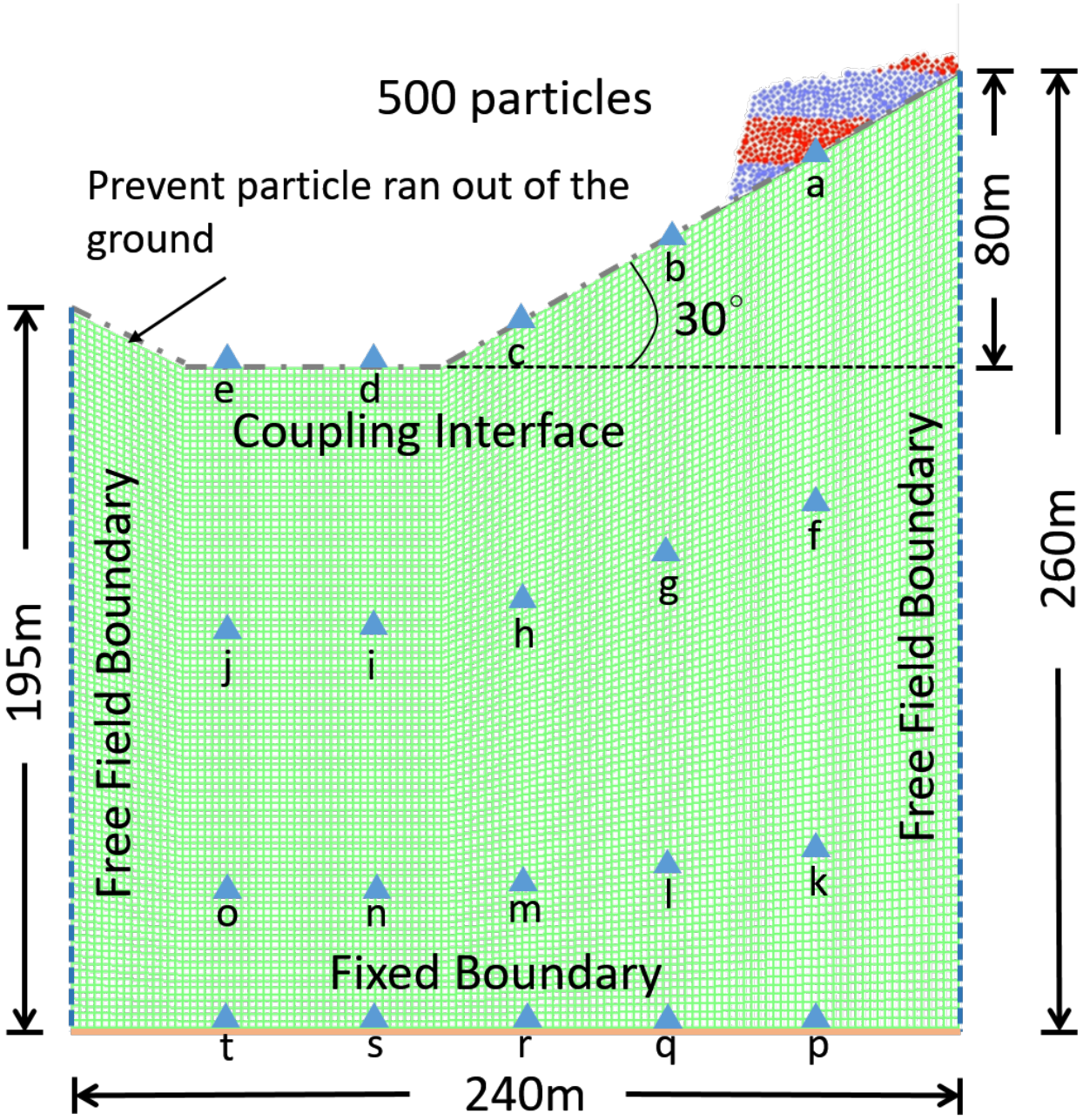

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Tertiary Creep Behavior of Soils and Corresponding Power Law Singularity

*Chengrui Chang[1], Gonghui Wang[2]

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1. Introduction

The prediction of landslides is of great social and economic significance and the related problems are widely encountered in recent decades. The preceding accelerating behavior is widely noticed and perceived as a precursor for the prediction of time to failure [Voight., 1988, 1989]. Since Saito and Uezawa [1966] pioneered an empirical attempt to predict the failure time of a landslide successfully, a phenomenological approach has been established gradually. Using slope models, Fukuzono [1985] found that the surface velocity is proportional to the acceleration in logarithmic coordinates in the terminal stage of slope failure. Further, Voight [1988, 1989] generalized Fukuzono's finding as a fundamental law that governs diverse forms of material failure. The approach had been widely applied for the retrospective analysis of volcano eruptions, landslides, and laboratory data. Nevertheless, since the approach did not consider the effect of the physical properties of the target materials, it might introduce uncertainty even great error into predictions. Besides, the validation of the approach is questionable without taking adequate account of mechanical behavior. Thus, we are devoted to examining the possible factors on this empirical approach, which attempts to deliver us a better understanding of the underlying physical process and background.

2. Methods

We conducted a series of ring shear tests to mimic the creep behavior of slopes due to the increasing ground water table during rainfall with different intensities. We employed two connected ring-shear apparatuses as one being a pore-pressure controlling system to induce failure in another being under constant stress conditions. The applied/monitored pore pressures were measured separately and simultaneously. All the samples were pre-consolidated at constant normal stress (σ) of 200 kPa, and we varied the shear stresses (τ) to simulate two different slope angles of 20° and 25°.

Additionally, the ring-shear apparatus enables us to carry out such tests repeatedly to investigate the shear behavior of pre-existing shear zones. Then the parameters (A and α) of the equation are determined by a retrospective analysis of the kinematic feature in the pre-failure stage with linear regression.

3. Results

The pore pressure in soil mass increases with the monotonic increase of the applied pore pressure, which reduces the effective normal stress and leads to failure eventually. The increase of the shear displacement ahead of the failure illustrates an acceleration process. We find that: (1) unlike pore pressure increases before the first failure, it doesn't increase prior to the second failure; (2) an outstanding dilation appears in the vicinity of the second failure; (3) shows that α (slope of the regression line) decreases with failure count (i.e., pre-sheared displacement).

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4. Discussion and summary

The value of α determines the kinematic precursors (velocity, acceleration) of an impending landslide and failure time. The reduction of it with longer pre-sheared displacement indicates the failure is prone to be less catastrophic. We infer that a pre-existing shear band exerts a fundamental control on such behavior as well the post-failure mobility. Wang et al. [2010] suggest catastrophic failure may not occur in some reactivated landslides with the shear resistance of soil exhibiting positive-rate-dependence.

In closing, our observation highlights a hitherto little-studied aspect of an empirical approach that is competent in the retrospective analysis of the accelerating behavior preceding material failure. We detected the variability of key parameters in this approach, which enables us to look further into the possible physical factors on such kinematic precursors and elevate the precision of prediction.

Keywords: creep behavior, precursor, time prediction

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[E] Oral | H (Human Geosciences)：H-DS Disaster geosciences

[H-DS09] Landslides and related phenomena

convener:Masahiro Chigira(Disaster Prevention Research Institute, Kyoto University), Fumitoshi Imaizumi(Faculty of Agriculture, Shizuoka University), Gonghui Wang(Disaster Prevention Research Institute, Kyoto University)

Mass movements, such as landslides, rockfalls, and debris flows, have been occurring extensively in a large number of countries, causing heavy damage. In order to understand them and mitigate induced disasters, we invite contributions that report and discuss on mass movements and related phenomena, focusing on improved understanding of their characteristics; new insights into landslide mechanisms; the development of new approaches to monitoring; novel approaches to behavior forecasting and prediction; studies of successful landslide management; and the development of methods for hazard and risk evaluation. In particular, papers about recent landslide hazards, such as those induced by 2015 Kundasang earthquake in Malaysia, 2018 western Japan rainstorm, and 2018 Hokkaido earthquake are welcome.

[HDS09-06] Long-term rates of gravitational slope deformations on a low-angle fault that forms a dip slope in the Shimanto Belt, in the Kanto Mountains

Masakazu Mashiko[1], *Masahiro Chigira[1], Hirokazu Furuki[2], Takehiko Suzuki[3] (1.Disaster Prevention Research Institute, Kyoto University, 2.Nippon Koei Co. Ltd., 3.Tokyo Metropolitan University)

[HDS09-07] Hydrological and Seismic Observations at a Gravitationally Deformed Slope

*Noriyuki Arai[1], Masahiro Chigira[1], Issei Doi[1] (1.Disaster Prevention Research Institute,Kyoto University)

[HDS09-08] Post Deformation Characteristics of a Large-scale Slope in the Reservoir Area

*Yao Jiang[1], Shenghua Cui[2] (1.Institute of Mountain Hazards and Environment, Chinese Academy of Sciences, 2.State Key Laboratory of Geohazard Prevention and Geoenvironment Protection, Chengdu University of Technology, China)

[HDS09-09] Geological structural control on rock mass movement in response to fluvial incision along the plateau margin of Tibet

*Siyuan Zhao[1], Masahiro Chigira[2], Xiyong Wu[3] (1.College of Water Resources and Hydropower, Sichuan University, Chengdu 610065, Sichuan, China, 2.Disaster Prevention Research Institute, Kyoto University, Gokasho, Uji, Kyoto 611–0011, Japan, 3.Faculty of Geosciences and Environmental Engineering, Southwest Jiaotong University, Chengdu, 611756, China)

[HDS09-10] A field example of flexural toppling at Song-Mao Village in central Taiwan

*Ching-Ying Tsou[1], Osamu Yokoyama[2], Fumitoshi Imaizumi[3], Hsi-Hung Lin[4], Yu-Chung Hsieh[4], Mien-Ming Chen[4], Masahiro Chigira[5], Chun-Yi Wu[6], Su-Chin Chen[6] (1.Faculty of Agriculture and Life Science, Hirosaki University, 2.Japan Conservation Engineers Co., Ltd., 3.Faculty of Agriculture, Shizuoka University, 4.Central Geological Survey, Taiwan, 5.Disaster Prevention Research Institute, Kyoto University, 6.College of Agriculture and Natural Resources, National Chung Hsing University)

[HDS09-11] The role of faults for the formation of uphill-facing scarps

*Osamu Yokoyama[1], Masahiro Chigira[2], Ching-Ying Tsou[3] (1.Japan Conservation Engineers & Co., Ltd., 2.Disaster Prevention Research Institute, Kyoto University, 3.Faculty of Agriculture and Life Science, Hirosaki University)

Long-term rates of gravitational slope deformations on a low-angle fault that forms a dip slope in the Shimanto Belt, in the Kanto Mountains

Masakazu Mashiko[1], *Masahiro Chigira[1], Hirokazu Furuki[2], Takehiko Suzuki[3]

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Deep-seated gravitational slope deformation (DGSD) proceeds very slowly and sometimes transforms into catastrophic failure, but its rates are not well addressed. The rates of DGSD must be strongly controlled by geological structures and landforms so they need to be examined from this view point. We performed geological investigation and dating of DGSD, which was found to be due to the sliding along a low-angle fault, in the Shimanto Belt in the Kanto Mountains. The Shimanto Belt is a typical accretionary complex with well-developed thrust faults, which have been recently found to control DGSD in wide areas in the Kii Mountains in Japan.

We found linear depressions that are aligned along an E-W-trending ridge top as long as 5 km. Geological investigation strongly suggests that these linear depressions are due to the sliding of the hanging wall of a low-angle fault nearly parallel to the slope surfaces. The linear depressions are up to 30 m deep and up to 1.3 km long. We made drill holes at 4 locations in the linear depressions and took filling sediments, which were 4.5 to 7 m thick. We analyzed the volcanic glass in the sediments and identified two horizons of tephra, AT (30 ka) and K-Tz (95 ka) and/or On-Pm 1 (98 ka). These ages suggest the bottoms of the sediments are of approximately 80 to 100 ka. On the other hand, the eastern linear depression is known to have tephra layers of AT, On-Om1 and Yt-Kw (171 ka), which suggest that the age of the bottom of the filling sediments is at least 210 ka. The ages of the sediment bottoms are interpreted as the starting ages of the DGSD. The age of the eastern DGSD is thus much older than the central and westernmost linear depressions, which may be attributed to that knickpoints migrated from the east to the west and that the low-angle fault is nearly exposed to the river side in the eastern DGSD. The displacement rates of DGSD were calculated using the displacements of the ridge tops and the initiation ages, which provided 0.2 to 0.5 mm/y for all the linear depressions.

Keywords: Deep-seated gravitational deformation, Landslide, Fault, River erosion

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Hydrological and Seismic Observations at a Gravitationally Deformed Slope

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To reveal the mechanism of deep-seated catastrophic landslides (DCLs) by heavy rainfall and large subduction-zone earthquake in accretionary complexes, we undertook detailed geological mapping, hydrological and seismic observations at a gravitationally deformed slope in the middle of the Kii peninsula. As a result, we found a thrust fault zone with clayey crush zones in the slope. The outstanding deformations have not been observed by the measurements by relatively small rainfall and seismic events, but seismic amplification characteristics were obtained in this slope.

Keywords: deep-seated catastrophic landslide, gravitational slope deformation, hydrological observation, seismic observation

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Post Deformation Characteristics of a Large-scale Slope in the Reservoir Area

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Landslides are geological process that potentially presents significant hazards to human safety and the built environment. The study of landslides generally focuses on three aspects: pre-failure deformation, the failure itself and post-failure movement. Normally, the pre-failure deformation of large-scale landslides is rarely documented because of the limited availability of early detection and monitoring data, whereas the short- and long-term characteristics of post-failure processes are commonly studied. On 29 November 2016, a colluvial slope located on the right bank of the Lancang River, Yunnan, southwestern China, experienced sudden failure with a large displacement, directly damaging two highways. After this movement, engineering geology investigations, field monitoring and laboratory tests were immediately carried out to reveal the possible failure mechanism and post deformation characteristics. Based on the in-situ survey, 6 scarps were identified on this slope, and their detailed characteristics were determined. The potential sliding zone was determined to be between the colluvium and the bedrock based on drilling and inclinometer readings. By examining the shear strength of the colluvial soils in the sliding zone under different water contents in the laboratory, the rise of the reservoir water level may have been the key factor triggering this large movement. The monitoring GPS data further showed that the horizontal and vertical displacement ratios decreased following the power function, and these findings provide more information for slope stability analyses and potential disaster mitigation for deforming slopes.

Keywords: reservoir area, deforming slope, inclinometer monitoring, sliding zone, water content, deformation ratio

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Geological structural control on rock mass movement in response to fluvial incision along the plateau margin of Tibet

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Landslides and deep-seated gravitational slope deformations frequently occur in valleys in the region of plateau margin which is the transitional terrain with the abrupt topographic change. These hillslope phenomena are expected to be controlled by the relationship between geological structures and fluvial incision. However, the systematic linkage of geological rock structures and river incision still keeps unclear. We aims to characterize rock mass movements in terms of geology and geomorphology along the two major rivers (the Minjiang River and its major tributary, the Heishuihe River) along the eastern margin of the Tibetan Plateau. We revealed that the effects of inner gorge formation on slope stability are substantially different according to the relationships between the geological trend and river trend. When the geological trend is normal or highly oblique to a river, very few DGSDs occur, but large rockslides commonly occur with adverse structural conditions along the Minjiang River. When the geological planar structures strike parallel or slightly oblique to the river, DGSDs with the types of buckling and toppling occurred along the Heishuihe River. This study provided conceptual model of slope movements concerning fluvial behavior and geological structure in similar high-relief areas of plateau margin.

Keywords: Plateau margin, Landslide, Deep-seated gravitational slope deformation, Geological structure, Fluvial incision

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A field example of flexural toppling at Song-Mao Village in central Taiwan

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Landslides can pose a serious risk to the urban environment and to line infrastructures in many humid, tectonically active regions. In this study, geological and geomorphological surveys were conducted at Song-Mao Village in central Taiwan, whereas the area has been affected by deep-seated gravitational slope deformation in the long-term. Aligned at the similar elevations at 1600 m a.s.l. along both sides of the Dajia River, a series of the flat ledge is distributed and ledges on opposite sides of the river sometimes interlock, suggesting that they are the remnants of ridges above slip-off slopes of an old meandering river. The study area is located at one of the flat ledges with two free surfaces (NE-facing and W-facing) along the Dajia River. The bedrock on the upper slope consists of slate striking NE-SW with steeply dipping cleavage at 85˚ to SE and the lower slope consists of alternating beds of sandstone and slate striking NE-SW and dipping 70˚ to 85˚ to SE. The beds show flexural toppling at NE-facing and W-facing slopes, totally cover an area of 0.25 km^2. Flexural toppling has led to the formation of ridge-top depression and bulging slope at the middle slope. Active unit of the slope deformation appears at the lower slope of W-facing slopes indicated by a slope failure and its debris deposit that looked quite fresh, suggesting they probably formed recently.

Keywords: flexural toppling, gravitational slope deformation, Taiwan

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The role of faults for the formation of uphill-facing scarps

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We made a thorough geological and geomorphic mapping in a slate area with uphill-facing scarps in the Abe River catchment, where many landslides were induced by previous strong earthquakes and heavy rains. We found that the uphill-facing scarps and linear depressions were made by the displacement along steeply-dipping faults during the flexural toppling of slate with steeply dipping cleavage. Uphill-facing scarps developed with the rotation of a wedge, which was defined by the high-angle fault and cleavage that passed through the intersection of the fault and basal hinge surface of the toppling. The wedge developed up- or downslope of the fault, depending on whether the fault dipped into the slope or valleyward. During wedge rotation, displacement occurred along the fault, and an uphill-facing scarp developed along the fault. The uphill-facing scarp became higher when the cleavage dipped into the slope and the fault dipped valleyward. On the contrary, when the cleavage dipped valleyward and the fault dipped upslope, high uphill-facing scarps unlikely to be formed. Instead, downhill-facing scarps are likely to be formed. When a high-angle fault or other weak layers was not involved, flexural toppling continuously deformed the slope and was unlikely to form an uphill-facing scarp. When flexural toppling extended to the ridge top, it generally formed a ridge-top depression, regardless of whether a fault was involved.

Keywords: uphill-facing scarp, flexural toppling, high-angle fault, deep-seated gravitational slope deformation, high-resolution geomorphic analysis

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[E] Oral | H (Human Geosciences)：H-DS Disaster geosciences

[H-DS09] Landslides and related phenomena

convener:Masahiro Chigira(Disaster Prevention Research Institute, Kyoto University), Fumitoshi Imaizumi(Faculty of Agriculture, Shizuoka University), Gonghui Wang(Disaster Prevention Research Institute, Kyoto University)

Mass movements, such as landslides, rockfalls, and debris flows, have been occurring extensively in a large number of countries, causing heavy damage. In order to understand them and mitigate induced disasters, we invite contributions that report and discuss on mass movements and related phenomena, focusing on improved understanding of their characteristics; new insights into landslide mechanisms; the development of new approaches to monitoring; novel approaches to behavior forecasting and prediction; studies of successful landslide management; and the development of methods for hazard and risk evaluation. In particular, papers about recent landslide hazards, such as those induced by 2015 Kundasang earthquake in Malaysia, 2018 western Japan rainstorm, and 2018 Hokkaido earthquake are welcome.

[HDS09-12] The 2016-17 landslide hazard in Siorapaluk and landsliding environment in NW Greenland

*Shintaro Yamasaki[1], Tastuya Watanabe[2], Shin Sugiyama[3] (1.Disaster Prevention Research Institute, Kyoto University, 2.Kitami Institute of Technology, 3.Institute of Low Temperature Science, Hokkaido University)

[HDS09-13] Landslides of altered rhyolite induced by the Heavy Rain Event of July 2018 in the south of Hiroshima Prefecture, Japan

*Yasuto Hirata[1] (1.Central Research Institute of Electric Power Industry)

[HDS09-14] **Characterization of rainfall events that triggered landslides in different regions in Japan**

*Slim Mtibaa[1], Haruka Tsunetaka[1] (1.Forestry and Forest Products Research Institute)

[HDS09-15] Landslides and driftwoods in headwater catchments: Supply, transport, and storage

*Takashi Gomi[1] (1.Tokyo University of Agriculture and Technology)

[HDS09-16] Temporal Changes in Landslide Frequency After Forest Harvesting in Ikawa, Central Japan

*Al Nuriza Rahmadania[1], Fumitoshi Imaizumi[2] (1.Graduate School of Integrated Science and Technology, Shizuoka University, 2.Faculty of Agriculture, Shizuoka University)

[HDS09-17] **Investigating the effect of forest stand age on slope stability in terms of root reinforcement in the Ikawa Artificial Forest, central Japan**

*Vany Fadhilah[1], Fumitoshi Imaizumi[2] (1.Graduate School of Integrated Science and Technology, Shizuoka University, 2.Faculty of Agriculture, Shizuoka University)

The 2016-17 landslide hazard in Siorapaluk and landsliding environment in NW Greenland

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Siorapaluk (77˚47’ N, 70˚38’ W), the northernmost settlement in Greenland, experienced landslide and flash flood events in the summers of 2016 and 2017. About 40 residents who mainly make their living for hunting were safe. However, hunting lodges were destroyed by landslides, and a part of the settlement was covered with debris by a flash flood.

We visited north Greenland including Siorapaluk in July 2018 and investigated the landslides from geological viewpoints. The timings of heavy rain events were estimated from interviews with locals and four years meteorological data observed by the expedition team of Hokkaido University in Qaanaaq settlement about 50 km southeast from Siorapaluk. Satellite images acquired from Planet Labs were used to check if landslides and flash floods occurred at the estimated heavy rain events.

Siorapaluk is located at the seacoast of Robertson fjord. Steep (more than 30 degrees) and high (more than 400-800 m) cliffs formed by glaciation dominate close to residence and hunting areas. Most of the landslides by the 2016-17 heavy rain events occurred on the upper- or middle part of their cliffs. According to our survey, more than two heavy rain events in August 2016 caused many landslides. Further landslides and flash floods occurred in August 2017. The total number of the landslides is more than 90. The largest landslide was about 300 m in width, about 720 m in horizontal length and about 250 m drop.

The cliffs including landslides are covered with sand and gravel. The base of the fragments consists of alternate layers of quartz sandstone and quartz conglomerate. Their bedding moderately or horizontally traverses the cliffs, making irregular shapes in vertical profiles of the cliffs. These irregular surfaces keep abundant fragments on steps formed by large stratums. The rain water could penetrate the covered fragments and saturates the bottom of fragments just on the steps, resulting in rock fragments collapse. The collapsed sediment flowed down on the steep slopes as debris flow and reached the sea or deposited in valley bottoms. A remnant of landslide dam at the valley bottom behind the settlement is probably related to the flash flood event that hit the settlement. Many topographic remnants of old landslide scratches are observed on the slopes, suggesting that landsliding events have repeatedly occurred.

This case is important to consider the relationship between landslide hazards and climate change because rising temperatures have been occurring clearly and remarkably in the Arctic.

Keywords: landslide, Arctic, Greenland, climate change, rainfall event

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Landslides of altered rhyolite induced by the Heavy Rain Event of July 2018 in the south of Hiroshima Prefecture, Japan

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The Heavy Rain Event of July 2018 caused numerous debris avalanches and debris flows in areas underlain by the Late Cretaceous Takada Rhyolites in the southern part of Hiroshima Prefecture. We made GIS analyses and field investigation along road cuts and landslide scars in order to clarify the geological factor of landslide sources in the rhyolite area. The study area is a 10 km long, 3 km wide rectangular area whose long sides are a WSW-ENE direction from Nikyukyo to Akozaka in Kure. According to precipitation data measured by MILT using radar-AMeDAS, the 45-hr cumulated rainfall before the landslide event from 05:00 to 06:00 on 7 July was 550–750 mm and the 4-hr cumulated rainfall was 120–180 mm. These rainfall distributions were common both in the western and eastern part of the study area. The landslide distribution plotted from aerial photographs showed that landslide density is 10–45 /km^2 in the eastern part and it is about ten times larger than that in the western part. This difference of landslide densities can be attributed to some geological and geomorphological factors in the rhyolite. The main rhyolite mass (Norosan Welded Tuff) in the study area has near-vertical joints with 0.5–3 m spacing and a considerable number of high-angle hydrothermal alteration veinlets and dikes. The hydrothermal alteration veinlets near the ground surface are made of white halloysite and are surrounded by altered or weathered rhyolite with blue, yellow, or red clay. These alteration bands have a width of 0.2–5 m and their predominant strike is N-S. The altered rhyolite was observed in parts of ridges that have a gentle slope of 20˚ or less. The area of altered rhyolite in the eastern part of study area was estimated to be larger than that in the western part. In the study area, landslide source areas had 10–20 m long and 5–10 m wide altered rock surfaces, on which 1-m-thick soil layers had slid down. The lower edges of some source areas were on slope breaks at the middle of slopes and coincided with boundaries between altered rock and wall rock. In addition, the presence of high-angle clay veinlets and the result of a cone penetration test implied that the boundaries are high-angle surfaces. Accordingly, landslides densities in this event may have become larger in the eastern part of the study area where hydrothermal alteration is more intensive.

Keywords: slope failure, hydrothermal alteration, clay veinlet, Takada Rhyolites

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Characterization of rainfall events that triggered landslides in different regions in Japan

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During the last decades, Japan has experienced several rainfall events, that induced hundreds to thousands of shallow landslides over large areas. For example, the 2017 July northern Kyushu torrential rainfall (> 500 mm / 24h) caused more than 1,500 shallow landslides widespread over 430 km^2. Landslide-triggering rainfall episodes may have a unique pattern that never experienced before in the region. Rainfall intensity-duration (ID) and accumulated rainfall-duration (ED) thresholds are often modeled for predicting the temporal occurrence of landslides. Such classical methods, define the rainfall conditions that must be reached or exceeded for the triggering of landslides, are subjective and affected by multiple uncertainties. Here, we studied the pattern of various rainfall events that triggered widespread landslides in different regions in the Japanese archipelago. We attempt at discriminating between experienced (non-triggering) and non-experienced (triggering or may-triggering) rainfall events by considering multiple minimum duration for rainfall interruption (MDRI). Hourly rainfall data (1976 ~ 2019) were obtained from selected rain gauges that represent different landslide events. Multiple MDRIs were tested for separating the rainfall records of each station into statistically independent storm events. Then, the ID threshold representing the upper limit of non-triggering rainfall events was computed. So far, our results showed that landslide-triggering rainfall events do not necessarily exhibit the highest record of average rainfall intensity, cumulative rainfall, or maximum hourly rainfall. The ID plots, developed using different MDRI, showed that the landslide-triggering rainfall events are generally characterized by high average rainfall intensity and long duration. The ID thresholds of non-triggering rainfall events were influenced by the choice of MDRI. Considering both the maximum hourly rainfall and ID threshold may improve the discrimination between experienced and non-experienced rainfall events. Our preliminary findings will help in following-up on the present research.

Keywords: Landslide-triggering rainfall, Rainfall ID thresholds, MDRI

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Landslides and driftwoods in headwater catchments: Supply, transport, and storage

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Recent landslides and debris flows produce numerous amounts of drifting woods together with sediment. Drifting woods produced in headwater areas cause serious damages for infrastructures and residential area in downstream. For instance, record amount of driftwood with 210,000 m^3 was produced by 586 mm during storm events in northern Kyushu, July 2017. Volume of drifting wood in headwaters possibly associated not only areas of landslides, but also for volumes of timber in mountainous landscapes. Therefore, supply, storage and runoff of drifting woods need to examine for developing countermeasure of driftwood and watershed-scale forest resources management. We examined supply, transport, and storage of driftwood produced by landslides in the upstream of Akaya River (6.2km^2) in Haki district, Asakura city, Fukuoka prefecture. The area covered by granite, pelitic schist, sedimentary rocks, and igneous rocks. Dominant forested vegetation is 5 to 95 years of cedar and cypress as well as broadleaf forest and bamboo. We conducted both field measurement and GIS analysis for landslides and forest conditions. Landslides occurred 67% in cedar forest, 24% in cypress forest, 4% in broad-leaved forest, 5% of bamboo forest and others. Greater percentages of collapse area occurred up to 20 years old plantation forest, while 40 to 50 years old plantation forest also had high parentages. The mean depth of landslide scared was 1.3 m (± 0.6) from 0 to 21 years, and 2.0 m (± 0.9) from 26 to 68 years, which may associate with growth of tree root. Relationship between the amount of sediment produced and volume of generated driftwood in this study was tended to be greater than that was proposed by Ishikawa et al. (1989). Because relationships between landslide sediment and driftwood was developed by Ishikawa et al. (1989) was conducted more than 30 years ago, increases in the volume of plantation timber for the last three decades possibly provide higher volume of timber by landslides. The finding of this study suggested that forest management for controlling the volume of timber in headwater areas is necessary for reducing the availability of drifting wood for landslides and debris flows.

Keywords: Landslide, Driftwood, headwater, Forest condition

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Temporal Changes in Landslide Frequency After Forest Harvesting in Ikawa, Central Japan

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Landslides are considered as one of the worst impacts of forest harvesting because landslides that occur rapidly in mountainous areas can supply a large amount of sediment to the downstream. Therefore, it is important to evaluate the effect of forest harvesting, including clearcutting and forest regeneration, on the landslide occurrences. This study aims to clarify the effect of forest harvesting on the landslide frequency in the artificial forest area in Ikawa. The rainfall threshold was also investigated for the occurrence of landslides in each forest age class. Aerial photograph in 10 periods (1970, 1975, 1980, 1984, 1986, 1991, 1996, 1998, 2003, 2008) was used to examine the landslide occurrences in Ikawa area, including location and area of the new landslide in each period. New landslide occurrences in each period (1970, 1975-1980, 1980-1984, 1984-1986, 1986-1991, 1991-1996, 1996-1998, 1998-2003, 2003-2008) were assessed by comparing the earlier and the later aerial photographs. Analysis results revealed that the number of new landslides in the period from 1980 to 1984, which includes the largest rainfall event (total rainfall of 747.5 mm) in the entire study period, was the highest in the 10 photograph periods. Area frequency of landslides in 0 to 5 years-old forests was the highest amongst all the forest age classes. These results indicate that the occurrence of landslides is affected by rainfall and young forest age. Landslides still occurred in the 15-years-old forests when rainfall events are more than 300 mm, while landslides did not occur in the forests older than 25 years even the rainfall event is 747.5 mm.

Keywords: Landslide, Forest harvesting, Heavy rainfall

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Investigating the effect of forest stand age on slope stability in terms of root reinforcement in the Ikawa Artificial Forest, central Japan

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The slope stability is an important issue to be concerned about preventing landslides. Roots have been widely recognized that it contributes to improve slope stability through its mechanical effect. The relationship between the development of the root network and soil strength in terms of the slope stability was also widely understood. The root tensile strength increases the shear strength of soil to prevent slope failure. However, roots are a part of vegetation growing gradually during its life. As a result, the shear strength of soil, which is reinforced by the root network, may also increase gradually with time. Previous studies have tried to evaluate the contribution of vegetation on the slope stability by interpreting the spatial distribution of underground roots and physical tests of the individual root. However, such studies cannot evaluate contribution of vegetation on the slope stability in hillslope-scale, because of difficulty in interpretation of root network in wide areas. Therefore, this study investigates the effects of root reinforcement at different life stages of forest stand scale on slope stability in Ikawa Artificial Forest, central Japan. GIS analysis and a distributed landslide model was applied to evaluate the root reinforcement. In this study, the effect of root reinforcements was quantified as an increase in apparent cohesion, which is total of root and soil cohesions). For that purpose, cohesion at different life stages of forests was estimated by back calculation based on landslide occurrences in Ikawa period 1975 –2003. The results show that quantification of mechanical effect of forest stand age was significantly influenced by temporal changes of root reinforcement. Temporal changes in cohesion of forest age stands also affect temporal changes on slope stability. Root reinforcement is still low when forest stand age less than 10 years old. As consequence, many landslides occur in this forest stand stage. While, root reinforcement affects significantly to prevent landslide when forest stand age more than 10 years old.

Keywords: Cohesion, Slope stability, Distributed landslide model

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[E] Oral | H (Human Geosciences)：H-DS Disaster geosciences

[H-DS10] Natural hazard impacts on human society, economics and technological systems

convener:ELENA PETROVA(Lomonosov Moscow State University, Faculty of Geography), Hajime Matsushima(Research Faculty of Agriculture, Hokkaido University)

The last decade set a record for the number and scale of natural disasters and demonstrates high vulnerability of human society, economics and ecosystems to their impacts. The most serious consequences have the so-called natural-technological disasters in which natural hazards trigger accidents at technology and infrastructure such as nuclear power and chemical plants, oil refineries and pipelines, power supply systems, buildings, roads, and railways. A distinctive feature of natural-technological events, such as of the 2011 Tohoku earthquake, is their multi-hazard and synergistic nature, which creates cascading impacts, resulting in simultaneous occurrences of myriad catastrophes. The main goal of this multidisciplinary session is to summarize case studies of relationships between natural hazards and technological disasters, their social and economic consequences; and to encourage a discussion about tools and methods to prevent disasters and to minimize their consequences, disaster reconstruction, and tourism for reconstruction, Eco-DRR, and green infrastructure.

[HDS10-02] Lessons Learned from Wind Turbine Failures Caused by Natural Hazards

*Jui-Sheng Chou[1] (1.National Taiwan University of Science and Technology)

[HDS10-03] Impacts of the risk of chemical release from unregistered plant triggered by a future local earthquake in Osaka

*Takehisa Ishida[1], Lisa Ito[1], Akihiro Tokai[1] (1.Graduate School of Engineering, Osaka University)

[HDS10-04] Effects of abandoned paddy field use for the conservation of threatened hydrophyte after the 2011 Tohoku-oki tsunami.

★Invited Papers

*Korehisa Kaneko[1], Hiroshi Jinguji[2] (1.Hokuso Creature Association, 2.Miyagi University)

[HDS10-05] **The influence of the construction of the seawall on the on the coastal plant community in Sendai coast**

*XIANGMEI ZHONG[1], Hajime Matsushima[2], Akira Suzuki[3], Yoshihiko Hirabuki[4], Kouji Kimura[5] (1.Graduate school of Agriculture, Hokkaido University, 2.Research Faculty of Agriculture, Hokkaido University, 3.Kita-no-satohama Hana-no-kakehashi Network, 4.Faculty of Liberal Arts, Tohoku Gakuin University, 5.Snow Brand Seed Co., Ltd.)

[HDS10-06] Japanese coastal dune crisis and future prospects

*Hajime Matsushima[1] (1.Research Faculty of Agriculture, Hokkaido University)

Lessons Learned from Wind Turbine Failures Caused by Natural Hazards

*Jui-Sheng Chou[1]

1. National Taiwan University of Science and Technology

In recent decades, the Taiwanese government has been vigorously promoting the development of the green energy industry, investing greatly in the photovoltaic and wind-energy sectors with the goal of developing renewable energy, the economy, and a sustainable environment. However, owing to its location, Taiwan is vulnerable to typhoons that bring fierce winds and torrential rain in the summer. These natural phenomena have damaged wind turbine blades and the collapse of many wind turbine towers in Taiwan, causing serious economic losses. This work examines the causes of these incidents and the mechanisms of turbine tower collapse and blade fracture to support risk prevention and the hazard-resistant design of wind turbines. Relevant domestic and foreign data are obtained to simulate wind turbine collapse. Next, mechanical analyses are performed using the finite element method to identify mechanisms of failure and structural weakness planes, with the ultimate goal of identifying possible causes of collapse. The structural mechanics of wind turbine blades are then analyzed using simulation models to identify the mechanisms of damage. Then, the root causes of strong wind-induced damage to, and collapses of, wind turbines are identified. Based on the results, methods for reducing the risk of such accidents are developed and solutions for improving the strong wind-resistance of wind turbine towers and their advantages are discussed. Recommendations concerning the use of weaker blades as a safety mechanism for a wind turbine tower, the torque capacity of the pitch system, and the required strength of joint bolts to be installed in steel structural connections, are made to help wind turbines and towers withstand severe storms. Hopefully, the analytical results of this study will help to prevent related engineering incidents in the future and provide a reference for stakeholders who must devise strategies to improve risk management and natural disaster prevention in wind power plants.

Keywords: Renewable Energy, Wind Turbine, Natural Hazard, Structural Failure, Forensic Investigation, Risk Management

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Impacts of the risk of chemical release from unregistered plant triggered by a future local earthquake in Osaka

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In recent years, especially in Europe, a concern arises regarding damage from industrial accidents caused by natural disasters, called Natech (Natural hazard triggering technological disasters). Natech is also a concern in Japan, and in the case of the Great East Japan Earthquake, harmful chemicals have released and caused health damage to numerous people. Chemical release caused by natural disasters have environmental effects on the air, water, and soil. In case of chemical release to the atmosphere, inhalation exposure becomes a central concern. In the area of chemical management, Pollutant Release and Transfer Register (PRTR) has been introduced 20 years ago and notified industrial plants have been required to report their annual release and transfer amount of chemicals. However, unregistered plants are under no such obligation. Therefore, the amount of chemicals handled and management conditions in unregistered plants under PRTR system are unknown. In this study, the impacts of the risk of chemical release from an unregistered plant triggered by the local earthquake originating from the Uemachi fault were examined.

Osaka City, the center of Osaka Prefecture, was selected as the research area. Osaka City has an office density of 22.3 cases / km^2 and a population of approximately 2.7 million, and can be considered an area with a large release volume of chemicals and exposed population in the event of an accident. As for chemical screening procedure, one of the PRTR chemicals, toluene was selected, which also fulfills Volatile Fire Service Class 4. Given the lack of data on the storage volume of unregistered plants under PRTR for predicting outflow at the time of the accident, the storage volume was estimated using the index of employee number of each geographical mesh (1 km ×1 km). The emission factor (emissions / handling volume) and storage conversion factor (storage volume is equivalent to two weeks of annual handling volume) were used to estimate the amount of storage. In the disaster simulation, a chemical substance was assumed to release from one unregistered plant in the event of the earthquake. Atmospheric chemical concentration was calculated using Atmospheric system exposure analysis software (CAMEO / ALOHA version.5.4.7) (USEPA). Subsequently, the calculated atmospheric concentration was compared to Acute Exposure Guideline Level (AEGL) (NAC/AEGL Committee). AEGL differs for each threshold level, with AEGL-3 set to cause fatal health damage, AEGL-2 to severe health damage, and AEGL-1 to discomfort.

As a result, we found that the area with a large amount of chemical storage, of which the population is also concentrated in the daytime had high risks of health damage in case of the accident. The cumulative exposure amounts of volatilized toluene at 5 m and 10 m from the accident site were 98,007 ppm・min and 25,159 ppm・min, which would cause serious health symptoms, since these values were 7 times and 1.8 times that of AEGL-2, respectively. At 30 m and 50 m points from the site, the values were 1,296 ppm・min and 750 ppm・min, which was 1.9 times and 1.2 times higher than AEGL-1, respectively. Therefore, it is important to stay away from the accident site immediately at least for 5 minutes for minimizing the health damage. This study revealed the risks from a small and unregistered plant and specified the extent of inhalation exposure of chemicals, which would lead the proper evacuation recommendations and alerts under Natech events.

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Keywords: Natech(Natural hazard triggering technological disasters), Chemical substance management, Atmospheric dispersion, Earthquake, unregistered plants under PRTR system

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Effects of abandoned paddy field use for the conservation of threatened hydrophyte after the 2011 Tohoku-oki tsunami.

*Korehisa Kaneko[1], Hiroshi Jinguji[2]

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1. Introduction

Threatened plant species, *Ottelia alismoides*, *Monochoria korsakowii*, *Najas graminea*, *Najas minor,* and *Chara braunii* were found in swampy paddy field after the 2011 Tohoku-oki tsunami Japan. These hydrophyte are classified as near-threatened or vulnerable species in the Red Data book of Ministry of environment, Japan. Hygrophyte communities were vanishing rapidly as reconstruction of road and agriculture proceeds. Therefore, surface soil of hygrophytes community was transplanted to abandoned paddy field 5km away from the original hygrophyte community.

In the present study, we transplanted soil seed to examine whether abandoned paddy field is effective for the hygrophytes species conservation. We investigated 1) whether hygrophytes including threatened species emerge and grow in the abandoned paddy field and 2) management methods of abandoned paddy field to conserve hygrophytes species.

2. Method

The sturdy site was located at Hadenya district in Miyagi prefecture Japan (lat.38˚38¢37.9’’ N. and long.141˚28¢10.5’’ E). vegetation survey conducted on July and September during 2014-2016 in accordance with the methodology of Braun-Blanquet (1964). The surface soil of paddy field was puddled by human power on April 2014 and 2015, and was strongly puddled by agricultural tractor on April 2016. water temperature was recorded using a thermo-logger (Tidbit, Onset, USA) at the center of each quadrate frame in transplantation sites and donor seed bank. water temperature was measured from May to September during 2014-2016 in transplantation site. The water depth was measured with ruler in the center of each quadrate frame.

3. Results

Monochoria korsakowii were recoveried in transplantation site from 2014 to 2016. In particular, *Monochoria korsakowii* formed large community in 2016, and the volume of plant increased singnificantly hihger than that in 2014 and 2015. *Ottelia alismoides* and *Chara braunii* were found in 2014 and 2016. The intensity disturbance with a agricultural tractor suppressed the flourishing of the herbaceous plants of *Phragmites australis* and *Typhaceae* spp. in 2016. Consequently, *Ottelia alismoides* and *Chara braunii* regenerated again in taransplantation site. *Najas graminea* and *Najas minor* were not found during vegetation survey. *Salvinia natans* and *Alisma plantago-aquatica* were newly appeared in transplantion site. Our findings suggest that transplantation of surface soil including seed bank to abandoned paddy field is effective for the conservation of hygrophyte, *Monochoria korsakowii, Ottelia alismoides* and *Chara braunii*. The intensity disturbance for suppression of herbaceous perennial plant is needed to maitain the habitat of threatened plant species.

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4. Conclusion

For the future, keeping the intensity disturbance with tractor is desirable on April. In addition, weeding of *Echinochloa spp* by human work is needed to conserve threatened plant species. Furthermore, we must develop the field at water depth 25 cm for the habitat of *Najas graminea* and *Najas minor* and re-transplantation. Long-term field monitoring is needed to elucidate frequency, intensity and period of suitable disturbance and water depth to maintain threatened hygrophytes.

Keywords: Threatened plant, Seed bank, Soil disturbance, Abandoned paddy field, Tsunami

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The influence of the construction of the seawall on the on the coastal plant community in Sendai coast

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[Introduction]

As a result of the tsunami disaster caused by the Great East Japan earthquake in March 2011, in the coastal area of Sendai, the living environment that constitutes the ecological system and its survival base has been destroyed and disturbed on a large scale. Since then, the spontaneous recovery of ecosystems has been confirmed, however, due to human modifications by the disaster recovery project such as the reconstruction of the seawall, afforestation for protection forest and the construction of elevated road as embankment, the ecosystem has been irreversibly modified again. However, the impact of these man-made changes on the coastal ecosystem has not been made clear.

The purpose of this study is to identify the impact of seawall construction on the coastal eco-tone. Therefore, the disturbance of coastal vegetation by tsunami disaster and their recovery rate were monitored at Miyagi after the restoration project in Miyagi prefecture. Most importantly, make clear the impact of the seawall on coastal ecosystem, especially on the division of coastal vegetation.

[Methods]

Considering the width of the beach, greening mode of the seawall and the change of the back area, the survey was carried out in three areas of Miyagi prefecture: the Arahama area, Ido area and Yuriage area. Three survey lines were set up from coastal forest to shoreline in each area, which are orthogonal to the seawall. 1 m ×1 m quadrats for vegetation survey were set up at every 5 m along the survey lines.

The plant species / coverage (%) / grass height (cm) were recorded. In addition, samples of sand were collected at every 10m along the survey lines, and the particle diameter composition (mm), electrical conductivity (mS / m) (EC) / potential of hydrogen (pH) /nitrate-nitrogen and phosphate-phosphorus content of each sample were measured. At the same time, digital surface model (DSM) were created by SfM using aerial photos taken by UAV. The surveys were conducted from 2018 to 2020, once a year, from late August to early September.

In order to clarify the relationship between the change of topography and soil environment and vegetation. In every area, Pearson 's correlation coefficient and Spearman’ s rank correlation coefficient were calculated in order to clarify the correlation between the number of species, Coverage (%), pH, EC and the particle diameter composition.

[Results & Discussion]

According to the vegetation survey results implemented in 2018 and 2019, the vegetation structure of the seaward and landward was also different according to the width of the beach from the shoreline to the seawall. The wider beach on seaward of the seawall was, the higher the number of species and vegetation

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coverage of the coastal dune plants were. And the wider beach also increased the number of species and vegetation coverage of the exotic plants and the inland plants. On the other hand, the number of species and vegetation coverage of coastal dune plants are higher in the area with less human disturbance. Those all suggest that the coastal ecosystems have resilience from natural disturbance but vulnerable to human disturbance.

Keywords: green infrastructure, coastal plant community, coastal dune plants, human modifications

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Japanese coastal dune crisis and future prospects

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Japan is the island country consisted about 7,000 islands in East Asia. Since the land is surrounded by the sea and has a steep and narrow terrain extending from north to south, the population has concentrated on the small coastal plains. Because the coastal area has played an important role as a place of living and trade in Japan, people developed intensively as close as possible to the sea. At the results, natural coast, especially sand dune system, were lost by development, afforestation or construction of seawalls. Besides such human activity in the coastal area, the risk of damage from high tides, sea breeze and sand drifting became remarkable issues due to the increasing of extreme events by climate change. To protect the inland developed area, more seawalls and coastal afforestation forests have been constructed on coastal sand dunes along the coastline in Japan. However, these constructions have resulted in the loss of resilience of the coastal sand dune systems that form the beach. Furthermore, it is predicted that it will be difficult to provide the budget for the maintenance costs of these infrastructures in Japan by population decrease. It is considered that the usage of coastal sand dune systems as green infrastructure will be important for the future goals.

Keywords: coastal sand dune system, Green Infrastructure, Eco-DRR

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[E] Oral | H (Human Geosciences)：H-DS Disaster geosciences

[H-DS11] Subaqueous Landslides and Their Anthropogenic Impact for Coastal Regions

convener:Yujin Kitamura(Department of Earth and Environmental Sciences, Graduate School of Science and Engineering, Kagoshima University), Kiichiro Kawamura(Yamaguchi University)

A large number of people inhabit coastal areas around the world that are susceptible to natural catastrophes and subaqueous landslides are one of such hazards as demostrated recently. The risk associated with the occurrence of subaqueous landslides is not only constrained to passive margins or subduction zones but any of water areas is also susceptible to their occurrence since subaqueous failures can be triggered at very low slope angles. This realization poses a significant challenge that requires the collection of vast amounts of information and data to unravel the true nature of these events and their potential risk to coastal communities. Despite these challenges, recent technical and engineering advances in the acquisition and processing of sea floor and shallow subsurface data are encouraging. There has also been a concerted effort by scientists from different earth-science disciplines to increase interdisciplinary cooperation at an international level to advance our collective understanding of subaqueous landslides and their consequences.
This session calls for technical contributions covering all aspects of subaqueous landslide research including but not limited to: physical properties of deformed sediments (pre- and post- deformation), role of interstitial fluids in subaqueous landslide development, slope stability and risk assessments, geomorphological and sedimentological/stratigraphic descriptions, tsunamigenic risk and modeling, description of ancient subaqueous landslides, sand-box models and numerical simulations of subaqueous landslides. Case studies from lacustrine landslides and subaerial coastal landslides transitioning into the marine realm are also welcome. Case studies associated with the broader topic of subaqueous gravity-driven flows (e.g.: turbidites and transitional flows) and their relationship with seafloor faulting are also of interest to this session. Participants of IUGS project S4SLIDE IGCP-640 sponsor this session.

[HDS11-01] The progressive development of microfabrics from initial deposition to slump deformation on the Nankai prism

*Kiichiro Kawamura[1] (1.Yamaguchi University)

[HDS11-02] Structure of submarine mass-transport complexes(MTCs) southern Mt.Kaimon

*Hiroto Yamaguchi[1], Mamoru Sano[2], Satoshi Shimizu[2], Hikaru Iwamaru[2], Nobukazu Seama[1,2], Tetsuo Matsuno[1,2], Yoshiyuki Tatsumi[1,2] (1.Department of Planetology, Graduate School of Science, Kobe university, 2.Kobe Ocean-bottom Exploration Center)

[HDS11-03] On generation mechanism of the tsunami due to the 1923 Great Kanto Earthquake and bathymetric change in Sagami bay

*Kazuki Murata[1], Toshikazu Ebisuzaki[2], Shigenori Maruyama[2] (1.Port and Airport Research Institute, Japan, 2.RIKEN)

[HDS11-04] What "tsunami earthquake" is?

★Invited Papers

*Toshikazu Ebisuzaki[1] (1.RIKEN)

[HDS11-05] Tsunami modeling by marine landslides and reduction of disasters

★Invited Papers

*Yuichiro Tanioka[1], Hideaki Yanagisawa[2], Kei Ioki[3], Tatsuya Nakagaki[1] (1.Hokkaido University, Institute of Seismology and Volcanology, 2.Tohoku-Gakuin University, 3.National Institute of Advanced Industrial Science and Technology)

[HDS11-06] Submarine mass transport marked by mercury-bearing sediments and tephra in active fault zone, Yatsushiro sea, Japan

*Yujin Kitamura[1], Takashi Tomiyasu[1], Daigo Ito[2], Ryoga Kimura[2], Yuki Tamachi[2], Kuniyo Kawabata[3], Yuta Ikebata[4], Ryoya Goto[5], Koki Hori[4], Hakuho-maru KH-18-3 Scientists (1.Department of Earth and

Environmental Sciences, Graduate School of Science and Engineering, Kagoshima University, 2.Department of Earth and Environmental Sciences, Faculty of Science, Kagoshima University, 3.Institute for Comprehensive Education, Kagoshima University, 4.Department of Earth and Planetary Sciences, Graduate School of Science, Kyushu University, 5.Graduate School of Frontier Sciences, The University of Tokyo)

The progressive development of microfabrics from initial deposition to slump deformation on the Nankai prism

*Kiichiro Kawamura[1]

1. Yamaguchi University

The progressive development of microfabrics from initial deposition to slump deformation and thena submarine slide was investigated in an active subduction zone using cores recovered during the Integrated Ocean Drilling Program Expedition 333(Kuranaga et al., 2018; J. Geol. Soc.). A Pleistocene–Holocene sequence was recovered at Site C0018A, which was located on a slope basin on the footwall of the megasplay fault in the Nankai Trough, SW Japan. Six mass-transport-deposit units intercalated with coherent intervals were recovered from the upper 190 m of the drilled succession. The initial microfabrics in the undeformed hemipelagic sediments were characterized by random and porous fabrics composed predominantly of clay aggregations and connectors. The initial fabrics were cardhouse fabrics, which consist of clay flakes with edge-to-edge (E–E) and/or edge-to-face (E–F) contacts. These initial microfabrics developed into compacted microfabrics, which are random and consolidated fabrics (bookhouse fabrics) that consist of clay flakes with E–F and/or face-to-face (F–F) contacts and develop during burial as a pure shear deformation. During slumping, these fabrics were then deformed under simple shear to become predominantly F–F contacts and form clay chains. Thus, the microfabrics in these submarine slides are an sedimentarymélange that developed locally into a preferred clay orientation with F–F contacts.

Keywords: Nankai Trough, Microfabrics, Slump deposits

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Structure of submarine mass-transport complexes(MTCs) southern Mt.Kaimon

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We discovered submarine mass-transport complexes (MTC) at southern Mt.Kaimon, southern Kagoshima Prefecture, and we conducted seismic reflection and seafloor topography surveys to clarify its structure in detail. We obtained the reflection seismic data, using 60cubic inch air gun and 6-channel multi-streamer to derive seismic reflection sections through the general method processing and CMP gather. Further, multi-hill shade map, slope map, and Terrain ruggedness index map were created using the seafloor topographic data. The resultant terrain structure allow us to divide the submarine MTC into six characteristic areas: Area Ⅰ: “Extensional ridges and blocks” of large-scale blocks with their length of more than 500 m, Area Ⅱ: “Remnant Blocks” of small-scale blocks with their length of less than 500 m, AreaⅢ: “longitudinal shares and pressure ridges”, AreaⅣ: “pressure ridges”, Area Ⅴ: “Outrunner blocks” Blocks on the edge, AreaⅥ: “Fold and thrust systems (and pop-up blocks)”. The seismic reflection results show following structures: Area Ⅰ have been deformed by external force, and its basal shear surface (BSS) has been cut-off at the area boundary. In Area Ⅱ, a slump structure and some deformed blocks were confirmed. In AreaⅢ, the sequence is clearly seen at the surface and bottom layer. A stratified structure remains between AreaⅢ and Ⅳ. AreaⅣ has a thrust that extends from BSS. Area Ⅴ indicates a disordered surface at more shallow layer than other area. AreaⅥ shows clear Folds and Fault above the BSS layer. A continuous BSS is observed in Areas Ⅱ-Ⅵ, while the BSS has been cut-off in Area Ⅰ. In the area where is continuous BSS and east-west compression fault, the structure changes continuously from east to west. AreaⅥ has north-south compression folds and faults. Area Ⅰ is considered to be an event that is temporally and spatially separated from the others, because Area Ⅰ cuts the BSS (the flow is southward), is discontinuous in topography, and shows the structure of north-south compression. And AreaⅥ may have terminated this flow because of north-south compression. We propose the following scenarios based on these facts: The seafloor collapsed westward at the cliff east of MTC before Mt.Kaimon erupted, and swept away the seafloor(Area Ⅱ-Ⅴ). And Area Ⅰ is estimated the flow from Mt.Kaimon after Area Ⅱ-Ⅴ had collapsed.

Keywords: Mt.Kaimon, mass-transport complexes(MTCs), seismic reflection(MCS)

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On generation mechanism of the tsunami due to the 1923 Great Kanto Earthquake and bathymetric change in Sagami bay

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The Great Kanto Earthquake on September 1, 1923 severed serious damage to the coastal Kanto region; the tsunami hit from the east coast of the Izu Peninsula to the west coast of the Boso Peninsula in Sagami Bay, and caused huge damage. In particular, Atami area was devastated. The fault model was proposed by Kanamori *et al.* (1971) in the 1923 Great Kanto Earthquake, and it was construed that a tsunami was generated by this crustal deformation. But we confirmed that the results of reproduction numerical simulation of coastal damage using the high-resolution submarine topography data and the fault model by Kanamori *et al.* (1971) cannot explain the recording tsunami height.

This report presents the results of a comparison between the reproduction numerical simulation and the recording tsunami height along the coast, and investigates the possibility that the tsunami of the 1923 Great Kanto Earthquake was induced by a large-scale submarine landslide in Sagami Bay based on the bathymetric change data reported by Imperial Japanese Navy. Then, in order to discuss the tsunami generation mechanism of the 1923 Great Kanto Earthquake, the tsunami scale and its arrival time which hit the coast of Sagami Bay are estimated using a simple one-dimensional model (Haugen *et al.*, 2005, Lovholt *et al.*, 2015, Harbitz 1992), and these consistencies are evaluated.

As results, it was confirmed that the bathymetric changes which observed before and after the 1923 Great Kanto Earthquake corresponded to the submarine valleys of the Sagami Bay from the analysis in comparison with the current submarine topographic data. And it was found that the tsunami scale, its arrival time and the location of tsunami source induced by submarine landslide in Sagami Bay were qualitatively consistent with the recording tsunami height by considering the characteristics of the shallow-water deformation and the tsunami convergence.

Keywords: 1923 Great Kanto Earthquake, tsunami, submarine landslide, bathymetric change

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What "tsunami earthquake" is?

*Toshikazu Ebisuzaki[1]

1. RIKEN

Kanamori (1972) defined “tsunami earthquakes” as earthquakes that excite much stronger tsunami waves than that expected from the amplitude of the earthquake waves. He pointed that tsunami earthquakes always associated with slow crustal deformations with the time scale of several hundred seconds, but did not specify what is the cause of it. In the present presentation, I will look for the possibility that a tsunami earthquake is amplified by large-scale submarine landslides with the area of ~10000 km^2, caused by liquification of the sediments in the slope, induced by vibration of the earthquake.

[1] Kanamori, H.: Mechanism of tsunami earthquakes. Physics of the Earth and Planetary Interiors, 6, 346-359, 1972.

Keywords: tsunami earthquake, submarine landslide, liquefaction

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Tsunami modeling by marine landslides and reduction of disasters

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The marine landslides due to large earthquakes caused much larger tsunamis than that expected from the magnitudes of the earthquakes. One example is the large tsunami along Aleutian Inlands due to the 1946 Aleutian earthquake (Ms7.2). The maximum tsunami height was about 40 m. The marine landslide is believed to be the main cause for this large tsunami near the source area. The other example is the 1929 Great Banks tsunami due to the earthquake of Ms7.2. The earthquake itself was caused by the marine landslide which cut the ocean bottom cables. Therefore, the large tsunami was completely generated by the marine landslide. We try to model the tsunami by our numerical simulation of marine landslide and tsunami to find volume of the landslide.

The marine landslides due to the volcanic eruptions also caused large tsunamis. One example is the landslide during the 1741 eruption of Oshima-Oshima volcano in Hokkaido, Japan, which generated a large tsunami. We numerically simulated the lanslide and tsunami generated by the 1741 Oshima-Oshima eruption using an improved two-layer model to explain the depositional area od the landslide, the tsunami heights writen in historical records, and the distributions of tsunami deposits (Ioki et al., 2019). Areas of erosion and deposition by the 1741 landslide were estimated from the bathimetric data on the northern slope of Oshima-Oshima volcano. From the bahymetry difference before and after the landslide, the volume of collapsed material was estimted at 2.2 km^3. Based on those data, the landslide and tsunami were numerically simulated by solving equations of an improved two-layer model that incorporates Manning's formula in the bottom friction terms of the lower layer. An apparent friction angle of 2.5 and a Manning's roughness coefficient of 0.15 were selectied to explain the area of deposition estimated from the bathymetry analysis and distributions of tsunami deposits. The thickness distribution of the computed landslide mass fits relatively well with the depositional area. Computed tsunami heights match those from historical records along the coast. Coomputed tsunami inundation areas cover most of the distributins of tsunami deposits identified along the coasts. The other recent exapmle is the 2018 Anal Krakatau volcano eruption which caused a landslide generated a large tsunami. The generation of the tsunami has been studied well (Grilli et al., 2019).

No tsunami forecast method for those tsunamis generated by marine landslides exists. The method is need to be developed for tsunami disaster mitigation. Becuase a dense cabled obsrvation network, called the seafloor observation network for earthquakes and tsunami along the Japan Trench (S-net), was installed in Japan recently, those ocean bottom pressure data should be used to forecast tsunami heights along the coast for marine landslide tsunamis. We developed a tsunami numerical simulation method by assimilating those ocean bottom pressure data as a tsunami forecast method (Tanioka and Gusman, 2018). The method was tested for tsunami generated by earthquakes, but it should be used for landslide tsunamis, too.

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Keywords: Landslide and Tsunami simulation, Tsunami forecast

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Submarine mass transport marked by mercury-bearing sediments and tephra in active fault zone, Yatsushiro sea, Japan

*Yujin Kitamura[1], Takashi Tomiyasu[1], Daigo Ito[2], Ryoga Kimura[2], Yuki Tamachi[2], Kuniyo Kawabata[3], Yuta Ikebata[4], Ryoya Goto[5], Koki Hori[4], Hakuho-maru KH-18-3 Scientists

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The 2016 Kumamoto Earthquake was sourced from a part of active faults of the Futagawa-Hinagu fault zones. Although the southwest section of the Hinagu fault zone, which consists of submarine active faults in Yatsushiro sea, was not activated this time, it is a section with high risk potentially. Earthquakes are one of the major triggers for submarine landslides. With a small trigger, gravitational catastrophe can take place easily even in a very gentle slope angle of less than one degree if in subaqueous condition. Yatsushiro sea is therefore yet to be a place to be that, however, any record of submarine landslide in this area has not been reported.

Minamata bay, southern Yatsushiro sea, is known to be mercury pollution from a chemical plant drainage. A complex space-time distribution of mercury content in the sediments has been revealed (Tomuyasu et al., 2014). This suggests some secondary transportation of the sediments in this area. As the transportation of the mercury-containing clastics depends on sedimentation rate and/or water current, submarine landslide is a candidate for the factor of drastic change in benthic environment.

Here we conducted four-days research cruise Hakuho-maru KH-18-3 in July, 2018 to reveal submarine landslide records and benthic environment in Yatsushiro sea. We conducted subbottom profiling, piston coring at 11 sites, and multiple coring at 13 sites). Recovered cores are analyzed by X-ray CT scanner, multi-sensor core logger, core imaging apparatus, visual core description, color spectroscope, X-ray fluorescence core scanner (Itrax), and so do discrete samples by vane shear tester, picnometer with sediments and by Radon monitor with sea water and pore water. We focused the core at site PC02 and examined benthic foraminifera assemblage and tephra.

Our results show that the bottom of the core corresponds to the age of ca. 10ka and infers marine regression at the time. The volcanic glasses obtained from this horizon is originated from the Aira-Tn tephra (26-29 ka). These volcaniclastics is suggested to be a secondary deposit. The delivery process is unknown but can possibly be a flood or a submarine landslide. The two examples of secondary sediment transportation, present slow movement of sediments and the delivery of Aira-Tn tephra, suggest that the sediments in Yatsushiro sea is remobilized actively and some of them would potentially be assisted by the earthquake shaking.

Keywords: 2016 Kumamoto earthquake, mercury, Minamata bay, shallow marine deposits, turbidites

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[E] Oral | H (Human Geosciences)：H-TT Technology & Techniques

[H-TT14] Geographic Information Systems and Cartography

convener:Takashi Oguchi(Center for Spatial Information Science, The University of Tokyo), Yoshiki Wakabayashi(Graduate School of Urban Environmental Sciences, Tokyo Metropolitan University), Yuei-An Liou(National Central University), Ronald C. Estoque(National Institute for Environmental Studies, Japan)

[HTT14-01] Analysis of the Land Surface Temperature Pattern in Kathmandu, Nepal, Using Remote Sensing and GIS.

*Siri Karunaratne Batugoda Gedara[1], Morimoto - Takehiro[2], Yuji - Murayama[3] (1.Division of Spatial Information Science,Graduate School of Life and Environmental Sciences, University of Tsukuba, 2.Division of Spatial Information Science,Faculty of Life and Environmental Sciences, University of Tsukuba, 3.Division of Spatial Information Science,Faculty of Life and Environmental Sciences, University of Tsukuba)

[HTT14-02] Detecting Heat Spot within the City using Drones

★Invited Papers

*Kotaro Iizuka[1], Yuki Akiyama[1] (1.Center for Spatial Information Science, University of Tokyo)

[HTT14-03] Landsat 8 data for soil salinity mapping in Tra Vinh Province, Mekong Delta, Vietnam

★Invited Papers

*Kim-Anh Nguyen[1], Yuei-An Liou[1], Ha-Phuong Tran[2] (1.National Central University, 2.Ho Chi Minh City Institute of Resources Geography, VAST)

[HTT14-04] Geospatial Approaches to Modell the Landslide Risk: A case study for Kegalle District-Sri Lanka

★Invited Papers

*Elibichchiralalage Nimala Chinthake Perera[1], HMDS Wijenayaka[1], DSP Kuruppuarachchi[1] (1.Faculty of Management and Finance, SANASA CAMPUS, SRI LANKA)

[HTT14-05] Permafrost environment in Kongsfjord, Svalbard, from the viewpoint of topography and vegetation change

*Jaeyong Lee[1], Takashi Oguchi[2] (1.Department of Environmental Studies, Graduate School of Frontier Sciences, The University of Tokyo, 2.Center for Spatial Information Science, The University of Tokyo)

[HTT14-06] Responses of suspended sediment yield to topography and land use in the Yellow River Basin, China

*Ruiqi Zhang[1], Takashi Oguchi[2], Zhiguo Meng[3], Lele Hou[3] (1.The University of Tokyo, Graduate school of Frontier Sciences, 2.The University of Tokyo, Center for Spatial Information Science, 3.The University of Jilin, College of Geoexploration Science and Technology)

Analysis of the Land Surface Temperature Pattern in Kathmandu, Nepal, Using Remote Sensing and GIS.

*Siri Karunaratne Batugoda Gedara[1], Morimoto - Takehiro[2], Yuji - Murayama[3]

1. Division of Spatial Information Science,Graduate School of Life and Environmental Sciences, University of Tsukuba, 2. Division of Spatial Information Science,Faculty of Life and Environmental Sciences, University of Tsukuba, 3. Division of Spatial Information Science,Faculty of Life and Environmental Sciences, University of Tsukuba

Land surface temperature (LST) is a striking parameter to detect urban environmental changes. In this study, we assess mean LST distribution pattern in the Kathmandu metropolitan area, Nepal, spatially and temporally based on Landsat standard terrain correction images, TM in 2001 and OLI /TIRS in 2013. Land use and land cover (LULC) were classified primarily into six categories. Then by reclassifying into two categories, we conducted a cross cover comparison. The spatial formation of LST was investigated along the eight directions from the city center. Density maps were generated using the 210m * 210m urban-rural gradient grid. The dramatic expansion of 1.23 percent of annual growth in impervious surface (IS) and, on the contrary, -0.99 percent annual decline in green space (GS) 2 was detected. A considerable correlation between impervious surface density and mean LST was observed in bivariate correlation analysis in 2001. The inverse relationship between green space density and mean LST (R = -0.589) was found in 2013. In the cross cover comparison, the IS-GS total was 0.687 ℃ mean LST, between 2001- 2013. Possible adaptation and mitigation measures should be implemented to achieve a sustainable, safe and resilient mountain city due to the evidence of accelerating the UHI effect in Kathmandu.

Keywords: Kathmandu, urban heat island, land surface temperature pattern, land use change, urban –rural gradient

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Detecting Heat Spot within the City using Drones

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Various researches have been conducted relating to the heat in urban spaces. Although, majority of the work tends to observe the trend for the whole city or district, meaning that such works estimates heats in a relatively large administrative units. Conversely, there are still challenges that needs to overcome for observing the urban heat on a micro-scale units such as individual buildings and roads that forms the city. This work challenges in observing the thermal information utilzing drones and thermal camera onboard, and evaluates the possibility of estimating the heat trend at a micro scale level using multiple variables collected through drone and satellite. Further discussion will be made for the potential heating areas where high risk lies that could affecting the peoples health relating issues.

Keywords: Urban Heat Island, Drone, Random Forest

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Landsat 8 data for soil salinity mapping in Tra Vinh Province, Mekong Delta, Vietnam

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1. National Central University, 2. Ho Chi Minh City Institute of Resources Geography, VAST

Salinity intrusion is a major environmental issue in the coastal area. It causes devastating impacts on agricultural and aqua-cultural production. Lower Mekong Delta of Vietnam is a growing and developing region. It is the major producer and exporter of paddy rice, crop and fish products of Vietnam. This research focuses on the evaluation of soil salinity by using freely accessible optical Landsat 8 data over the Tra Vinh Province, Mekong Delta, Vietnam. Salinity is assessed through several indices including the single bands, Vegetation Soil Salinity Index (VSSI), Soil Adjusted Vegetation Index (SAVI), Normalized Difference Vegetation Index (NDVI), and Normalized Difference Salinity Index (NDSI). Statistical analysis between the electrical conductivity ($EC_{1:5}$, dS/m) and the environmental indices derived from Landsat 8 OLI image was performed. Results indicated that spectral values of near-infrared (NIR) band and VSSI were better correlated with $EC_{1:5}$ (r^2 = 0.8 and r^2 = 0.7, respectively) than the other indices. Comparative results show that soil salinity derived from Landsat 8 was consistent with *in situ* data with coefficient of determination, R^2 = 0.89 and RMSE = 0.96 dS/m for NIR band and R^2 = 0.77 and RMSE = 1.27 dS/m for VSSI index. Findings of this study demonstrate that Landsat 8 OLI images reveal a high potential for spatiotemporally monitoring the magnitude of soil salinity at the top soil layer. This study documents the current status of soil salinity over the Tra Vinh Province of Vietnam. Our proposed assessment method allows fast-detection of the salinity in the soil with low cost and sufficient accuracy. It is suggested that regular monitoring and assessment of soil salinity level would be useful to manage the crop and fisheries in the coastal regions.

Keywords: Soil salinity, environmental issue, Landsat 8, Mekong Delta, Vietnam

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Landsat 8 data for soil salinity mapping in Tra Vinh Province, Mekong Delta, Vietnam

Kim-Anh Nguyen, Yuei-An Liou*, and Ha-Phuong Tran

Abstract:

Salinity intrusion is a major environmental issue in the coastal area. It causes devastating impacts on agricultural and aqua-cultural production. Lower Mekong Delta of Vietnam is a growing and developing region. It is the major producer and exporter of paddy rice, crop and fish products of Vietnam. This research focuses on the evaluation of soil salinity by using freely accessible optical Landsat 8 data over the Tra Vinh Province, Mekong Delta, Vietnam. Salinity is assessed through several indices including the single bands, Vegetation Soil Salinity Index (VSSI), Soil Adjusted Vegetation Index (SAVI), Normalized Difference Vegetation Index (NDVI), and Normalized Difference Salinity Index (NDSI). Statistical analysis between the electrical conductivity ($EC_{1:5}$, dS/m) and the environmental indices derived from Landsat 8 OLI image was performed. Results indicated that spectral values of near-infrared (NIR) band and VSSI were better correlated with $EC_{1:5}$ ($r^2 = 0.8$ and $r^2 = 0.7$, respectively) than the other indices. Comparative results show that soil salinity derived from Landsat 8 was consistent with *in situ* data with coefficient of determination, $R^2 = 0.89$ and RMSE = 0.96 dS/m for NIR band and $R^2 = 0.77$ and RMSE = 1.27 dS/m for VSSI index. Findings of this study demonstrate that Landsat 8 OLI images reveal a high potential for spatiotemporally monitoring the magnitude of soil salinity at the top soil layer. This study documents the current status of soil salinity over the Tra Vinh Province of Vietnam. Our proposed assessment method allows fast-detection of the salinity in the soil with low cost and sufficient accuracy. It is suggested that regular monitoring and assessment of soil salinity level would be useful to manage the crop and fisheries in the coastal regions.

Keywords: Soil salinity; environmental issue; Landsat 8; Mekong Delta; Vietnam

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Geospatial Approaches to Modell the Landslide Risk: A case study for Kegalle District-Sri Lanka

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Landslides have become a frequent natural hazard and pressing severe environmental issues in Sri Lanka. The upward trend in high-intensity rainfall events, growing population, expansion of plantation, and lifelines increased the landslide risk of the country. Though developed countries adopted in risk assessment based management, conversely, developing countries rely on conventional landslide hazard assessment based risk management. Therefore, this study is attempted to develop a standardized landslide risk assessment framework, combining susceptibility and vulnerability. In the experimental design, landslide susceptibility was determined by nine landslide causative factors, and fourteen factors were used to assess the vulnerability. Factors were standardized and analyzed to model the susceptibility and vulnerability by using multi-criteria evaluation (SMCE) and Entropy method respectively adopting Geospatial modeling. Spatial distribution of susceptibility and vulnerability were used to obtain the spatial distribution of risk and standardize to generate a landslide risk map. Analyses indicate high susceptible and vulnerable areas not demonstrated a high level of risk individually. However, a combination of them creates a high level of risk. The risk was classified into six classes, such as highest, high, moderate, low, lowest, and no risk. The highest-risk and high-risk zones of the area show 257 Km2 (15%) and 21 % (350 Km2) of the total land area, respectively. Moderately risk zones take part 27 % (446 Km2). However, 22 % (375 km2) of land area categorized as low or lowest risk and 15% (255 Km2) under the no-risk. The study concluded that the developed framework is transparent and easy to update periodically by the local authorities. Hence, public policymakers can use the findings of this study for their planning. In contrast, the developed method is useful for decision-makers' for spatial and civil protection planning on the possible future development of plantation within the region.

Keywords: Entropy method, Geospatial model, Hazard, Landslide, Risk, Vulnerability

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Permafrost environment in Kongsfjord, Svalbard, from the viewpoint of topography and vegetation change

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Global warming is considered as the main reason for the recent dramatic changes in the Arctic environment. The thawing of permafrost due to global warming has been attracting special attention. Changes in permafrost cause damage to properties of residents and infrastructure. Warming also leads to vegetation expansion and changes in the albedo and the ecosystems. Released greenhouse gases from thawed permafrost into the atmosphere are believed to accelerate warming.
This study deals with changes in the permafrost environment of Kongsfjord, the Svalbard archipelago. We used WorldView-2 and Sentinel-2 satellite images, aerial orthophotos provided by the Norwegian Polar Institute, and data from a field survey in October 2019 to detect topographic and vegetation changes. Various forms of slope erosion including collapses were observed at 33 points. Most of them occur in front of glaciers, indicating that areas devoid of ice have been expanding and meltwater has been increasing with the retreat of glaciers. Vegetated areas also expanded in some places. These observations support the view that environmental changes in Svalbard have been accelerating.

Keywords: Permafrost thawing, Arctic environment, Ny-Alesund, Remote Sensing

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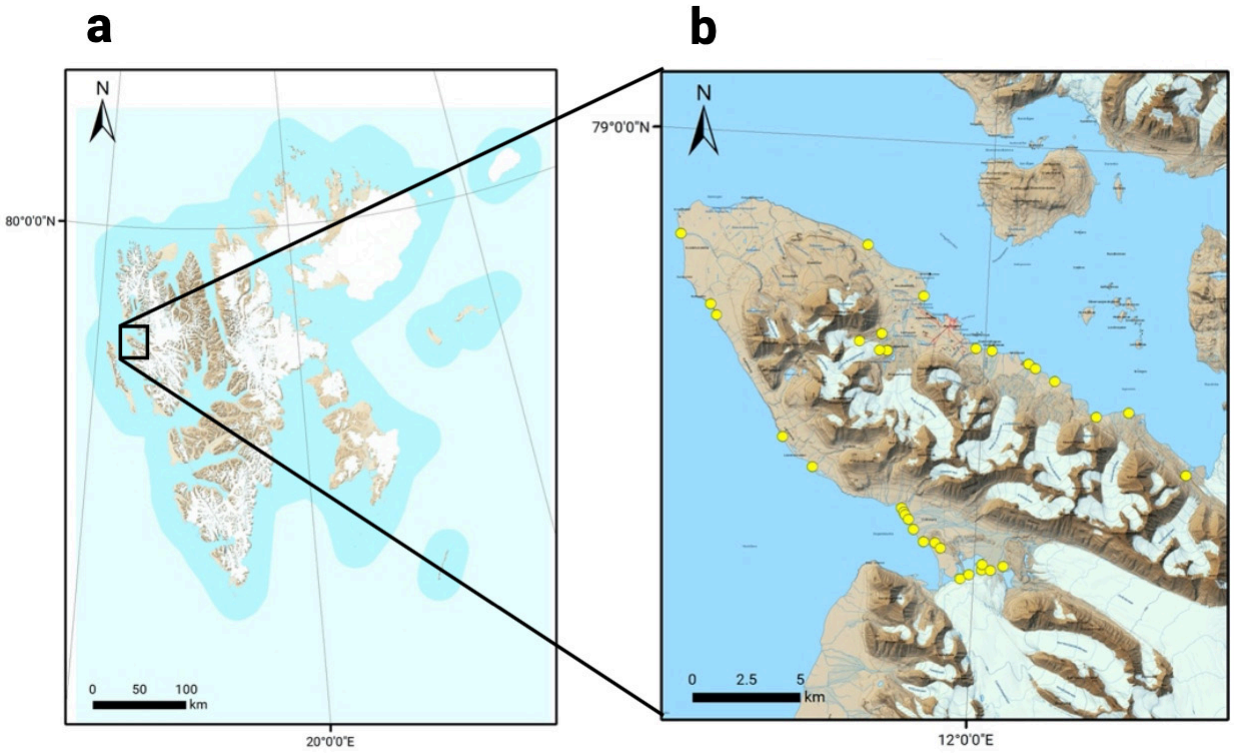

Fig. 1. Map of Svalbard archipelago (a) and the location of erosion forms including collapses in Kongsfjord (b).

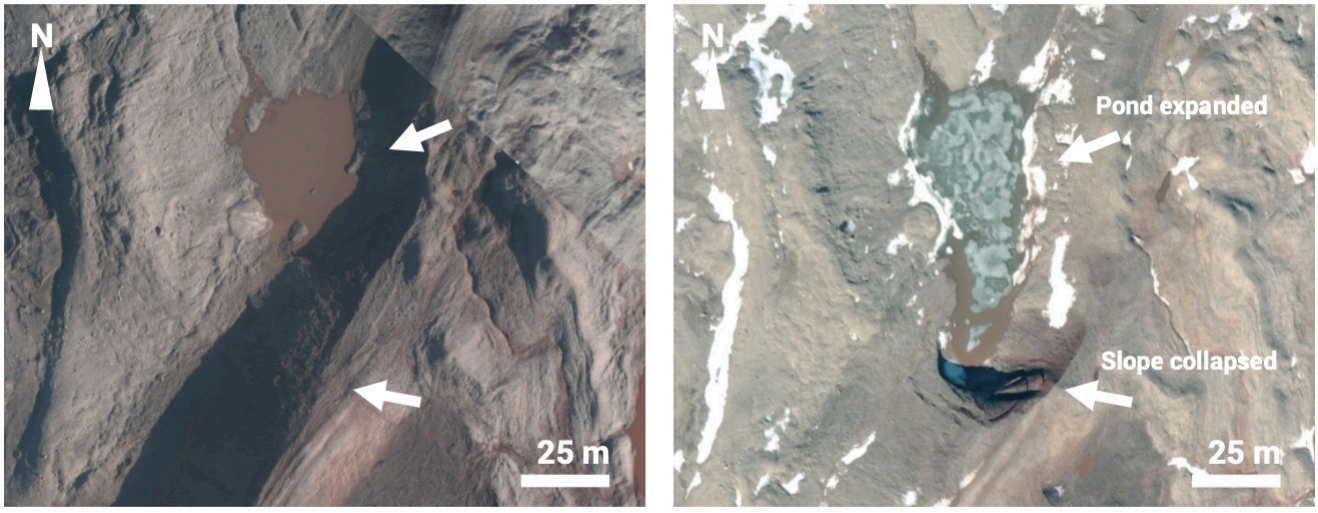

Fig.2. Example of the topographical changes (78.9131°N,11.7903°E).
Left: NPI's Aerial orthoimage (Aug 2010). Right: WorldView-2 image (Jul 2019).

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Responses of suspended sediment yield to topography and land use in the Yellow River Basin, China

*Ruiqi Zhang[1], Takashi Oguchi[2], Zhiguo Meng[3], Lele Hou[3]

1. The University of Tokyo, Graduate school of Frontier Sciences, 2. The University of Tokyo, Center for Spatial Information Science, 3. The University of Jilin, College of Geoexploration Science and Technology

The Yellow River (YR) is one of the most sediment-laden rivers in the world. Hyper-concentrated flows triggered by rainstorms are widely distributed during summer in the YR basin (YRB). Many previous studies examined suspended sediment yield using the product of water discharge (Q) and suspended sediment concentration (SSC) within a specific period, which may downplay the effect of hyper-concentrated flows. Besides, research on large watersheds was limited in the past when investigating the interactions among sediment yield and corresponding environmental factors in the YRB. This situation may hinder the understanding of determining factors of erosion and deposition for watersheds with different sizes.

Motivated by the scientific issues mentioned above, this study has utilized Q and SSC data independently for the YRB from 2008 to 2012 and investigated the effects of watershed size, topography and land use based on 94 gauged watersheds whose area ranges from 43.3 to 730036 km^2. For Q and SSC, we mainly analyzed daily mean and maximum values, respectively, during July to September. Data analysis indicated the following four characteristics of the watersheds: 1) Q increases with the watershed area (A) for small watersheds, while it almost stays constant for large watersheds. The latter observations could be caused by the limited ability of river channels to obtain baseflow as well as enhanced water infiltration and evapotranspiration in gentle downstream areas. 2) SSC is uncorrelated to A for tributary watersheds but tends to be positively correlated for mainstream watersheds; The latter observation may reflect the complex and highly variable characteristics of small watersheds and increase in SSC with increasing sediment supply for large watersheds encompassing the Loess Plateau. 3) Of the selected topographic variables, Q is more affected by slope-related variables, suggesting the effects of water infiltration and evaporation on water flow over different slopes. In contrast, SSC is more affected by elevation-related variables, and the associations may be due to stronger water flow and sediment transportability in higher areas when sediment availability is sufficiently high. 4) Compared with topography, the effects of land use on both Q and SSC are weak, and of the four land-use variables, Q is only correlated to the percentage of grassland; However, this correlation could be superficial without a cause-effect relationship since some watersheds with high percentage of grassland may be located in mountainous regions where rainfall infiltration is not significant, while some watersheds with low percentage of grassland may be located in downstream plains where water flow is less concentrated. The obtained results have revealed the major influence of topographic factors, which may help people understand the regularities of sediment yield under current environmental conditions in the YRB.

Keywords: The Yellow River Basin, water discharge, suspended sediment concentration, topography

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[E] Oral | H (Human Geosciences)：H-TT Technology & Techniques

[H-TT14] Geographic Information Systems and Cartography

convener:Takashi Oguchi(Center for Spatial Information Science, The University of Tokyo), Yoshiki Wakabayashi(Graduate School of Urban Environmental Sciences, Tokyo Metropolitan University), Yuei-An Liou(National Central University), Ronald C. Estoque(National Institute for Environmental Studies, Japan)

This session discusses various methods which acquire, store, analyze and visualize geospatial data, and presents the outcomes of empirical studies using GIS or mapping methods. The session also deals with applications of digital data, and GIS, and mapping to various fields of earth and planetary science and human society. All presentations and discussion of this session are made in English.

[HTT14-07] **A study on the selection process of tsunami evacuation sites using qualitative GIS approaches: the case of Ishinomaki city, Miyagi prefecture**

*Yuki Iwai[1,2] (1.Graduate School, University of Tsukuba, 2.JSPS Research Fellow)

[HTT14-08] **A Comparative Analysis of the Impacts of Various Natural Disasters on Human Mobility based on Geotagged Photos**

★Invited Papers

*Ahmed Derdouri[1], Toshihiro Osaragi[1], Takuya Oki[1] (1.School of Environment and Society, Tokyo Institute of Technology)

[HTT14-09] **Impact of Curriculum Design for Disaster Risk Reduction Education Using Web GIS Technology on Student Learning Effects in Secondary Schools**

*Jiali Song[1], Takashi Oguchi[1] (1.The University of Tokyo)

[HTT14-10] **Urban Expansion and Its Impact on the Urban Flood Disaster: A Case Study of Colombo Metropolitan Area, Sri Lanka**

*Ranagalage Mahinda Manjula[1], Yuji Murayama[1], Takehiro Morimoto[1] (1.Faculty of Life and Environmental Sciences, University of Tsukuba)

[HTT14-11] Changes in the landscape pattern of the Muthurajawela Marsh and Negombo Lagoon Sri Lanka: Socio-ecological implications

*SUMUDU DARSHANA ATHUKORALA ARACHCHIGE[1], Yuji Murayama[2], Bunkei Matsushita[2], Ronald C. Estoque[3] (1.Graduate School of Life and Environmental Sciences, University of Tsukuba, Japan, 2.Faculty of Life and Environmental Sciences, University of Tsukuba, Japan, 3.National Institute for Environmental Studies, Japan)

[HTT14-12] Relationships between the locations of ancient sites and topographic factors in Japan and China to explore interactions between human and nature

*Yuan Wang[1], Takashi Oguchi[1] (1.The University of Tokyo)

A study on the selection process of tsunami evacuation sites using qualitative GIS approaches: the case of Ishinomaki city, Miyagi prefecture

*Yuki Iwai[1,2]

1. Graduate School, University of Tsukuba, 2. JSPS Research Fellow

1. Introductions

The qualitative GIS is an approach that words and numbers are used together to compose contextualized visual narratives elaborated through geographical discourse to derive theories of social phenomena. Therefore, a qualitative GIS approach is powerful for analyzing behavioral geography as the integration of subjects and objects. In contrast to previous studies, this study tries to discuss the significance of the qualitative GIS approach using tsunami evacuation behavior. The purpose of this study is to clarify the true meaning of selecting evacuation sites by individuals. This study uses the "Digital Archiving of the Great East Japan Earthquake Survey." In this data, origin and destination of evacuees are created as the point feature, and the routes are represented as the line feature.

2. Methodology

The introduction of qualitative GIS to geographical phenomena is challenging. This is because there are significant discrepancies between the objective knowledge represented by visual images generated with GIS technologies and the people’s partial and surrounding knowledge. The careful comparison of these two types of knowledge is useful to overcome this problem. Regarding the technical method of integrating quantitative and qualitative analysis using GIS, the qualitative data according to reasons for selecting evacuation sites were stored in the attribute table of the destination displayed as spatial objects. As a target area, Ishinomaki city, Miyagi prefecture, was selected in this study. Most of the data in the survey were collected in Ishinomaki city because the urban scale is larger than other struck areas. The routes of 140 people who evacuated on foot alone in the flatland area were employed to achieve the study purpose.

3. Results

Of the subjects, 104 people responded that they recognized the evacuation site at the time of the earthquake. However, 10 people out of them moved to “higher places” that they recognized. Then, their evacuation sites were overlaid on the Digital Elevation Model to understand the meaning of "higher" objectively. As a result, 6 people evacuated to a hill; then, the average elevation was 31.0m. On the other hand, the 3 people who evacuated to school were far from the hills and lived near the central city area. Therefore, "higher" for the residents of the central area can be regarded as robust public facilities. Against all their origin was at home, and the origin of 1 person who backed to his home was a workplace. His house was located on the most inland side, and the elevation in the surrounding was less than 1m. For this reason, it was found that "higher" for him did not mean higher elevation and public buildings, but it meant the second floor of his house, which was relatively far from the sea.
Next, an attempt was made to investigate the 5 people who answered "far away" as a reason for changing the evacuation place from the one they recognized. As a result, the average distance that was actually moved of the 3 out of 5 people was 1187.3m longer than the distance to the nearest evacuation facility. This result contradicts their feeling that the evacuation facility at the earthquake was "far away." Incidentally, these 3 people were damaged at the going out. On the other hand, 2 people whose actual

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moving distance was shorter than the distance to the nearest evacuation facility, were damaged at their homes. Thus, the meaning of "Far" for them was the distance that was recognized from their homes. Therefore, it is considered that the accuracy of their cognition of distance was more accurate.
Through these two cases, it is considered that their true evacuation site-selection is not “higher” or “closer,” but is more closely related to the meaning that the home has. In particular, it is thought that the meaning that "my home gives a sense of security" caused the false cognition of "higher (i.e., safety)" and "closer (i.e., convenience)."

Keywords: qualitative GIS, evacuation, tsunami, spatial behavior, spatial cognition

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A Comparative Analysis of the Impacts of Various Natural Disasters on Human Mobility based on Geotagged Photos

*Ahmed Derdouri[1], Toshihiro Osaragi[1], Takuya Oki[1]

1. School of Environment and Society, Tokyo Institute of Technology

Natural disasters perturb the daily movement of individuals. Researchers have previously investigated human mobility patterns under steady and unsteady conditions using text-based geotagged data collected from social media giants of the likes of Twitter and Weibo characterized by their low cost and availability. However, with a growing number of new limitations to access to their historical databases, new alternatives of geodata sources of mass have been proposed. Image sharing platform Flickr is one of the suggested options given not only its free-to-use Application Programming Interface (API) but also the type of information that can be extracted from photos using advanced techniques of deep learning. This might give an insightful output regarding human mobility patterns in urban areas during steady conditions as well as during temporary unstable states caused by different types of disasters. In the light of this, the aim of the present study is to analyze and compare the impacts of several past natural disasters (earthquake, typhoons, etc.) that occurred in the Tokyo metropolitan area (TMA) on human mobility patterns based on Flickr geotagged data during three periods: before, during, and after each disaster. First, out of 22 natural catastrophic events that occurred between 2008 and 2019, we chose the significant ones based on the number of Flickr active users and the availability of images that were taken during that period. Second, based on occurrence day(s) and relevant weather information associated with each type of disaster, we selected steady and perturbation periods (before, during, after) for each disaster. Third, we analyzed mobility patterns through multiples indicators namely displacement, radius of gyration, and mean square displacement. We then compared the obtained results of all disasters. Preliminary results show that the probability distribution of displacement and radius of gyration follow a truncated power-law, which is in agreement with previous studies. Next, we developed a transfer learning-based convolutional neural network (CNN) model to classify images into indoor and outdoor categories. This classification helped to reconstruct popular trajectories by type of environment and duration of stay under steady and unsteady conditions. The results of this study are expected to stimulate future research on the impacts of natural disasters on the mobility of foreign tourists given the popularity of Tokyo as a touristic hotspot and yet as a metropolitan area of recurring disasters with scarce spatial data and studies on tourists mobility patterns.

Keywords: Natural disasters, Human mobility, Geotagged photos, Flickr, Convolutional Neural Networks

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Impact of Curriculum Design for Disaster Risk Reduction Education Using Web GIS Technology on Student Learning Effects in Secondary Schools

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1. The University of Tokyo

As the United Nations Development Programme (UNDP) pointed out in 2015, the first priority to implement disaster risk reduction (DRR) is to understanding disaster risk. The concept of disaster safety must be included in education from the childhood stage to reach the goal of sustainable disaster reduction. Geospatial thinking is essential to the Earth sciences where there is a heavy reliance on cognitive thinking skills that include understanding spatial relationships, the ability to use tools of representation properly, and reasoning skills. Some researchers have already constructed online systems based on the geospatial technologies for DRR education using hazard maps. The US National Research Council pointed out that the research base still lacks specific knowledge of what kinds of geospatial learning experiences lead to student improvement, of how to infuse geospatial thinking in the Earth science curriculum, and of how to use geospatially enabled learning technologies with classroom learners. The Web-based GIS (Web GIS) enables online geographic visualization and analysis using a web browser. This study utilizes Web GIS as a visual instructional technology to support geospatial thinking, and analyzes factors affecting the learning effect of students based on the developed systematic DRR education material and a curriculum design approach. They were implemented multiple times in the classrooms of Japan and China, to explore what kind of technological, pedagogical, and content knowledge is required for teachers to effectively use Web GIS. This approach may provide a coherent chain of reasoning to link evidence to theory so that the structured education systems can be generalized and replicated in a variety of schools. Questionnaire surveys were also conducted to collect information about the understanding of teachers and students along with their feedback on the system and the curriculum design. The results may allow us to construct an optimal guideline for DRR education combined with science and technology.

Keywords: Web GIS, Geospatial Thinking, Disaster risk reduction, Curriculum approach

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Urban Expansion and Its Impact on the Urban Flood Disaster: A Case Study of Colombo Metropolitan Area, Sri Lanka

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In recent decades, population growth and economic development have directly affected changes in the urban landscape in cities around the world. These rapid changes are prominent in developing regions in Asia and Africa. Rapid changes of the urban landscape resulted to occur several environmental problems such as weakling air and water quality, increasing urban heat island, rising poverty levels, decrease in agricultural land, increasing demand for urban land, high energy consumption, reducing urban green spaces, increasing vector-borne disease, waste-disposal problems, and rising flash flooding. This study aims to capture the impact of rapid urbanization to increase urban flood disasters in the Colombo Metropolitan Area (CMA). There are three specific objectives, such as; examine the spatiotemporal urbanization pattern and driving factors, capture the urban flood disaster trend based on the historical record, and analyze the negative impact of urban disasters towards the introduction of sustainable urban planning. We have selected 1996, 2009, 2019 as the time point to capture the landscape changes over the 23 years' time. Landsat data and geospatial techniques, including machine learning algorithms, urban-rural gradient, and statistical analysis, were used to map and examine the landscape change in CMA during the 1996–2009 and 2009–2019 periods. The CMA has been selected as a study area by considering the urbanization pattern of Sri Lanka. CMA shows rapid urbanization over the past few decades and recorded several negative environmental issues. In addition to that, the urban flood has resulted in occurring savior damages to CMA during recent years. Unplanned urban development patterns have been effected to recode savior flood damages on people, the environment, and the economy in CMA. We strongly believe that the findings of this study will help policymakers and urban planners to introduce proper remedial measures to control the damages witch course by the urban flood.

Keywords: Urban expansion, urban disasters, flood, geospatial techniques, Colombo Metropolitan Area, Sri Lanka

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Abstract

Urban Expansion and Its Impact on the Urban Flood Disaster: A Case Study of Colombo Metropolitan Area, Sri Lanka

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In recent decades, population growth and economic development have directly affected changes in the urban landscape in cities around the world. These rapid changes are prominent in developing regions in Asia and Africa. Rapid changes of the urban landscape resulted to occur several environmental problems such as weakling air and water quality, increasing urban heat island, rising poverty levels, decrease in agricultural land, increasing demand for urban land, high energy consumption, reducing urban green spaces, increasing vector-borne disease, waste-disposal problems, and rising flash flooding. This study aims to capture the impact of rapid urbanization to increase urban flood disasters in the Colombo Metropolitan Area (CMA). There are three specific objectives, such as; examine the spatiotemporal urbanization pattern and driving factors, capture the urban flood disaster trend based on the historical record, and analyze the negative impact of urban disasters towards the introduction of sustainable urban planning. We have selected 1996, 2009, 2019 as the time point to capture the landscape changes over the 23 years' time. Landsat data and geospatial techniques, including machine learning algorithms, urban-rural gradient, and statistical analysis, were used to map and examine the landscape change in CMA during the 1996–2009 and 2009–2019 periods. The CMA has been selected as a study area by considering the urbanization pattern of Sri Lanka. CMA shows rapid urbanization over the past few decades and recorded several negative environmental issues. In addition to that, the urban flood has resulted in occurring savior damages to CMA during recent years. Unplanned urban development patterns have been effected to recode savior flood damages on people, the environment, and the economy in CMA. We strongly believe that the findings of this study will help policymakers and urban planners to introduce proper remedial measures to control the damages witch course by the urban flood.

Keywords: Urban expansion, urban disasters, flood, geospatial techniques, Colombo Metropolitan Area, Sri Lanka

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Changes in the landscape pattern of the Muthurajawela Marsh and Negombo Lagoon Sri Lanka: Socio-ecological implications

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Rapid population growth and uncontrolled urban expansion are important drivers of land-use changes, posing critical challenges towards the sustainability of urban ecosystems. Urban wetlands ecosystems (UWEs) play important social and ecological roles but are often affected by urban landscape transformation processes. The primary purpose of this research was to understand the effects of urbanization on one UWE in Sri Lanka to help wetland management, land-use planning and in the protection of UWEs in the country and elsewhere in the world. The western region of Sri Lanka is one of the emerging growth centers in the country where natural environment and wetland ecosystems have been under extreme pressure. In this study, we developed a framework to evaluate the changes in the spatial configuration of the Muthurajawela Marsh and Negombo Lagoon (MMNL, an important UWE in Sri Lanka) during the period of 1997-2017. Such a framework cuts across various disciplines, including environmental history, urban ecology, wetland science and GIScience and remote sensing. More specifically, this research focused on understanding and assessing the current potential spatial stress on the MMNL due to human interference. We found that the MMNL has experienced rapid landscape transformation over the past 20 years. The area of marshland and mangrove in the MMNL has decreased by 48% and 24%, respectively, while the area of built-up has increased by 79%. We also found that the most marshland lost due to built-up expansion. Indeed, rapid population growth and uncontrolled urban expansion have impacted the MMNL. Such a landscape transformation of the MMNL might have considerably affected the biodiversity and ecosystem services of the area. Hence, there is a need for land-use planning strategies that could protect and enhance the biodiversity and ecosystem services in the area and, at the same time, guide actions towards the sustainability of this important UWE in the country.

Keywords: Wetland, Muthurajawela Marsh and Negombo Lagoon, Socio-ecological, Spatio-temporal analysis, Urban ecology, Remote Sensing

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Relationships between the locations of ancient sites and topographic factors in Japan and China to explore interactions between human and nature

*Yuan Wang[1], Takashi Oguchi[1]

1. The University of Tokyo

Locations of ancient sites including historical castles and archaeological monuments reflect activities and thinking of ancient people who built them as well as related environmental factors such as topography, water availability, and proneness to natural hazards. Relationships between the ancient sites and topographic factors are expected to be stronger in the past when human control on nature was limited, and their analysis is useful to understand how ancient people interact with the nature environment. This research utilizes GIS and DEMs to investigate topography as well as surface hydrological conditions. Based on the spatial analysis methods of GIS, the distribution characteristics of ancient sites in Japan and China were investigated, and statistical analysis were conducted to examine relationships between the ancient sites and natural/social environmental conditions. The results were interpreted based on not only geography but also historical and archaeological knowledge. It found that the ancient sites in Japan are mainly located at 0 ~ 250 m in elevation, and they tend to be close to hills and mountains, while in Shanxi, China they are concentrated on flat plain areas with an average elevation of around 400 m. The ancient sites are densely located close to major drainage lines with a range of 0 ~ 2.5 km in Japan as well as in Shanxi, China, suggesting that ancient people considered water availability or a strategic role of rivers before they built the sites, and their dependence on rivers must have been stronger than today under technologically less developed situations.

Keywords: GIS, DEM, Geomorphology

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[E] Oral | H (Human Geosciences)：H-TT Technology & Techniques

[H-TT14] Geographic Information Systems and Cartography

convener:Takashi Oguchi(Center for Spatial Information Science, The University of Tokyo), Yoshiki Wakabayashi(Graduate School of Urban Environmental Sciences, Tokyo Metropolitan University), Yuei-An Liou(National Central University), Ronald C. Estoque(National Institute for Environmental Studies, Japan)

This session discusses various methods which acquire, store, analyze and visualize geospatial data, and presents the outcomes of empirical studies using GIS or mapping methods. The session also deals with applications of digital data, and GIS, and mapping to various fields of earth and planetary science and human society. All presentations and discussion of this session are made in English.

[HTT14-13] Potential influence of the use of sample survey data on spatial statistical analysis

★Invited Papers

*Ikuho Yamada[1] (1.Center for Spatial Information Science, University of Tokyo)

[HTT14-15] **Modeling and Mapping the Suitability of Parcel Pick-up Points using GIS-based Multivariate Binary Logistic Regression Model: A Case Study of Guangzhou City, China**

*ZILAI ZHENG[1], Takehiro Morimoto[2] (1.Graduate School of Life and Environmental Sciences, University of Tsukuba, 2.Faculty of Life and Environmental Sciences, University of Tsukuba)

[HTT14-16] **Simulating Land Use Change with Rapid Urbanization under the Natural and Anthropogenic Driving Forces**

*BINGYU WANG[1], Takashi Oguchi[1,2] (1.Department of Natural Environment Studies, The University of Tokyo, 2.Center for Spatial Information Science, The University of Tokyo, Japan)

[HTT14-17] Visualization of the supply-demand gap in childcare services in Tokyo

*Yoshiki Wakabayashi[1], Hitoshi Miyazawa[2] (1.Graduate School of Urban Environmental Sciences, Tokyo Metropolitan University, 2.Faculty of Letters and Education, Ochanomizu University)

[HTT14-18] **Comparative analysis of spatial patterns of tourists' behavior in Japanese cities using Online Geotagged Photographs**

*Bochra Bettaieb[1], Yoshiki Wakabayashi[1] (1.Tokyo Metropolitan University)

Potential influence of the use of sample survey data on spatial statistical analysis

*Ikuho Yamada[1]

1. Center for Spatial Information Science, University of Tokyo

Data used in spatial analysis are often based on samples rather than the population. Especially when research interests lie in human related issues such as their attributes, behaviors, and opinions, conducting a questionnaire survey for individuals sampled from areal units, for example, municipalities and ZIP code areas that compose a study region is a frequently used method to generate spatial data about the issues. Because characteristics of the population estimated based on the sample survey data inevitably have some discrepancies from true characteristics of the population, a variety of research and discussion have been done in the field of traditional, non-spatial statistics. However, in the context of spatial statistical analysis, there has been little discussion on potential influence that such sample survey data might have on analysis results, whereas the discrepancies in sample survey data could be more problematic in spatial statistical analysis, which integrates multiple data values collected for individual areal units. This research therefore aims to investigate how the use of data collected through sample surveys potentially influences spatial statistical analysis as the first step to develop methodologies to avoid and/or diminish such influence.

To quantitatively examine potential influence of sample survey data, this research used statistical simulations in which clustering spatial patterns were intentionally generated in a study region and then analyzed by a spatial statistical method to see if/how analysis results with the entire population data and those with sample data selected from it would differ from each other. The study region was a simple, 10x10 grid system, and the statistical method used was local Moran's *I* statistic designed to identify spatial autocorrelation around individual areal units in the study region. Systematically designed 8 types of clustering spatial patterns were examined with 5 levels of sampling rates. Results suggested that statistical power of local Moran's *I* analysis to detect clustering patterns decreased as the sampling rates decreased, and the sampling rates of less than or equal to 0.01 seem to be critically problematic. It was also suggested that strength of such influence varied depending on the types of clustering patterns and relative locations of areal units in the study region. As these results confirmed that the use of sample survey data actually influence results of spatial statistical analysis, further research is needed to obtain more generic, detailed properties of such influence for contributing to development of methodologies to avoid and/or diminish it.

Keywords: Sample survey data, Spatial statistical analysis, Sampling rate, Local Moran's I analysis

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Modeling and Mapping the Suitability of Parcel Pick-up Points using GIS-based Multivariate Binary Logistic Regression Model: A Case Study of Guangzhou City, China

*ZILAI ZHENG[1], Takehiro Morimoto[2]

1. Graduate School of Life and Environmental Sciences, University of Tsukuba, 2. Faculty of Life and Environmental Sciences, University of Tsukuba

The parcel pickup point (PPP) is an effective way of solving the last-mile problem and becoming a hot topic in logistic geography. In this study, we developed a GIS-based multivariate binary logistic regression model to mapping the suitability of the PPPs in Guangzhou city, which parcel number ranks the first in China from 2014 to 2018. Five influential factors are determined based on the density and the gathering of the existed PPPs: population, distance to bus-stop, distance to road, distance to a subway station, and distance to a residential area. The multivariate binary logistic regression model was introduced to analyze the relativity of affecting factors of the PPP and quantified a suitability equation of the spatial distribution of the PPPs in Guangzhou city. The results verify that the distance to the residential area is the most important factor to impact the PPPs' distribution. Moreover, this approach provides an accurate way to model the suitability of PPPs quantitatively according to the spatial pattern of existing PPPs. It gives a reference for decision-makers to decide the location of new PPPs.

Keywords: Parcel Pick-up points, Mapping the suitability, GIS-based logistic regression model

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Simulating Land Use Change with Rapid Urbanization under the Natural and Anthropogenic Driving Forces

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1. Department of Natural Environment Studies, The University of Tokyo, 2. Center for Spatial Information Science, The University of Tokyo, Japan

Land use/Land Cover Change (LUCC) significantly affects the structure and function of the ecosystem, including biodiversity, biogeochemical cycles, and the sustainability of resources. LUCC involves complex underlying mechanisms and diverse driving factors concerning both human activities and the natural environment. Therefore, understanding the LUCC processes under multi-dimensional driving factors to investigate the future tendency is of high research value. Accompanied by rapid urban population growth and socio-economic development, the world has undergone large-scale urban expansion. Many scholars have put effort into better optimizing urban planning and configuration to achieve urban sustainability. Spatiotemporal LUCC simulations are effective and reproducible methods for analyzing both the causes and consequences of future land dynamics under various scenarios. There is a growing body of approaches and software packages for modeling future LUCC, and many of them are empirical approaches based on historical data such as regression models, artificial neural networks, CLUE-S, and CA_MARKOV. This study has newly applied a patch-level land-use simulation model (PLUS) developed from the future land use simulation model based on the cellular automata (CA). A case study has been undertaken in the three metropolitan areas of Japan. By applying a land expansion analysis strategy (LEAS), we extracted the LUCC in the metropolitan areas of Japan between 2010 and 2015. Driving factors such as landscape condition, population, railway distance, and protected areas were considered to explore the effect of those factors on the change in different land-use types. Besides, we have simulated the land use of the study area in 2017 with a CA model based on multi-type random seeds integrated into the PLUS model. The simulation result corresponds well to the real land use map in 2017 with acceptable accuracy, suggesting that our approach can provide practical information for understanding land use alternation and contribute to the decision-making for sustainable urban planning. Future work will focus more on significant driving factors, regional differences, and the impact of climate change.

Keywords: land use and land cover change, urban expansion, driving factors, PLUS model, future scenarios simulation

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Visualization of the supply-demand gap in childcare services in Tokyo

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With an increase in the number of working mothers in Japan, metropolitan areas face a shortage of childcare services. To overcome this problem, the Japanese government has, since 2015, sought to expand childcare facilities by implementing a comprehensive support system for children and child-rearing. This system is aimed at increasing the supply and type of childcare services available by creating more certified centers for early childhood education and care, in addition to providing greater public financial support for small-scale unlicensed childcare facilities. Some municipalities have also implemented their own childcare provision measures. In planning childcare resource allocation, the spatial distribution of childcare services supply and demand must be understood. This study examined the spatial aspects of the development of the supply–demand gap following the implementation of this system. To achieve this, spatial patterns of the gap between childcare supply and demand were visualized using geographic information systems (GIS). The study area was Koto Ward in Tokyo, where an extremely large number of children await enrollment in licensed childcare centers. To map the supply–demand gap using GIS, the difference between supply and demand densities was calculated after converting the vector data concerning childcare supply from the licensed childcare centers and preschool children into raster data using kernel density estimation. The results of the analysis reveal a spatial imbalance between childcare supply and demand within the municipality. A map adding the distribution of small-scale childcare centers proves that the gap in childcare supply from the licensed centers is spatially complemented by childcare services of small-scale childcare centers. Additionally, the map provides evidence of the effect of the new “satellite childcare service” measures originally enacted in Koto Ward.

Keywords: childcare services, supply–demand gap, kernel density estimation, raster calculation

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Comparative analysis of spatial patterns of tourists' behavior in Japanese cities using Online Geotagged Photographs

*Bochra Bettaieb[1], Yoshiki Wakabayashi[1]

1. Tokyo Metropolitan University

Exploring tourists' spatial behavior and preferences has been one of the most important topics in tourism studies, geography, and geographic information science (GIScience). While it had been difficult to capture the spatial behavior of tourists within a city, new sources of geospatial data derived from social networking services (SNS) provide the possibility of analyzing high-resolution big data to analyze the patterns of human spatial behavior across space and time. By employing the geocoded photos from a photo-sharing service of SNS, this study aims to examine the spatial patterns of tourists' behavior at the main tourist attractions in two major tourist destinations in Japan –Tokyo and Kyoto. The authors employed geotagged photos uploaded by tourists to the photo-sharing social media, Flickr, which is one of the most popular online platforms where people share their travel experiences. The data obtained were geocoded photos from 2018, taken within 1 km from Shinjuku, Ginza, and Asakusa stations in Tokyo and 5 km from Shijo station in Kyoto. Information on the nationalities of contributors recorded in the Flickr data were used to compare the tourist spots by visitors' nationalities. The spatial distribution of places where the photographs were taken (photo location) were analyzed with geographical information systems (GIS). The results indicated the concentration and dispersion of photo locations in each city and their main hotspots. Marked differences in the distribution of photo locations in two cities were observed between Asians and other tourists such as Europeans and North Americans, whereas similarities in the distribution patterns were found for European and North American tourists. The results may be due to the differences in tourists' behavior and their preferences between the countries as well as the spatial structure of tourist attractions in each city.

Keywords: tourist behavior, Flickr, spatial analysis, Tokyo, Kyoto

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[E] Oral | H (Human Geosciences)：H-TT Technology & Techniques

[H-TT15] Environmental Remote Sensing

convener:Wei Yang(Chiba University), Akihiko Kondoh(Center for Environmental Remote Sensing, Chiba University), Carolynne Hultquist(Columbia University), Elena Sava(US Army Corps of Engineers Geospatial Research Laboratory), Guido Cervone(Pennsylvania State University Main Campus)

Our human beings are encountering various environmental issues on the Earth, and it is urgent to find out the solutions based on corresponding observations and models. Remote sensing is currently the only feasible means to observe the Earth environment at regional/continental /global scales over long periods, and consequently detects the environmental changes occurred all over the world. Although remote sensing has been extensively applied in numerous environmental studies, there are still many challenges for data analysis and applications. Consequently, this session invites presentations on theory, science, technology, and applications of remote sensing to study the Earth environment from local, regional to global scales. Both oral and poster presentations are sincerely welcome.(TBD)

[HTT15-01] Satellite-based Regional Scale Evapotranspiration Estimation Mapping

*Manoj Hari[1], Bhishma Tyagi[1], Mohammad Sanaulla K. Huddar[2], Harish A.[3] (1.National Institute of Technology Rourkela, Odisha, India., 2.Indian Council of Agricultural Research, New Delhi, India., 3.Karaikal, Puducherry, India.)

[HTT15-02] Remote sensing of floating macroalgae in the coastal areas based on machine learning

*Zhaoxin Li[1], Zhongfeng Qiu[2], Wei Yang[1] (1.Chiba Univ., 2.NUIST)

[HTT15-03] Update of GCOM-C/SGLI Leaf Area Index & fraction of Absorbed Photosynthetically Active Radiation products

*Toshiyuki Kobayashi[1], Hideki Kobayashi[2], Wei Yang[3], Yoshiaki HONDA[3], Yuhsaku Ono, Shin Nagai[2], Tomoko Akitsu[4], Kenlo Nasahara[4], Masahiro Hori[1], Hiroshi Murakami[1] (1.Japan Aerospace Exploration Agency, 2.Japan Agency for Marine-Earth Science and Technology, 3.Chiba University, 4.University of Tsukuba)

[HTT15-04] Comparison of five smoothing methods for noise removal in MODIS LAI time series data

*Bageshree K[1], Tsuyoshi Kinouchi[1] (1.Tokyo Institute of Technology)

[HTT15-05] Mapping and comparing the geomorphological environments of designated conservation area and urban city in Majuro using drone data

*Benedict Yamamura[1,2], Hayate Kimura[1], Wataru Sano[1], Soko Hirabayashi[1], Yukihiko Imai[1], Kyotak Ishiguro[2], Hironobu Kan[1] (1.Kyushu University, Integrated Sciences for Global Society - Research Center for Coastal Seafloor , 2.Marshall Islands Marine Resources Authority)

[HTT15-06] Spatial Investigations of Surface Urban Heat Islands in 10 Chinese Metropolises: A Perspective from Land Cover/Use Composition

*Fei LIU[1] (1.University of Tsukuba)

Satellite-based Regional Scale Evapotranspiration Estimation Mapping

*Manoj Hari[1], Bhishma Tyagi[1], Mohammad Sanaulla K. Huddar[2], Harish A.[3]

1. National Institute of Technology Rourkela, Odisha, India., 2. Indian Council of Agricultural Research, New Delhi, India., 3. Karaikal, Puducherry, India.

India is a country of agricultural background, with 140 million hectares (Mha) of fallow land out of which a myriad area of 64.4 Mha comes under the irrigated land. Improved regular and rapid monitoring techniques are needed to quantify the evapotranspiration (*ET*) precisely on agricultural fields to enhance the efficient usage of water resources and to protect the water quality and environment. Therefore, it is noteworthy to understand the estimation of *ET* on a regional scale. The present study develops an overarching framework on spatial and temporal assessment of crop evapotranspiration and the associated agro-hydro factors of Tanjore, a delta district of Tamilnadu, India. The analysis has a pivot role in incorporating the estimation of *ET* using the FAO's standardized Penman-Monteith *ET* model by considering various climatic parameters. The present study correlates alfalfa-based crop coefficient (*Kc*) and high-resolution satellite image vegetation index (*VI*) which was normalized with remodelled *Kc-VI* for the study period to generate *ET* maps. These approaches have been influential in the field because of due to the free and facilitate access. The analysis holds various climatic elements such as temperature, precipitation, soil moisture, insolation, etc., which will significantly help in understanding the climate change effects over agricultural areas on a regional scale. To stress that the analysis has been performed in-depth where the *ET* maps generated with the remodelled *Kc-VI* normalization, indicate positive stand with *RMSE* of 0.05 mm day^{-1} for the study period which can perform an important role in the management of agro-hydro decisions on a regional scale. The *ET* maps generated at the field scale will help to enhance the irrigational pattern and utilization. The output will also be helpful to reduce the seasonal usage of irrigation water by 18% that helps to optimize the hydrological resources. The *ET* maps generated from the relation helps to project the agro-hydrological squandering at a regional scale.

Keywords: Evapotranspiration, Hydrological cycle, Penman-Monteith Model, Vegetation Index, Delta region

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Remote sensing of floating macroalgae in the coastal areas based on machine learning

*Zhaoxin Li[1], Zhongfeng Qiu[2], Wei Yang[1]

1. Chiba Univ., 2. NUIST

Timely and accurate information about floating macroalgae blooms (MAB), including their distribution, movement, and duration, is crucial in order for local government and residents to grasp the whole picture, and then plan effectively to restrain economic damage. Plenty of threshold-based index methods have been developed to detect surface algae pixels in various ocean color data with different manners; however, these methods cannot be used for every satellite sensor because of the spectral band configuration. Also, these traditional methods generally require other reliable indicators, and even visual inspection, in order to achieve an acceptable mapping of MAB that appears under diverse environmental conditions (cloud, aerosol, and sun glint). To overcome these drawbacks, a machine learning algorithm named Multi-Layer Perceptron (MLP) was used in this paper to establish a novel automatic method to monitor MAB continuously in the Yellow Sea, using Geostationary Ocean Color Imager (GOCI) imagery. The method consists of two MLP models, which consider both spectral and spatial features of Rayleigh-corrected reflectance (Rrc) maps. Accuracy assessment and performance comparison showed that the proposed method has the capability to provide prediction maps of MAB with high accuracy (F1-score approaching 90% or more), and with more robustness than the traditional methods. Most importantly, the model is practically adaptable for other ocean color instruments. This allows customized models to be built and used for monitoring MAB in any regional areas. With the development of machine learning models, long-term mapping of MAB in global ocean is conducive to promoting the associated studies.

Keywords: Floating macroalgae, Image identification, Remote sensing, Machine learning

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Update of GCOM-C/SGLI Leaf Area Index & fraction of Absorbed Photosynthetically Active Radiation products

*Toshiyuki Kobayashi[1], Hideki Kobayashi[2], Wei Yang[3], Yoshiaki HONDA[3], Yuhsaku Ono, Shin Nagai[2], Tomoko Akitsu[4], Kenlo Nasahara[4], Masahiro Hori[1], Hiroshi Murakami[1]

1. Japan Aerospace Exploration Agency, 2. Japan Agency for Marine-Earth Science and Technology, 3. Chiba University, 4. University of Tsukuba

The Japan Aerospace Exploration Agency (JAXA) launched the Global Change Observation Mission - Climate (GCOM-C) satellite on December 23rd, 2017. The 1st version of the GCOM-C/SGLI Leaf Area Index (LAI) and fraction of Absorbed Photosynthetically Active Radiation (fAPAR) products were released on December 2018. LAI and fAPAR were estimated based on the look-up tables showing the relationships between the multi-angle atmospherically-corrected surface reflectance data and the LAI or fAPAR. The relationships between LAI/fAPAR and surface reflectance data at the top of canopy were simulated using a radiative transfer simulator, the Forest Light Environmental Simulator (FLiES) [1].

This year, we are planning to release the 2nd version of the products, in which the algorithms and the data quality will be improved. In this research, we introduce the current situation of the Leaf Area Index (LAI) product and summarize the updates for the 2nd version of the products.

[1] H. Kobayashi *et al.*, A coupled 1-D atmosphere and 3-D canopy radiative transfer model for canopy reflectance, light environment, and photosynthesis simulation in a heterogeneous landscape, *Remote Sensing of Environment*, **112** (2008), 173-185.

Keywords: LAI, FAPAR

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Comparison of five smoothing methods for noise removal in MODIS LAI time series data

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Time series remotely sensed satellite data plays an important role in understanding the dynamics of the climate change. These datasets are not continuous and consistent over space and time. Sensor degradation and atmospheric disturbances often introduce noise in the spectral signature retrieval by such satellites. This noise needs to be corrected to understand the underlying dominant pattern. Moderate resolution imaging spectroradiometer (MODIS) Terra/Aqua Leaf Area Index (LAI) time series data, which tells the underlying photosynthetically active foliage is particularly popular among the researchers considering its high temporal resolution (1 / 2 daily) and fairly good spatial resolution (250m). MOD15A2H LAI/FPAR MODIS product is used in this study to compare five smoothing methods for noise removal: Savitzky Golay (SG), Double Logistic (DL), Local Polynomial Regression (LOESS), Asymmetric Gaussian (AG) and STL (Seasonal Trend Decomposition by Locally weighted regression smoother in TIMESAT). MODIS data is provided with the pixel level retrieval quality information. These methods are evaluated using R and TIMESAT assimilating the pixel level quality information. We use Maharashtra state of India as our study area and compare the results based on land use type such as forests, agriculture, grasslands and savannas. We evaluate the performances of these methods based on Root Mean Squared Error (RMSE) and roughness of the LAI time series. The use of pixel level quality information plays an important role in terms of accuracy of smoothing. Although the result does not confirm any outperforming method for smoothing the time series, filtering with SG with use of quality pixels stands out well among other methods in terms of RMSE and roughness. The SG shows RMSE from 0.002 to 0.6 under different filter settings without using quality information, while the use of quality information gives RMSE of 0.26 and is comparatively smoother. LOESS method in R gives high smoothing but it fails to capture the minute variations in the time series. Our contribution will benefit the researchers in terms of pre-processing of the time series data.

Keywords: Time Series, Noise Removal, MODIS, TIMESAT

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Mapping and comparing the geomorphological environments of designated conservation area and urban city in Majuro using drone data

*Benedict Yamamura[1,2], Hayate Kimura[1], Wataru Sano[1], Soko Hirabayashi[1], Yukihiko Imai[1], Kyotak Ishiguro[2], Hironobu Kan[1]

1. Kyushu University, Integrated Sciences for Global Society - Research Center for Coastal Seafloor , 2. Marshall Islands Marine Resources Authority

The Marshall Islands are located on the eastern Pacific Ocean in Micronesia region. The country consists of 29 atolls and 6 table reefs. Majuro atoll is the capital city, inhabiting more than half of the country’ s population of more than 53,000 people. Like many other low-lying atoll nations, Majuro is only composed of coral cays and it is estimated to be about 3-meter above sea level therefore makes it vulnerable to coastal erosion due to rising sea level and coastal development. In addition to those factors, the increase in human population and degradation of natural resources are also influential factors, contributing to the vulnerability and sustainability of the city. During the summer of 2019, we conducted a research trip to Majuro and examine the physical features that contribute to island formation in designated conservation areas and urban area. The study’ s objectives are to map and compare the geomorphological features of locally-owned marine protected area (MPA) and urban city in Majuro atoll by utilizing the use of high-resolution image data derived from unmanned aerial vehicles (UAVs) integrated with a Real Time Kinematic (RTK) technology –Phantom 4 RTK. Topographic profile data was also considered to compliment the UAV dataset. We collected 14,555 UAV photos from three study sites then used Agisoft Metashape Pro software to generate the 3D models and orthomosaic dataset. The output data were transferred to ArcGIS software for spatial and classification analysis to determine different geomorphological environments. Various geomorphic within and outside the conservation area were classified according to the high-resolution dataset. We also observed healthy foram zones around the conservation area that played an important role in maintaining the island sustainability. The next field trip is scheduled to validate the output data, visit to other traditional area, then consult with stakeholder on the expectations.

Keywords: marine protected area (MPA), unmanned aerial vehicle (UAV), real-time kinematic (RTK), Marshall Islands, Majuro, Geomorphology

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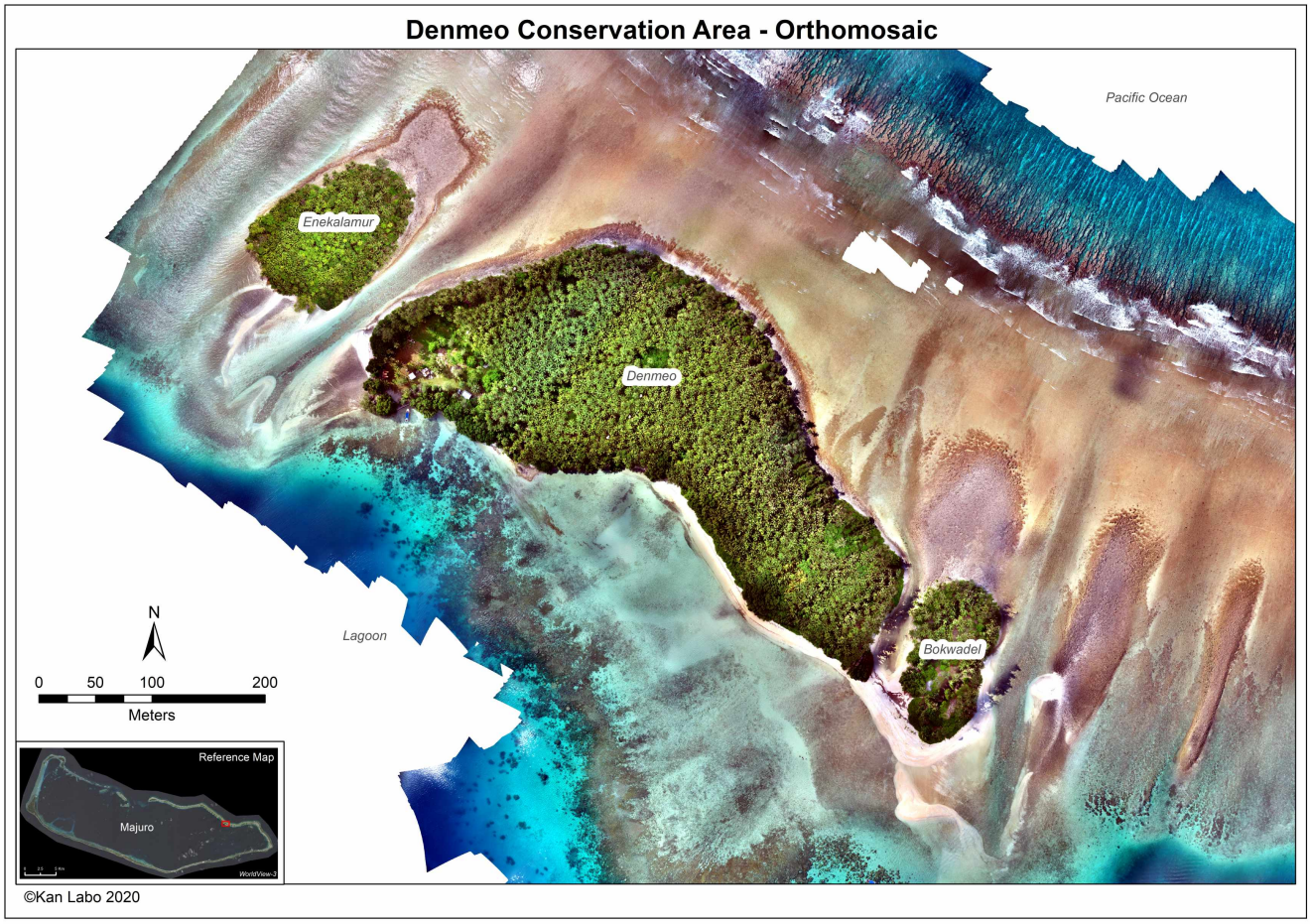

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Spatial Investigations of Surface Urban Heat Islands in 10 Chinese Metropolises: A Perspective from Land Cover/Use Composition

*Fei LIU[1]

1. University of Tsukuba

The surface urban heat islands (SUHI) phenomenon emerges as a source of multiple environmental issues and climate crises, as well as exacerbates the urban ecosystem services and geo-health. The urban climate situations and environmental qualities in Chinese metropolises cannot be neglected. This study focuses on spatially evaluating the influence of land cover/use composition on the SUHI in ten populated Chinese cities using Landsat data. The thermal performances of different Chinese metropolises were examined based on satellite monitoring. The thermal behaviors of land cover/use types were also identified at a spatial scale using diverse quantitative methods. Besides, it was assumed in this study that the formations of SUHI patterns in these ten metropolises were mainly attributed to land cover/use composition and population gathering. The patterns and characteristics of the thermal field in Chinese metropolises were spatial-sensitive. Their spatial causality among SUHI, land cover/use composition, and population were investigated based on spatial regression models. The differentials and convergences of multiple Chinese thermal environments were depicted. The SUHI intensity was the strongest and most varied in the metropolis of Suzhou. SUHI in the Harbin metropolis was weaker than other metropolises. Waterbody plays a significant role in the thermal environments of Suzhou, Wuhan, and Tianjin. Findings from this study would strive for relieving SUHI and improving urban thermal regimes in Chinese metropolises, and inspire the urban planners and decision-makers for urban sustainability in China.

Keywords: Surface Urban Heat Islands (SUHI), Land use/cover, Chinese Metropolises

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[E] Oral | H (Human Geosciences)：H-TT Technology & Techniques

[H-TT15] Environmental Remote Sensing

convener:Wei Yang(Chiba University), Akihiko Kondoh(Center for Environmental Remote Sensing, Chiba University), Carolynne Hultquist(Columbia University), Elena Sava(US Army Corps of Engineers Geospatial Research Laboratory), Guido Cervone(Pennsylvania State University Main Campus)

Our human beings are encountering various environmental issues on the Earth, and it is urgent to find out the solutions based on corresponding observations and models. Remote sensing is currently the only feasible means to observe the Earth environment at regional/continental /global scales over long periods, and consequently detects the environmental changes occurred all over the world. Although remote sensing has been extensively applied in numerous environmental studies, there are still many challenges for data analysis and applications. Consequently, this session invites presentations on theory, science, technology, and applications of remote sensing to study the Earth environment from local, regional to global scales. Both oral and poster presentations are sincerely welcome.(TBD)

[HTT15-07] Landscape changes in the Cordillera Real, Andes detected from satellite images

*YILIN HUANG[1] (1.Tokyo Institute of Technology)

[HTT15-08] **Assessment of local climate zones in Tokyo (Japan) and Lyon (France) using satellite and mobile measurements**

*Florent Renard[1,2], Lucille Alonso[1,2] (1.University of Lyon, France, 2.UMR CNRS Environment City Society)

[HTT15-09] **Deep learning for atmospheric duct estimation from radar sea clutter**

*Xiaofeng Zhao[1], Huadong Du[1], Zhixian Luo[1] (1.College of Meteorology and Oceanography, National University of Defense Technology)

[HTT15-10] Verification of forest cover changes in China using multiple satellites

*Takuto Taguchi[1], Kazuhito Ichii[1], Jingfeng Xiao[2] (1.Chiba University, 2.University of New Hampshire)

[HTT15-11] High-resolution aerosol remote sensing retrieval using Chinese High-Resolution Earth Observation Satellite I (GF-1) wide-field images (WFI) and MODIS surface products

*Fangwen Bao[1] (1.Center for Oceanic and Atmospheric Science at SUSTech (COAST), Department of Ocean Sciences and Engineering, Southern University of Science and Technology)

[HTT15-12] Toward operational satellite monitoring of chlorophyll-a concentrations in turbid inland waters

*Wei Yang[1], Bunkei Matsushita[2], Akihiko Kondoh[1] (1.Chiba University, 2.University of Tsukuba)

Landscape changes in the Cordillera Real, Andes detected from satellite images

*YILIN HUANG[1]

1. Tokyo Institute of Technology

Strong glacier recession was observed worldwide during the last decades. Among all, glaciers in tropical Andes have been showing the large negative specific mass changes which strongly limit the water resources available in the downstream area. A lot of research has been conducted on the study of glaciers changes, however, less focus has been given to the change of landscapes such as lakes and vegetation, although they are essential for water resources and have a significant meaning to the livelihood of local people because of the potential water storage provided by new or growing lakes and water storage in vegetated area by preserving meltwater and precipitation.

However, the Cordillera Real, Bolivia, has not been drawing much attention compared to the mountain ranges in Peru because of less large glaciers, although the glaciers are playing an important role in the water supply for several big cities in Bolivia, including its capital cities, La Paz and El Alto. Considering the important role of various landscapes that are playing in the water supply, this study is aimed at identifying the long-term change of landscape in the Cordillera Real, Andes.

In this study, a model was designed to identify five types of landscapes including glacier, lakes, wetland, vegetation and gravel using four normalized difference indexes which are calculated from Landsat-5 and Landsat-8 atmospheric corrected satellite images in the dry season (May to Oct) from 1991 to 2019, with the help of other data sources including ASTER GDEM, STRM water body data, ArcGIS world imagery and Google Earth map.

With this model, different types of landscapes were automatically identified, thus it is more efficient than previous studies and avoids errors brought by manual operation.

The result revealed the spatial changes of each type of landscape from 1991 to 2019. Overall, vegetation and gravel take most of the area, and their areas are relatively stable. The area of glacier shows a decreasing trend during the study period and the decreasing rate is consistent with the result of previous studies. It was found that the area of wetlands fluctuates with seasonal changes, and it normally reached the highest in May and early June, and the lowest area often shows in August and September. Five-year average of the wetland area showed an increase in the most recent periods. The area of lakes is slowly increasing, and new lakes have been detected near the retreated glacier.

The areal increase of wetland and lakes indicates the improvement of water storage capacity and possible increase of water resources in Cordillera Real. Although the retreated glaciers will temporarily provide sufficient meltwater runoff but the long-term sustainability of water resources is highly uncertain due to the influence of other landscapes and uncertainty in the remaining mass of glaciers.

Keywords: Landscape, Cordillera Real, Tropical glacier, Landsat

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Assessment of local climate zones in Tokyo (Japan) and Lyon (France) using satellite and mobile measurements

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1. University of Lyon, France, 2. UMR CNRS Environment City Society

According to the IPCC, current climate change is likely to increase the intensity and frequency of extreme events. This is particularly the case for heat waves, the severity of which has increased in Europe in recent decades. In addition, the rise in temperatures due to global climate change is amplified by the urban heat island effect (UHI). This phenomenon is widely analysed and is one of the major themes of urban climatology, especially its impact on human health. A UHI is characterized by a difference in temperature between an urban area and the surrounding rural areas. In general, the temperature in urban areas is higher than in rural areas, especially at night. Solutions must be found through urban planning policies by implementing sustainable adaptation strategies to improve the thermal comfort of the inhabitants. Solutions must start with a better understanding of UHI and urban microclimates.

For this purpose, the use of Local Climate Zones (LCZs) is often used. This concept proposes the use of a common methodology to define the physical characteristics of cities for urban planners, architects and urban climatologists. Therefore, this terminology is transferable to all geographical and cultural areas. The 18 main zones are set up according to the characteristics of the surface structure.

These zones have a theoretical basis and it is necessary to ensure the thermal coherence of this territorial division before its use in development projects. The objective of this study is therefore to compare the LCZs with land surface temperature (LST) data from Landsat measurements and mobile air temperature (AT) measurements carried out in the Tokyo (Japan) and Lyon (France) agglomerations during moving observations, in order to ensure the relevance of the different sectors.

LCZs are obtained by supervised classification of Landsat and Sentinel images. The random tree classifier was used. Results were visually verified using 8 cm resolution orthophotography and edited for classification inaccuracies.

The LSTs were obtained using the single channel algorithm. All images with less than 10% cloud cover were processed from 2000 to mid-2019 (53 for Tokyo and 49 for Lyon). In addition, only pixels with sufficient quality according to the band quality assessment were retained. Air temperature measurements on foot or by bicycle were also carried out at moderate speed (< 8 km/h) at both sites. A Log32 continuous recorder was used under a white ventilated radiation protection shelter. Location was provided by a Garmin 64s GPS. 30 measurement campaigns in Lyon and 23 in Tokyo were carried out during the summer months from 2016 to 2019. LSTs and ATs are studied as a function of LCZs using the Kruskal-Wallis test followed by the Steel-Dwass-Critchlow-Fligner multiple pair comparison procedure.

The results of the LSTs indicate significant differences between areas and thus confirm the value of using LCZs (figure 1: LSTs over Tokyo metropolitan area according to the LCZs, 20th, March 2017). Specifically, the highest surface temperatures are obtained in compact and open low-rise areas, activity zones and heavy industrial zones. The lowest temperatures are found in dense forests and water areas. The results are less significant for ATs, but the overall results are the same. This is due to the fact that ATs have a much lower range than LSTs. Indeed, for the same day, it is very rare to find ATs differences of 3˚C when

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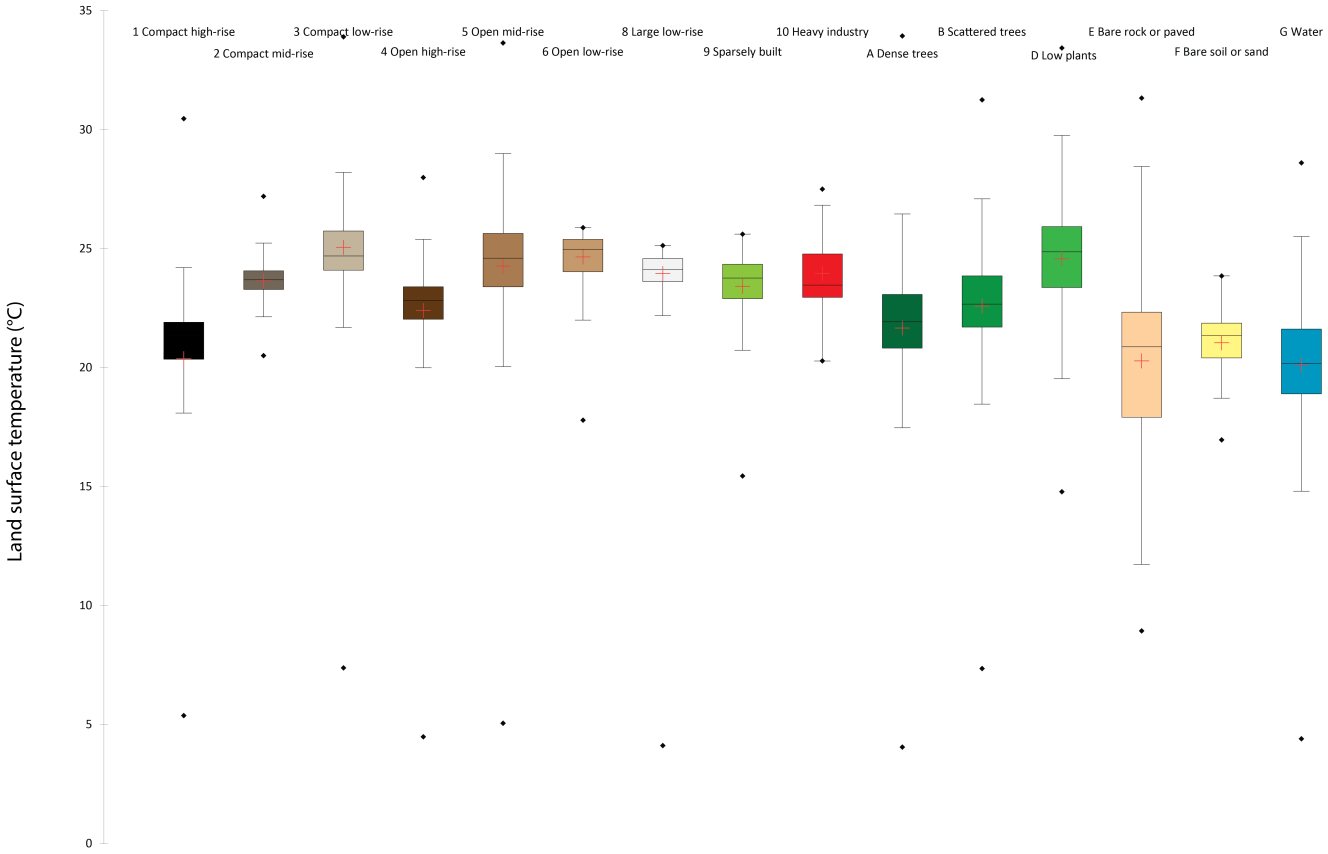
the differences in LSTs can exceed 30˚C. Furthermore, mobile AT measurements are much more dependent on wind and sun exposure than LSTs. In these two agglomerations, LCZs are therefore appropriate planning tools that can be mobilized to tackle UHI and improve urban thermal comfort.

Keywords: Local climate zones, Land surface temperature, Air temperature, Landsat



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Deep learning for atmospheric duct estimation from radar sea clutter

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1. College of Meteorology and Oceanography, National University of Defense Technology

Atmospheric duct is a kind of non-standard refractive structure. It can change the electromagnetic wave (EM) propagation paths and capture the EM rays in the duct layer to form the atmospheric duct propagation, leading to substantial influences on the performance of radar and wireless telecommunication systems. On the other hand, when the EM waves propagate in the duct layer, they carry the information of this layer. From the perspective of inverse problem, the structure of the duct layer can be retrieved from these EM signals. Nowadays, deep learning (DL) has been applied in many remote sensing areas. This paper proposes the feasibility of using the DL for the inverse problem of “refractivity from clutter (RFC)”. Through the simulation data, a DL network mapping model between the radar sea clutter and the duct parameters is constructed, and the factors that may affect the accuracy of the network model are discussed.

Keywords: atmospheric duct, radar sea clutter, deep learning

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Verification of forest cover changes in China using multiple satellites

*Takuto Taguchi[1], Kazuhito Ichii[1], Jingfeng Xiao[2]

1. Chiba University, 2. University of New Hampshire

The Earth’ s vegetation greenness has been increasing globally over the past few decades largely due to land-cover change, CO2 fertilization, and climate change. The forest area in China accounts for approximately 6% of the world’ s total, occupies the top ranks in terms of forest cover growth worldwide. For example, the latest national forest inventory (NFI), led by governmental organizations reported that the forest cover in China has increased from 18.21% to 22.96%, between 1999 and 2018. Even though many studies have reported that China plays a key role as dominant forest resources, there has been very little research reported on the forest cover changes except for the inventory as previously we stated. The method of this investigation has not been officially disclosed, and the reported numbers remain unclear.

In the present study, supported by the long-term datasets of land-cover and percent tree cover data from 2001-2018 based on multiple satellite datasets, we derived detailed information of the forest cover percentage over mainland China in the past 20 years. Furthermore, the validity of the data was demonstrated through intercomparing among those results with the NFI results.

Our results suggest that estimates of forest cover among five satellite datasets had their own characteristics respectively. In most datasets (expect for ESA/CCI) forest coverage increased, but the variation and distribution varied. Taken together, the results of C5 and PALSAR/PALSAR-2 are perceived to be suitable from various perspectives based on our results. However, there are several additional factors that could have contributed to the difficulties in forest cover estimates from these datasets. PALSAR/PALSAR-2, only data for 2007-2010 and 2015-2017 are available, which causes hard to estimates it continuously, even though MOIDS-derived datasets can provide data from the beginning of the 21st century. Further, regarding C5 and C6, the former is a previous version of later. As a result, C5 provides only information up to 2013 and cannot be verified in recent years. In this regard, it has been reported that a significant change in land cover classification was identified in the course of changing the algorithm from C5 to C6.

Keywords: Remote sensing, Forest cover in mainland China

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High-resolution aerosol remote sensing retrieval using Chinese High-Resolution Earth Observation Satellite I (GF-1) wide-field images (WFI) and MODIS surface products

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1. Center for Oceanic and Atmospheric Science at SUSTech (COAST), Department of Ocean Sciences and Engineering, Southern University of Science and Technology

The high-spatial-resolution aerosol retrieval algorithm using Chinese High-Resolution Earth Observation Satellite I (GF-1) wide-field images is developed, which retrieves the 1km aerosol optical depth (AOD) over China based on the red/blue surface reflectance correlations and the lookup table method. To reduce the enormous relative error caused by the constant surface reflectance relationship in the retrieval algorithm, the correlation is parameterized as a function of low, medium, and high values of normalized difference vegetation index (NDVI). Three linear relationships are simulated using MODIS BRDF-adjusted reflectance products (MCD43A4), and MODIS NDVI products are used to ascertain the value of NDVI. The retrieved AOD results are found to be highly correlated with Aerosol Robotic Network (AERONET) sunphotometer observations (R = 0.931) and MODIS AOD productions (R = 0.912 for Dark Target AOD and R = 0.895 for Deep Blue AOD). Compared with the results relying on the MODIS surface reflectance model, preliminary validation is encouraging that the method based on our updated surface reflectance assumptions successfully improved the accuracy, particularly under the clear sky background and over bright surface.

Keywords: Aerosol Optical Depth, High resolution observation, Chinese High-Resolution Earth Observation Satellite I

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Toward operational satellite monitoring of chlorophyll-a concentrations in turbid inland waters

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1. Chiba University, 2. University of Tsukuba

Inland lakes are essential fresh water resources for human populations in terms of providing multiple ecosystem services, but are encountering serious eutrophication all over the world. Accurate monitoring of chlorophyll-a concentration (Chl-a) is essential for sustainable management of inland lakes. Satellite remote sensing provides the only feasible technique for monitoring Chl-a at large scale over long-term. Nevertheless, the conventional ocean-color satellite data are not applicable for small-size inland lakes due to the course spatial resolutions. In contrast, the Sentinel-2/MSI data provide a new opportunity for monitoring water quality of global lakes owning to its high spatial resolution and plentiful band configurations. However, the current land surface reflectance product of Sentinel-2/MSI data (i.e., the L2A product) cannot always guarantee high data quality for water monitoring applications. Consequently, we developed a novel quality assurance (QA) system to screen the atmospherically corrected water-leaving reflectance for Chl-a estimation. In the proposed QA system, a simulation dataset of water-leaving reflectance was first generated to include extensively wide ranges of water constituent concentrations. Then, satellite data were remained only if the similar spectral shape can be found from the simulation dataset. Finally, the Chl-a estimation models based on the three-band index were compared between the whole match-up datasets and the screened datasets. The validation results for Lakes Inbanuma, Teganuma and Kasumigaura of Japan demonstrated that the estimation accuracy was improved with the root-mean-square-errors (RMSE) decreased from 38.3 mg/m3 to 25.7 mg/m3, and R2 increased from 0.54 to 0.69, respectively. Moreover, reasonable spatial and temporal distribution patterns were also observed for the study lakes in 2018. The results indicate that the proposed QA system has the potential for operational monitoring of Chl-a in turbid inland lakes based on the Sentinel-2 images.

Keywords: inland lakes, remote sensing, chlorophyll-a

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[E] Oral | H (Human Geosciences)：H-CG Complex & General

[H-CG21] International Comparison of Landscape Appreciation

convener:yoji aoki(Open University of Japan)

Evaluation of landscape has been developed in a variety of fields, such as geography, landscape architecture, nature protection, and some others. Landscape appreciation is a complex and sophisticated psychological phenomenon. There is no consensus among researchers on what the phenomenon of "landscape" truly is, how people physiologically and mentally experience it, which human attributes affect the perception of it, and why it is apprehended the way it is. The concept of landscape appreciation has yet to be clearly defined and there is a lack of agreement on evaluation methods, the factors that determine landscape preferences, the steps in appreciation, and so forth. This session aims to discuss the research findings of landscape evaluation in various fields, including geography, geomorphology, landscape planning, architecture, engineering, social sciences, environmental psychology, meteorology, phenology, and so on.

[HCG21-01] “The Original Landscape” of Niigata City in the Early Meiji Era (1876): from the Viewpoint of a Russian Geographer, *A. I. Voeikov*.

★Invited Papers

*Masahiro Nakatani[1] (1.none)

[HCG21-02] Recognition Structure about Japanese Garden Identity analyzed from the Incongruity Feelings of Overseas Japanese Gardens

★Invited Papers

*Liu Ming[1], Kazuhiko Nakamura[1] (1.Graduate School of Agricultural and Life Sciences, The University of Tokyo)

[HCG21-03] Perception Differences between Managers and Visitors on Landscape Changes in Urban Woodlands' Understory: A case in suburban Tokyo

*Bao Guo[1], Toru Terada[1] (1.Graduate School of Frontier Sciences, The University of Tokyo)

[HCG21-04] Consideration on the technique of landscape formation in Japanese garden

★Invited Papers

*Masayshi Kikuchi[1] (1.Tokyo Metropolitan Park Association)

[HCG21-05] **A Study on the Gugok Distribution as Current Status in Chungcheong-do and Jeolla-do　Korea**

★Invited Papers

*HyunBin Park[1,2], KeeRae Kang[3], dongpil kim[1,2] (1.The Korean Institute of Landscape Architecture, 2. Dept. of Landscape Architecture, Pusan National University, 3.Institute of Comprehensive Bio industrial, Pusan National University)

[HCG21-06] Spatial conditions related to the sublimity of the shrine forest of Meiji Jingu :Landscape evaluation of the 100-years plan forest at 100 years after afforestation

*Yusuke Mizuuchi[1], Kazuhiko W. Nakamura[1], Katsunori Furuya[2] (1.Graduate School of Agricultural and Life Sciences, The University of Tokyo, 2.Graduate School of Horticulture, Chiba University)

“The Original Landscape” of Niigata City in the Early Meiji Era (1876): from the Viewpoint of a Russian Geographer, *A. I. Voeikov*.

*Masahiro Nakatani[1]

1. none

Introduction

This report will show “the original landscape” of Niigata City in the early Meiji Era (1876), which was described by a Russian geographer and meteorologist, *Aleksandr Ivanovich Voeikov*. He came to Yokohama on July 4, 1876 (Meiji 9) and left Nagasaki on November 27. During the period, he has travelled all over Japan from Hakodate (Hokkaido) to Kagoshima (Kyushu) for only five months. After returning to Russia, *Voeikov* contributed six papers to *Izvestiia imperatorskogo russkogo geograficheskogo obshchestva* (*the Bulletin of the Imperial Russian Geographical Society*) in 1877-78. In this report I will extract and analyze the *Voeikov*’s descriptions of Niigata City (hereafter, simply Niigata).

Voeikov in Niigata

It was early in the morning on August 16, when *Voeikov* entered Niigata Prefecture and he arrived at Niigata in the evening on August 17 by jinrikisha (rickshaw) and boat. He stayed in Niigata until August 20. He mainly referred to the following three points about Niigata.

(1) “Dislike for foreigners” (Xenophobia)

When *Voeikov* arrived at Niigata, for the first time after leaving Tokyo, he encountered a “dislike for foreigners”, when he experienced the difficulty of booking an inn. *Voeikov* suggested that dislike for foreigners not only in Niigata, but also in Japan resulted from the impolite attitude of Europeans, especially British. Moreover, *Voeikov* pointed out that Niigata had no concession (kyoryûti).

(2) Maritime trade in Niigata

In 1876, Niigata had little trade with Europe, although “Niigata was one of the so-called open ports” (in Niigata the port opened to Europeans in January 1869). *Voeikov* indicated several causes of the insignificant trade with Europe in Niigata: a lack of the so-called harbor, severe weather in winter and the arrival of the Japanese mail ships (once a month) from Yokohama.

On the other hand, domestic trade was significant in Niigata. Niigata was mainly engaged in a lot of trade with Osaka. *Voeikov* described that “Niigata looked like a suburb of Osaka”, because both of cities were the typical commercial sites with many rivers, canals (moats) and bridges.

(3) The weather and temperature in Niigata

During his stay in Niigata, *Voeikov* recorded the weather and the temperature (mainly in the morning and in the evening). In those days, Europeans in Japan thought that Niigata had a cold climate because of much snow in winter. But *Voeikov* objected to their view, referring to the weather data of A. Reisner (a German merchant) and A.-R. Weber (a German consul and merchant) and comparing the vegetation in

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Niigata with that of Sendai. On the other hand, from their meteorological observation (in Summer and Winter) it is assumed that Niigata about 150 years ago was 4-5 degree cooler than today.

Conclusion

For 144 years, the landscape of Niigata has changed dramatically. The modernization and westernization of our life have brought us not only convenience and comfort, but also many problems, like global warming. We also have lost many things like “the original landscape” with canals (moats). Now it might be the time that we should rethink our modern life.

Keywords: The Original Landscape, Meiji Era, Niigata, A. I. Voeikov

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Recognition Structure about Japanese Garden Identity analyzed from the Incongruity Feelings of Overseas Japanese Gardens

*Liu Ming[1], Kazuhiko Nakamura[1]

1. Graduate School of Agricultural and Life Sciences, The University of Tokyo

When studying people's image of Japanese gardens,it is necessary to pay attention to the "recognition research",which is a study on whether a certain garden is established as a Japanese garden.As one of the methods,we tried to extract the identity of Japanese gardens from the sense of the incongruity of Japanese people feels about overseas Japanese gardens.When building a Japanese garden overseas,even if the design is made by a Japanese designer,the construction is typically made by a local team,and the garden materials used (such as plants and garden stones) are also obtained locally.That may be the reason why so many Japanese people express their feelings about the Japanese garden overseas as ‘strange or uncomfortable’.The purpose of this study is to clarify the factors and parts of gardens that cause discomfort feelings in Japanese gardens abroad and the points to focus on,and to consider the recognition structure of Japanese gardens.We designed a questionnaire to study the incongruity feelings of overseas Japanese gardens. Firstly,we picked up 13 photos from “*The report of the overseas Japanese gardens*” published by Japanese Institute of Landscape Architecture, republished in 2006 for our survey.Secondly, to clarify the reasons we design a “Statement of Reasons” from the results of our preparatory study.We have concluded the reasons form the shape of elements or the structure of a part of a garden, and the characteristics of the landscape.The questions are as follows: (1)Do you feel somehow strange of the garden in the picture as a Japanese garden? (1: Not at all, 2: Not very much, 3: Slightly felt, 4: Very felt) (2)Which part of the photo did you feel particularly strange? (up to 3) (3)Regarding the discomfort in each part, please tell us the reason by number with reference to the “Statement of Reasons” that we presented.We conduct a survey in which our questionnaire which could be collected by mail and web, is distributed at the front gate of Rikugien Garden on April 29 and May 3, 2019.We have distributed 500 questionnaires and the number of valid responses is 166.Results and Discussion:1.Verified that non-professional Japanese people do in fact have a feeling of discomfort regarding overseas Japanese gardens.2.Through correspondence analysis, 3 dimensions that showed the focus points from the aspects of ‘natural objects/artifacts’ ‘landscape features/element features’ and ‘clear/unclear boundary’ were found. Analysis within this structure suggests that the main elements are easy to see and ‘the traditional’ ‘the depth of the landscape’ ‘the fit with adjacent elements’ are important when recognizing Japanese gardens.The contrast with the surroundings of landscape elements such as color and texture is also an important part.

Keywords: Japanese Garden identity, recognition structure, overseas Japanese gardens

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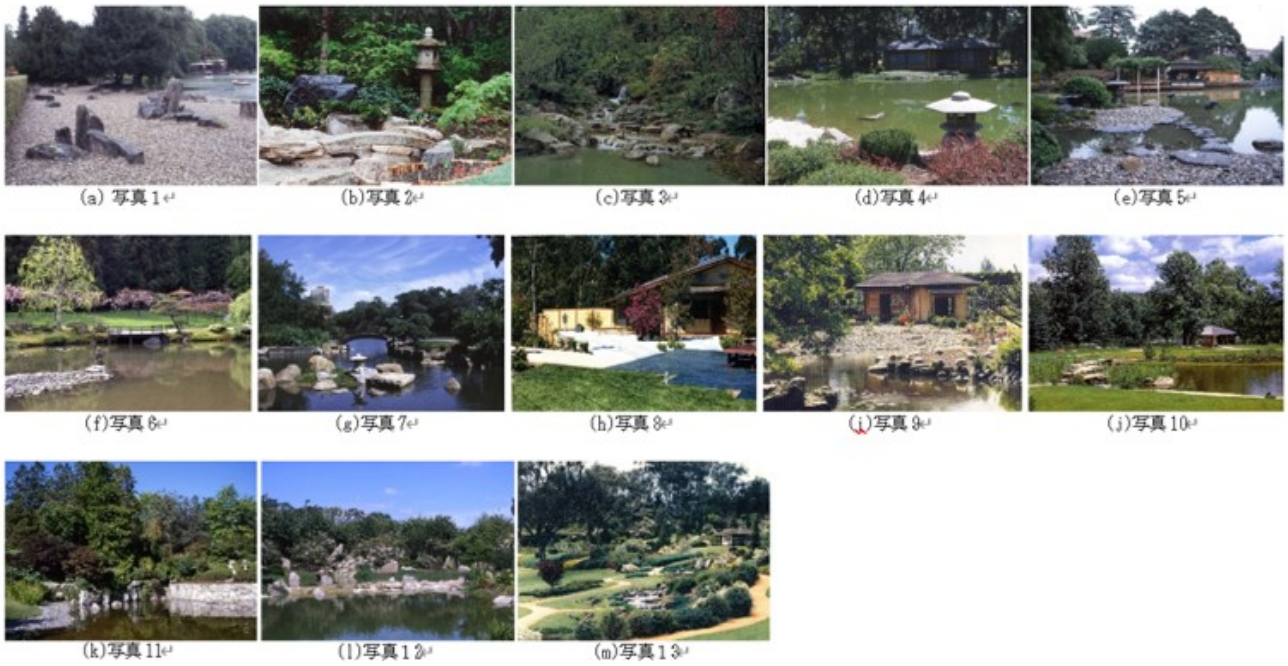

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Perception Differences between Managers and Visitors on Landscape Changes in Urban Woodlands' Understory: A case in suburban Tokyo

*Bao Guo[1], Toru Terada[1]

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1. Introduction

Urban woodlands both provide environmental benefits and increase human well-being. In Japan, the woodlands are facing problems of depletion and abandonment, due to rapid urbanization and change in lifestyle. Since the 1990s, more and more woodland conservation activities have been carried out by citizens and non-profit organizations, whose members volunteer to help manage urban woodlands.

Understory, which usually refers to small trees and shrubs, plays an important role in woodland conservation, as it is intrinsically related to biodiversity and appearance, and changes significantly through management. An improperly managed woodland results in aggressive understory species gradually taking over all the space, thereby leading to poor biodiversity, which may not be appreciated by people.

People may appreciate the same landscape differently. Such differences lead to a conflict on how woodlands should be managed, or the existing woodlands do not meet the public demand. Understanding perception helps to set up a management strategy for better conservation, to mitigate the differences so that more people can enjoy the woodlands. Although landscape changes in understory is an important aspect of woodland conservation, little is known about how different groups of people perceive such changes.

This study aims to increase understanding of people’ s perception of landscape changes in woodlands’ understory vis-à-vis management. To achieve this aim, three objectives were proposed: 1) to identify group differences in perceptions of landscape changes in understory associated with weeding; 2) to identify group differences in perceptual factors; and 3) to discuss how the factors influence group differences in perception.

2. Methodology

A sample woodland was chosen from the No.1 Neighbourhood Park in Kashiwa City, a suburb of Tokyo Metropolitan Area. A trail camera recorded landscape changes in understory before and after weeding. Three scenes documenting the changes were collected and made into time-lapse videos, A) dense vegetation before weeding; B) open woodland in the first month after weeding; and C) recovering understory in the second month after weeding.

Then, a questionnaire survey using the time-lapse videos assessed respondents' perception of landscape changes in understory, and investigated factors influencing people's perception, such as knowledge and demographics. In all, 95 valid responses were collected from managers (members of non-profit organizations managing the neighbouring woodlands) and visitors (people who have visited the study area).

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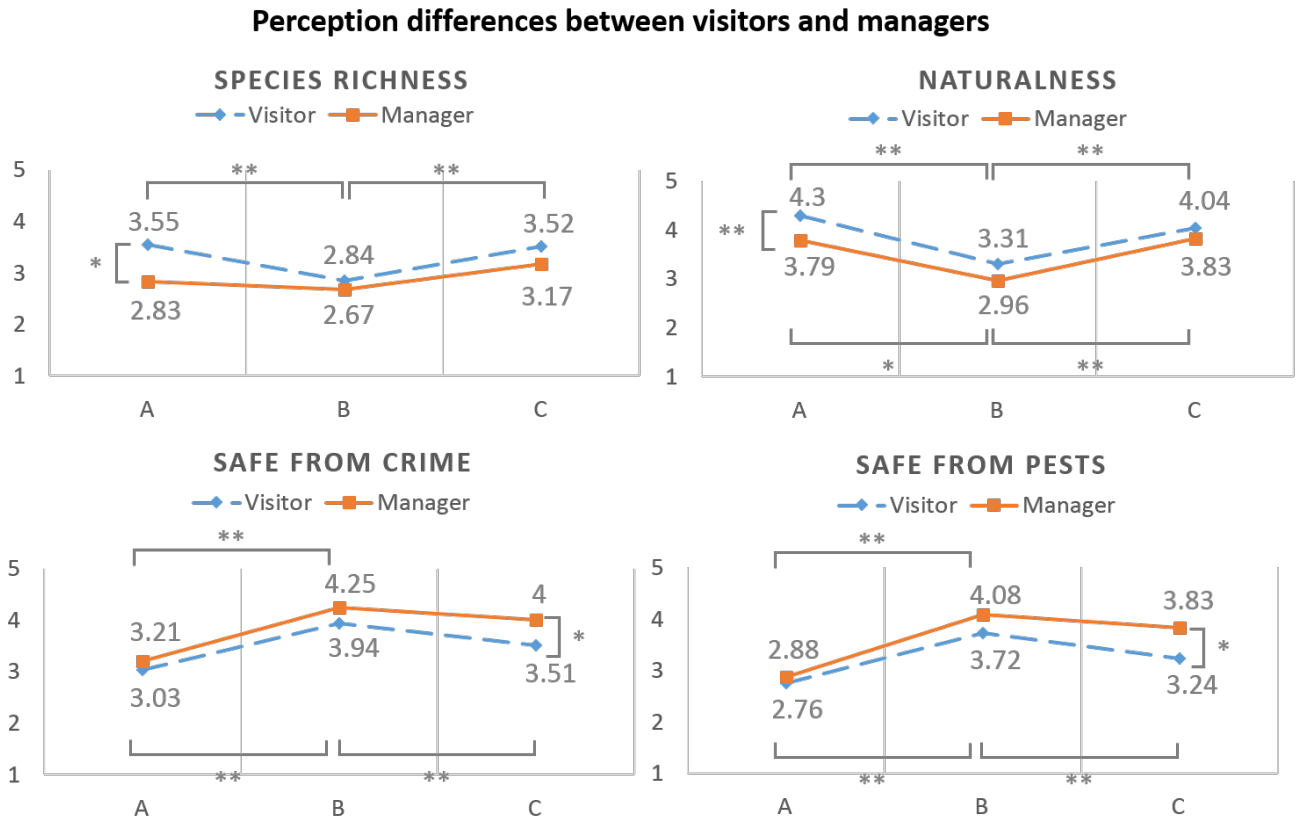
3. Results and Discussion

The results indicate that in a dense understory before weeding, visitors' perceptions of naturalness and species richness were significantly higher than those of managers. However, such differences were not found in the following two scenes. This shows that the managers distinguished between the meanings of species richness and naturalness, while the visitors did not. Such a difference suggests a possibility that certain routine woodland management; may be perceived by visitors as a loss of species richness.

The other difference of perception was found in perceived safety, including "safe from crime" and "safe from pests" when understory started to recover in the second month after weeding, where rated means of the visitor group were lower than those of the manager group. This suggests that visitors' perception of safety is more sensitive to recovering understory than managers'.

The two groups differed significantly in nature relatedness and all items of knowledge, with the manager group rating higher. Such differences could be interpreted by the different aims of visiting the woodland, the experience in it, and recreational and management activities. Influential factors differed between the groups as well. Nature relatedness was positively correlated to visitors' perception, while knowledge of species negatively influenced managers' perception.

Keywords: Urban woodland, Understory vegetation, Landscape perception, Time-lapse video



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Consideration on the technique of landscape formation in Japanese garden

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Japanese gardens have changed their form under the influence of society and culture at that time as the times change.

A pond with an island in the temple where the nobles live, and a flow that flows into the pond "Shinndenndukuri garden". A pond with an island in the temple where the nobles live, and a flow that flows into the pond "Jyoudosiki garden". "Karesansui" is a garden style that expresses the flow and the ocean with stones and sand without using water. The"Shoin-style garden" is a place where ponds and Nakajima are placed in a limited range and direction of the line of sight from the room to represent famous places in Japan.One of the most comprehensive garden styles that incorporates the traditional garden style during the Edo period was the ” K aiyuusiki Garden" where you can stroll around the pond and enjoy the changinag landscape. This is the so-called “Daimyo Garden”.With the change of the times, Japanese gardens have also created garden styles that reflect the times.However, what does not change consistently is that it is a garden that reflects the natural landscape, incorporating the natural landscape.There are several types of Japanese gardens, but the style of the garden, which captures the natural scenery in the garden, is a characteristic of Japanese gardens.
Therefore, this time, we consider how to reproduce the natural scenery in the garden, taking the case of a daimyo garden, which can be said to be a comprehensive garden style that incorporates various styles of a Japanese garden, as a case study.
The following three are considered to be the main garden techniques for forming landscapes in Japanese gardens.The first is the Syukukei" (Nature-modeling). This is a technique of pruning the tree to make it smaller while leaving it as if it were a large tree, or a method of reproducing beautiful landscapes in the garden using perspective. The second is "Syakukei"(borrowed scenery). In this method, the landscape of the garden is integrated with the natural scenery that is the background by incorporating the scenery of the distant mountains and forests into the garden. The third is a "Mitate"(model). A method to compose a landscape of a garden by comparing the hills, stone groups, trees, etc. in the garden with other objects. Japanese gardens mainly use these techniques to create landscapes in the gardens.
This time, I will examine what kind of technology the actual Japanese garden forms with the landscape using the case of Koishikawa Korakuen, a nationally designated special historic spot, and Rikugien, a nationally designated special scenic spot. It shall be.

Keywords: Landscape formation of Japanese garden, Syakkei (Borrowed scenery),
Syukukei(Nature-modeling), Daimyo garden

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A Study on the Gugok Distribution as Current Status in Chungcheong-do and Jeolla-do, Korea

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The history of introducing Korean Confucianism began with the nobility of the period of the Three states. It began with the study of ethical examples that emphasized social morality. In the Goryeo Dynasty(918~1392), Exegetics developed with an emphasis on interpreting the meaning of the scriptures.Afterwards, a new study, the Neo-Confucianism, was introduced as an alternative to Exegetics, and developed into a study that revealed the basic principles of human mind and truth, and further developed into an idea that served as the basis for the founding of Joseon by the rising nobility.

At the root of these studies were the desire to gain peace of mind through the acquisition of truth and the methodological presentation of it. One of the methodologies for these truths is the crater that awakens the truth through things. This concept includes not only the objects around us but also the extended nature and universe around us. The chinese Confucius said that it was Jija-Yosu and Inza-Yosan. It is a word that expresses the metaphor of truth that does not change like a mountain, flowing with life without rest like water.

The concept of Yosan-Yosu was organized systematically by the runners of Songdae, and as a place for practical experience of truth, we chose to live with nature. Zhuzi opened Muijeongsa in his hometown of Mui-mountain to discuss his studies, and wrote Muigugokdoga, which sang his academic achievements and pledges projected on the landscape of the surrounding by the Nine-Valley.

The influence of a runner who advocated theology in the social norms and the governing ideology of the Joseon Dynasty based on the Neo-Confucian theory served as a code of conduct for the Confucian-scholars, which made them take "schoolers" for granted. In other words, learning Zhuzi's writings and doing such actions was an act of trying to prove himself to be in a sense of consciousness and to be in the process of study. It made a number of Muigugokdo and Gugokga, and left a trace in nature.

This study was performed from May to October in 2019 to confirm 'Gugok', which has been oralized, destroyed or well preserved in the field of 'Gugok' in Chungcheong-do and Jeolla-do areas. There are 24 places of Gugok in the Chungcheong-do area that have been handed down in the region. However the number of Gugok that were confirmed this time is 6 places. including Galeun-Gugok, Seonyu-Gugok, Hwayang-Gugok, Yongsan-Gugok, Gapsa-Gugok and Bongnae-Gugok. Three places of Gugok in Jeolla-do have been handed down, and there are two places of Gugok that were confirmed this time: Cheongryu-Gugok and Yongho-Gugok.

Gugok is relatively clearly shown by the setters, and often the Gugok is set up by the moorings around the living area where they live. However, as time passed, there were not many corners that retained their old appearance due to changes in mountain streams due to changes in natural and artificial conditions, river maintenance and road extension projects, and destruction of landscapes due to urbanization.

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The study of Gugok, which began with Confucian tradition and established itself as a culture for nature, has been conducted in various fields. In the early days, it began as a field of Korean poetry and Chinese literature and Confucianism, and expanded to the fields of scenic beauty, geography, topography, and landscape architecture. Although research on the thoughts of Gugok's setters is occupied, much research has not been conducted on the identification of its location and the place where it is passed down. Therefore, this study was carried out to verify the reality through the on-site confirmation survey on the curves of Chungcheong-do region and Jeolla-do region, and it is meaningful to provide basic data on the verification of the curves of other researchers in the future.

Keywords: Neo-Confucianism, Confucian tradition

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Spatial conditions related to the sublimity of the shrine forest of Meiji Jingu :Landscape evaluation of the 100-years plan forest at 100 years after afforestation

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Meiji Jingu is a shrine which built in 1920. The shrine forest of Meiji Jingu was also afforested at the same time aimed sublime landscape scenery with an over 100-year plan, a pioneering attempt at the time using the mechanism of plant succession. Hence, the purpose of this research is to assess whether the shrine forest reached a sublime landscape and, what spatial condition let the forest sublime by on-site evaluation of landscape scenery in the year of 2020 that is target year of the forest plan. A survey composed by visitor employed photography and questionnaire was conducted at Meiji Jingu with 90 respondents using Survey 123(Esri Inc.), an application which can collect geotagged photographs The respondents were instructed to take over 10 geotagged photographs of landscapes which respondents felt sublime during walking along approach road in Meiji Jingu. Immediately after walking the site, respondents were evaluated the forest of Meiji Jingu by 17 measures and answered whether sublime or not and its reason.

951 photographs were collected, and its objects were identified by ten categories. The largest number of objects was "forest", the second was “tree” each accounted for 21.2 % and 18.2 % of the total photos. The result of GIS analysis, four popular location was identified related to spatial feature: 1) vicinity of the big torii gate of the shrine, 2) vicinity of a stream, 3) vicinity of the wine barrel buildings 4) vicinity of the main shrine buildings. The result of questionnaire showed, 98.9 % of respondent felt sublime to the shrine forest of Meiji Jingu. The largest number of the reason was “tree height” and, the second was “tree density”, each accounted for 40.0 % and 24.4 % of the total respondents.

As a result, it became clear that one hundred years have passed since the shrine forest had afforested it evaluated as a sublime forest from respondents in the current era. Height of crown trees which had planted hundred years ago have reached over 25m height, tree height affected to sublimity of the forest. The shrine forest plan had aimed dense and dark forest by multi-storied forest management, tree density affected to the evaluation as well. The sublimity of Meiji Jingu is composed not only shrine buildings, but also forest is a rather important role. These were beneficial knowledges to develop the shrine forest of Meiji Jingu and its management.

Keywords: shrine forest, GNSS, GIS, Meiji Jingu

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[E] Oral | H (Human Geosciences)：H-CG Complex & General

[H-CG23] Earth surface processes related to deposition, erosion and sediment transport

convener:Koji Seike(Geological Survey of Japan, AIST), Masayuki Ikeda(University of Tokyo), Hideko Takayanagi(Institute of Geology and Paleontology, Graduate School of Science, Tohoku University), Hajime Naruse(Department of Geology and Mineralogy, Graduate School of Science, Kyoto University)

To understand landscape evolution and dynamics of erosion, transport and sedimentation of earth-surface materials, the latest results of multiple research fields including engineering and earth sciences will be presented. As well as any researches of sedimentology and sedimentary petrology, interaction between fluid, sediments and geomorphology is focused. Interdisciplinary discussions of science, disaster prevention and resource exploration will be expected.

Introduction

[HCG23-01] Formation of Large Blocked-Valley Lakes by Holocene Sea Level Rise: Poyang and Dongting Lakes, China

★Invited Papers

*Gary Parker[1], Chenge An[2], Li Zhang[2], Hongwei Fang[2], Xudong Fu[2] (1.University of Illinois at Urbana Champaign, 2.Tsinghua University)

[HCG23-02] Evolution of a Mixed Bedrock-Alluvial Canyon Incising into an Uplifting Plateau and Debouching into a Subsiding Valley: Linked Knickpoint Migration and Valley Fill

Li Zhang[1], *Gary Parker[2] (1.Tsinghua University, 2.University of Illinois Urbana-Champaign)

[HCG23-04] Detrital Zircon and Provenance Analysis of Sedimentary Rock in the Nemuro and Urahoro Groups, Eastern Hokkaido, Northern Japan.

*Harisma Harisma[1], Hajime Naruse[1] (1.Department of Geology and Mineralogy, Graduate School of Science, Kyoto University)

Discussion

Formation of Large Blocked-Valley Lakes by Holocene Sea Level Rise: Poyang and Dongting Lakes, China

*Gary Parker[1], Chenge An[2], Li Zhang[2], Hongwei Fang[2], Xudong Fu[2]

1. University of Illinois at Urbana Champaign, 2. Tsinghua University

Poyang and Dongting Lakes are the first and second largest freshwater lakes entirely within China. Surface areas fluctuate strongly, but fall in the range 2700 ~ 3206 km2. The lakes are directly connected to the Changjiang (Yangtze) River, the largest river in China, which until the construction of the Three Gorges Dam carried a sediment load of about 400 Mt/a. Here we address the question as to why these lakes exist. Based on experience in the Fly River Basin, Papua New Guinea and the Amazon Basin, Brazil, it appears highly likely that these are blocked valley lakes. The period of 120 m of rapid Holocene sea level rise at the end of the last glaciation forced the Changjiang, Fly and Amazon Rivers into aggradation. These rivers are sourced in uplands, and had enough sediment to fill the accommodation space created by water surface rise. In the case of the Fly and Amazon, however, many of the tributaries are sourced in the lowlands, and did not have enough sediment supply to fill the accommodation space created by main-stem water surface rise. The main stem thus blocked the tributaries, creating extensive lakes. We apply this line of thinking to Poyang and Dongting Lakes. We offer a morphodynamic model that contains two dimensionless numbers, one capturing the threshold rate of main-stem water surface rise for lake formation, and the other capturing the amount of time for lake formation. We apply the model to the Changjiang River using field numbers. We offer appropriate generalizations for the future.

Keywords: large river, blocked valley lake, sea level rise

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Evolution of a Mixed Bedrock-Alluvial Canyon Incising into an Uplifting Plateau and Debouching into a Subsiding Valley: Linked Knickpoint Migration and Valley Fill

Li Zhang[1], *Gary Parker[2]

1. Tsinghua University, 2. University of Illinois Urbana-Champaign

Arid, tectonically active regions such as the Basin and Range Province of the western United States are often riddled with normal faults. These normal faults are associated with tablelands undergoing (relative) uplift, adjacent to valleys undergoing (relative) subsidence. These conditions in turn foster the formation of canyons incising into the tablelands. These canyons receive some of their sediment from the tableland upstream of a well-defined knickpoint, and some from the collapse of the canyon walls themselves. Here we treat canyon-valley evolution using a formulation that can smoothly handle transitions between purely alluvial reaches and bedrock-alluvial reaches. We model bedrock incision in terms of wear due to collision of bedrock particles, and capture knickpoint migration using a moving-boundary formulation. Our model captures tableland uplift, canyon incision, failure of canyon walls, and the transition to pure deposition in the downstream subsiding basin, in a symphonic interaction of different parts of the landscape.

Keywords: canyon, bedrock, uplift, subsidence

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Detrital Zircon and Provenance Analysis of Sedimentary Rock in the Nemuro and Urahoro Groups, Eastern Hokkaido, Northern Japan.

*Harisma Harisma[1], Hajime Naruse[1]

1. Department of Geology and Mineralogy, Graduate School of Science, Kyoto University

This study aims to examine development processes of the Cretaceous to Paleogene sedimentary basins in collisional zone between the North East Japan and Kuril Arc systems on the basis of the U-Pb age distribution of detrital zircon grains in sandstones. The study area is located in the eastern part of Hokkaido Island, a part of the Nemuro Belt, which has been interpreted as a complex of deposits of forearc and foreland basins. Recently, paleomagnetic analysis suggested that the Nemuro Belt complex records collisional process associated with block rotation that driven by tectonic activity. This tectonic event is likely to cause uplifting of colliding arc crusts, and thus sediment provenance analysis in the depositional sequences of the Nemuro Belt will provide information about the exact timing and mode of the collision of two arc systems. For this purpose, this study investigated the Nemuro and Urahoro Groups that are well exposed in the Nemuro Belt complex area.

Fifty five samples of sandstones were collected from outcrops. Detrital zircons were separated using standard mineral separation techniques at the Kyoto University. Approximately 200 grains were mounted for each samples, and their U-Pb age was measured by LA-ICP-MS (*Laser Ablation Inductively Coupled Plasma Mass Spectrometry*) to estimate temporal variation of sediment provenances. The result of this study contribute to understand the tectonic history of two arc collisions through constrain the analysis of sediment provenances.

Keywords: Nemuro Group, Sandstone, Urahoro Group, U-Pb dating, Zircon

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DETRITAL ZIRCON AND PROVENANCE ANALYSIS OF SEDIMENTARY ROCK IN THE NEMURO AND URAHORO GROUPS, EASTERN HOKKAIDO, NORTHERN JAPAN.

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This study aims to examine development processes of the Cretaceous to Paleogene sedimentary basins in collisional zone between the North East Japan and Kuril Arc systems on the basis of the U-Pb age distribution of detrital zircon grains in sandstones. The study area is located in the eastern part of Hokkaido Island, a part of the Nemuro Belt, which has been interpreted as a complex of deposits of forearc and foreland basins. Recently, paleomagnetic analysis suggested that the Nemuro Belt complex records collisional process associated with block rotation that driven by tectonic activity. This tectonic event is likely to cause uplifting of colliding arc crusts, and thus sediment provenance analysis in the depositional sequences of the Nemuro Belt will provide information about the exact timing and mode of the collision of two arc systems. For this purpose, this study investigated the Nemuro and Urahoro Groups that are well exposed in the Nemuro Belt complex area.

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Keywords: Nemuro Group, Sandstone, Urahoro Group, U-Pb dating, Zircon

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[E] Oral | H (Human Geosciences)：H-CG Complex & General

[H-CG23] Earth surface processes related to deposition, erosion and sediment transport

convener:Koji Seike(Geological Survey of Japan, AIST), Masayuki Ikeda(University of Tokyo), Hideko Takayanagi(Institute of Geology and Paleontology, Graduate School of Science, Tohoku University), Hajime Naruse(Department of Geology and Mineralogy, Graduate School of Science, Kyoto University)

To understand landscape evolution and dynamics of erosion, transport and sedimentation of earth-surface materials, the latest results of multiple research fields including engineering and earth sciences will be presented. As well as any researches of sedimentology and sedimentary petrology, interaction between fluid, sediments and geomorphology is focused. Interdisciplinary discussions of science, disaster prevention and resource exploration will be expected.

[HCG23-05] Spatio-temporal changes in sedimentation rate and its impact on overpressure evolution in offshore Suriname

*Nifuku Ko[1], Yuki Kobayashi[1], Yasuhiko Araki[1], Takafumi Ashida[1], Takashi Taniwaki[1] (1.INPEX Corporation)

[HCG23-06] Spatial–temporal evolution of blowout on the southeastern fringe of Otindag sandy land in recent decade

*Rina Hu[1], eerdun Hasi[1], jie Yin[1] (1.Beijing Normal university)

[HCG23-07] Can Superoxide Nanobubbles Inhibit the Release of Phosphorus from Reservoir with Stagnant Water?

*Qingqing Sun[1], Siliang Li[1], Jingfu Wang[2], Pingping Yu[3] (1.Institute of Surface-Earth System Science, Tianjin University, 2.State Key Laboratory of Environmental Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, 3.Zunyi City Drainage Limited Liability Company)

[HCG23-08] Short to long term morphological changes and migration of sand waves in a semi-enclosed sea: a case study in Okinose area of Osaka Bay

Kojima Hibiki[1], *Atsushi Tani[1], Tetsuo Matsuno[2,3], Mamoru Sano[2], Nobukazu Seama[3,2], Noritaka Endo[4], Ken'ichi Ohkushi[1], Xu Zhang[5], Yusuke Uchiyama[5] (1.Graduate School of Human Development and Environment, Kobe University, 2.Kobe Ocean Bottom Exploration Center (KOBEC), Kobe University, 3.Graduate School of Science, Kobe University, 4.School of Geoscience and Civil Engineering College of Science and Engineering, Kanazawa University, 5.Graduate School of Engineering, Kobe University)

[HCG23-09] Heavy mineral assemblage of river sands along the Kaligandaki River, central Nepal and its application for Bengal Fan sediments

*Kohki Yoshida[1], Nakajima Toru[3], Lalit Kumar Rai[2], Asako Masuda[4] (1.Department of Geology, Faculty of Science, Shinshu University, 2.Graduate School of Medicine, Science and Technology, Shinshu University, 3.Graduate School of Science, Kyoto University, 4.Graduate School of Science and Technology, Shinshu University)

[HCG23-10] Spatial variability of grain size parameters and depositional process in the coastal marshland of Orissa, India

*Koushik Saha[1,2], Subhajit Sinha[1] (1.Department of Geology, University of Calcutta, 35 Ballygunge Circular Road, Kolkata-700019, India, 2.Department of Geology, University of North Bengal,Raja Rammohunpur, West Bengal 734014, India)

Spatio-temporal changes in sedimentation rate and its impact on overpressure evolution in offshore Suriname

*Nifuku Ko[1], Yuki Kobayashi[1], Yasuhiko Araki[1], Takafumi Ashida[1], Takashi Taniwaki[1]

1. INPEX Corporation

Overpressure has been recognized in many sedimentary basins around the world. Various geological processes have been proposed as mechanisms capable of generating overpressure conditions. However, many of them seem to be closely related to sedimentary processes in a basin. An increase of total stress by sediment loading leads overpressure formation by disequilibrium compaction (insufficient dewatering during sedimentation). Progress of sedimentation also results in heating of underlying strata, which induces geochemical reactions and overpressure generation by fluid expansion (an increase in the fluid mass in the pore space of a deposit). Previous research showed complex overpressure evolution in sedimentary basins in response to changes in sedimentation. However, overpressure evolution and the range of causal mechanisms has not been extensively compared with a full context of the spatio-temporal characteristics of the depositional history of an area.

The present study investigated the spatial and temporal changes in sedimentation rate and its relation to the overpressure evolution in the passive continental margin of offshore Suriname. This study conducted well data analysis to estimate the relevant overpressure-generating mechanisms. Three-dimensional basin modeling was subsequently performed to reconstruct overpressure evolution in the area. The results indicated that the temporal variation of sedimentation rate resulted in cycles of overpressure generation and dissipation in the region. Overpressure was generated during periods of high sedimentation, and it was released during the period of quiescent sedimentation. The spatial changes in sedimentation rate caused lateral changes in overpressure, with greater overpressure being produced in areas with higher sedimentation rate. Disequilibrium compaction generated larger overpressure in the area of higher sedimentation rate, due to faster increasing rate of sediment load. Fluid expansion produced additional overpressure in the deeper section beneath the high sedimentation area. Hydrocarbon generation played the secondary role in overpressure formation in such area, with minor contribution from dehydration during smectite-to-illte formation. As a result, significant overpressure develops beneath the depocenter by a combination of multiple overpressure-forming mechanisms.

The present study revealed that a single controlling factor (i.e., sedimentation rate) mainly caused the complex overpressure history and its lateral variations in offshore Suriname. This study gives an insight into overpressure evolution in other sedimentary basins, especially in the mud-dominated regions without the influence of major tectonic compression, by providing a viewpoint of the spatio-temporal variation of sedimentation rate and its impact on overpressure formation.

Keywords: Sedimentation rate, Pore pressure, Overpressure, Passive margin, Basin modeling

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Spatial–temporal evolution of blowout on the southeastern fringe of Otindag sandy land in recent decade

*Rina Hu[1], eerdun Hasi[1], jie Yin[1]

1. Beijing Normal university

In Otindag sandy land, the activation of stabilized sand dunes caused by climate change and human activities is the main reason of the development of desertification, and the activation of stabilized sand dunes is main manifested by the formation and evolution of blowouts. This paper explores historical evolution of blowouts in Otindag sandy land —a site that hosts a large number of active and stabilized blowouts. The multi-period high-resolution image data is applied to extract patterns of morphometric changes in erosional deflation basins. Blowout development in Otindag sandy land is characterized by several geometric and movement, including: i) generation, ii) extension, iii) union. Between 2010 and 2019, the area of blowout increased by 6.47hm^2 from 2010 to 2013. During 2013-2016, the area increased by 4.89hm^2, following by the next three years, it continued growing by 3.04hm^2. With little disturbance of human activity, the growth of blowouts in this area is largely affected by the change of climate factors. As the dynamic factor of blowouts, the reduction in sand drift potential, only decreases the development rate and slows down the process. The shapes of the blowout themselves also work as the main influencing factor.

Keywords: Blowout, Drift Potential, Otindag Sandy Land

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Can Superoxide Nanobubbles Inhibit the Release of Phosphorus from Reservoir with Stagnant Water?

*Qingqing Sun[1], Siliang Li[1], Jingfu Wang[2], Pingping Yu[3]

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Natural mineral materials (a) Calcined Organobentonite (450℃, 9.5h), (b) Organobentonite, sieving 2000 mesh, (c) Kaolinite, sieving 6000 mesh, (d)Talc Powder, sieving 5000 mesh, (f)Sericite, sieving 3000 mesh, (g) Silicone microbeads, sieving 3000 mesh, (h) biological material, Calcined Oyster Powder were firstly selected as nanobubble carriers. Then methanol, ultrapure water, and oxygen were used to generate nanobubbles. The miniature devices were used to simulate the inhibiting effect of the above agents on the sediment-water interface, and were 40 cm high, with an outer diameter of 6.5 cm. The sediment inside the simulators was 6 cm high and the lake water was 28 cm high. The sediment was collected from the front of the Dam of Hongfeng Lake. The nanobubble inactivation agents were added to the simulators and precipitated for 24 hours to form stable sediment-water interfaces as the experimental group, which was monitored continuously for 30 days and a control group (without any inactivation agents) was synchronously monitored. PO_4^{3-} -P concentrations were measured in the 21 out of 30 days. Fe^{2+}, NO_2^- -N, NH_4^+ -N contents were measured during the first 7 days. Oxidation-Reduction Potential (ORP), dissolved oxygen (DO), pH and water temperature were also measured. V, Cr, As, Se, Mo, Sb, W, Cu, Cd, Co, Ni, Pb, Zn, P, Mn and Fe in overlying water, pore water, and sediment only were monitored twice in primary sediment cores on the 0 day (without inactivation agents) and the final ones on the 30th day (with inactivation agents). Combined with the changes in phosphorus and heavy metal morphology in sediment before and after the simulation experiments, these experimental results show that (f) sericite has a better effect. Constrained by the small-scale of the exploratory simulation experiment, larger simulation experiments need to be conducted, and more demonstration work with new efficient materials and preparation methods need to be applied to the actual lake management.
Hongfeng Lake Reservoir (E106˚20'10"~106˚27'00", N26˚24'37"~26˚34'17"), a river-type and Phosphorus(P) limited reservoir in canyon rift basin, was built in 1960. Due to the domestic, industrial and agricultural pollution being discharged into the reservoir from 1988 to 2009, especially phosphogypsum piled up of phosphate fertilizer industry, environmental pollution incidents occurred frequently: dead fish incident in cages in 1994 and 1998, periodic black water in 1995, high arsenic pyrite acid wastewater pollution and blue-green algae eruption in 1996, *Aphanizomenon* bloom in 1998, and multiple algae outbreaks in 2006, 2007 and 2008. As a source of drinking water in Guiyang City, China, although exogenous pollution is well controlled and water quality is improving in the last decade, there is still a risk of secondary release. Refer to previous studies, the two-end member mixing model of $\delta^{18}O_P$, the diffusive models of the diffusive gradient in thin films (DGT) technique and the sediment core incubation method, the relative contribution of internal P released from sediments even reached 35.7%~59%. The main P forms of surface sediment also changed from organic P and Fe-P (80%~88%) to NaOH-P (Fe, Al-P) and Rest-P (67%~77%). According to the Bayesian modeling of $\delta^{18}O\text{-}NO_3$ and $\delta^{15}N\text{-}NO_3$, the relative contribution of endogenous modified nitrogen (N) source (denitrification) released from sediments reached 24~38%. Especially in the stratification period (from March to August), the bottom water is anaerobic, and the release fluxes from the sediment are higher. The degradation of organic N and denitrification are closely related to the early mineralization of P. The above facts highlight the influence of the internal P and N on water eutrophication and the necessity to control the internal P pollution. Due

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to the discharge of acidic coal mine wastewater near the reservoir, the release fluxes of heavy metals also cause concern, especially for geochemical cycles in which these elements are coupled with P. On 24 July 2019, sediment cores from the center of the north lake (A), Dam(B), Huayudong(C), water-intake of Xijiao Water Plant (D), Houwu(E) and hydro-fluctuation belt(F) in the shore near Xijiao Water Plant were collected. The P(V), NH_4-N and NO_3-N, and mean Fe(II), Mn(II), Zn(II), Pb(II), As (V) fluxes were (0.041~0.136) nmol·cm^{-2}·s^{-1}, (0.39~8.98) ×10^{-3} nmol·cm^{-2}·s^{-1}, (0.046~5.10)×10^{-3} nmol·cm^{-2}·s^{-1}, 2.20×10^{-3} nmol·cm^{-2}·s^{-1}, 3.67×10^{-4}nmol·cm^{-2}·s^{-1}, 3.04×10^{-5} nmol·cm^{-2}·s^{-1}, 2.04×10^{-5} nmol·cm^{-2}·s^{-1}, 4.53×10^{-6} cm^{-2}·s^{-1} in sediment-water interfaces respectively, and monitored by DGT.

Keywords: superoxide Nanobubbles, phosphorus, diffusive gradient in thin-films technique, sediment-water interface

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Short to long term morphological changes and migration of sand waves in a semi-enclosed sea: a case study in Okinose area of Osaka Bay

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Sand waves are small-scaled topography of unconsolidated sand particles on seafloor or river bottom formed by water flow, and of wavelengths from a few meters to several hundreds of meters. Because of morphological changes and migration of sand waves by water flow, repeated surveys are required to observe short to long term behavior of sand waves. In the areas where oceanic current is dominant, sand waves migrate along the direction of oceanic current. In contrast, in the areas where tidal current is dominant, it is not easy to detect the relationship between morphological changes/migration of sand waves and the water flow near the seafloor, because velocity and direction of the water flow near the seafloor change gradually and complicatedly in the natural condition (Xu et al., 2008). In recent years, oceanic modeling system have been developed significantly and the water flow has been simulated with fine grid spacing for a long time and over a wide area especially in the case that the water flow into and out of the survey area is restricted such as bays (Uchiyama et al., 2018). Osaka Bay, where tidal current is dominant, has shallow eastern area (5-20 m in depth) and deep western area (20-70 m). A submarine dune is found in Okinose area apart from ~12 km southeast of the Akashi Strait, where the water depth is 25-45 m and shallower than the surrounding area (Yashima, 1992). On the sand dune of Okinose, sand waves with a wavelength of 20-100 m has been observed. In this study, focusing on the sand waves in Okinose as a model case where tidal current was dominant, we combined multiple topographic surveys with numerical simulations of the water flow near the seafloor to elucidate short to long term morphological changes and migration of the sand waves formed in a semi-enclosed sea and to discuss the mechanism.

Multiple surveys for submarine topography were conducted from September 2017 to October 2019 with the training ship Fukae Maru (Graduate School of Maritime Sciences, Kobe University) using MBES (Multi-Narrow Beam Echo Sounder), CTD (Conductivity Temperature Depth profiler) and a grab type mud sampler. The water flow near the sea floor in Osaka Bay was numerically simulated using the multi-nested high-resolution 3-D circulation-dispersal model developed by Uchiyama et al., (2018).

The distribution of the sand waves on the sand dune of Okinose shows that the crest lines of the sand waves extend from west-northwest (WNW) to east-southeast (ESE). Ikehara (1996) suggested that crest lines of sand waves were perpendicular to the water flow in the case that the current directions at the maximum flood tide and ebb tide are 180 degrees opposite. The numerical simulations of the water flow near the seafloor show that the current direction at the maximum flood tide is north-northwest (NNW) and the current direction at the maximum ebb tide is south-southeast (SSE) in the northwestern part of Okinose. It means that the crest line orientation of the sand waves was not perpendicular to the current directions at the maximum flood tide and ebb tide. Considering the average size (~0.65 mm) of the particles obtained from the sand sample and the water depth in the northwestern part of Okinose (25-45

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m), water flow velocity to change sand waves morphologically is estimated to be at least 0.1 m/s (Rubin & McCulloch, 1980). By averaging the velocity through high pass filtering at 0.1 m/s, the direction of the mean velocity was south-southwest (SSW) and perpendicular to crest lines of the sand waves. Therefore, we conclude that in the area where the currents at the maximum flood and ebb tides are not 180 degrees opposite, short to long term morphological changes and migration of the sand waves reflect the temporally-averaged tidal currents over the critical velocity for sediment movement. In the presentation, we will discuss them together with observation of short-term morphological changes of the sand waves other than crest lines within two years.

Keywords: sand wave, Osaka Bay, morphological changes

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Heavy mineral assemblage of river sands along the Kaligandaki River, central Nepal and its application for Bengal Fan sediments

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The Bengal fan is the widest submarine fan in the world and was formed as a direct result of Himalaya by the Asia and Indian continental collision from the early part of the Cenozoic era. The huge amount of detritus from Himalaya was carried into the Indian Ocean by Ganges and Brahmaputra rivers. The International Ocean Drilling Program (IODP) Expedition 354 Bengal Fan provides the data set of the erosional history of Himalaya from Early Miocene to present days. We examined the heavy mineral assemblage and chemical composition of specific minerals in the river sediments in the Himalayan river and compared it to Bengal Fan deposits in order to clarify the provenance history recorded in the Bengal Fan deposits. The heavy minerals in modern river sediments are taken from the Kari Gandaki river-tributaries, in central Nepal.

The assemblage of heavy minerals in Kari Gandaki river tributaries clearly reflected the rock assemblage distributed in the catchment. The tributaries from the catchment area of the Tethys Himalaya zone shed ultra-stable minerals, such as zircon, tourmaline and rutile. The High Himalayan Crystalline zone provided metamorphic minerals, such as amphibole, sillimanite, kyanite, staurolite. The catchment consists of the Main Central Thrust zone (MCT zone) and the Lesser Himalayan zone carried the mica-rich detritus with oxidized iron minerals and amphiboles.

The detrital garnet compositions are also depending to geological units distributed in the catchment area; Tethys Himalaya area derives mainly almandine (Mg<20 mol %) garnets, whereas High Himalaya Crystalline produces Mg-rich (Mg>20 mol %) almandine garnets with specific amount of Ca-rich (Ca>20 mol %) almandine derived from calculous gneiss.

Comparison with Bengal Fan sediments which recovered in IODP Exp. 354, sillimanite and kyanite were found from Early Miocene sediments. The detrital amphiboles dramatically increased from the Middle Miocene (13 Ma), which is suggestive to initial major uplift of High Himalaya Crystalline started from this period. In addition, though Mg-rich garnets are minor components until the Early Miocene time, those are clearly increased from Late Miocene time (9.2 Ma). Several compositional fluctuations were detected in the Middle and Late Miocene sections in Bengal Fan sediments, above described compositional change, which is irreversible in the historical record of detrital garnet chemistry, suggests several stages of major uplift of the Himalaya during Miocene time.

Keywords: Miocene, Himalaya, Bengal Fan

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Spatial variability of grain size parameters and depositional process in the coastal marshland of Orissa, India

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Spatial variability of bulk sediment properties enable us to understand the textural characteristics of sediments and decipher the sediment transport process. In the present study, grain sizes were measured from surface sediments collected in the tropical marshland of Chandipur, Orissa. Particle size analysis was performed on all sub-samples using a Horiba Partica mini LA-350 laser granulometer. Grain size distribution analysis was conducted for identification of sedimentary transport behaviours with different textural parameters such as mean, sorting, skewness, and kurtosis. CM diagram (C = one percentile in micron, M = median in micron) describes the mechanism of sediment deposition on the marsh happened from uniform, graded suspension and some amount of bottom suspension and rolling. End-member modelling analysis helps to unmix the grain sizes into six geologically meaningful populations. Six grain size end members corresponds to clay, silty clay, clay silt,silt,sandy silt and silty sand. These particle size distributions are influenced by sediment transport and depositional processes. Particle size analysis has been used to identify variation in the hydrodynamic processes of marsh environments. The lower saltmarsh is characterized by dominantly ‘fast tide’ Particle size distribution which indicates a relatively coarse grained, moderately sorted, fine-skewed, meso-to leptokurtic distribution. But, the uppermost saltmarsh deposits shows a relatively fine grained, poorly sorted, near symmetrical, meso- to platykurtic Particle size distribution. The regions near the tidal flat and lower marshland is relatively coarse grained and dominated by deposition through saltation and traction whereas the mean grain size becomes finer towards the eastern side of the marshland controlled by suspension and settling population.

Keywords: Marsh, Grain size distribution, End member modelling analysis, Laser granulometry

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[E] Oral | H (Human Geosciences)：H-CG Complex & General

[H-CG24] Enhancing Integrated Research for Sustainable Future - a human geoscience perspective

convener:Yukio Himiyama(Emeritus Professor, Hokkaido University of Education), Takeshi Sakurai(Graduate School of Agricultural and Life Sciences, The University of Tokyo), Akihiko Kondoh(Center for Environmental Remote Sensing, Chiba University)

Global environmental programmes have been re-structured under the framework of Future Earth, and Future Earth is playing increasingly important role in guiding and coordinating research for the world sustainability, and in contributing to the United Nation's Sustainable Development Goals (SDGs), which has also been impressively successful in mobilizing and leading the society to the more sustainable paths at global, regional, national and local levels. Human geoscience, which has been built on geoscience which studies dynamic nature and phenomena of the Earth including lithosphere, hydrosphere, atmosphere and biosphere, is uniquely committed to human sphere, where human and its various activities, the environment, global environmental problems and disasters all exist and human dimensions of global change is of primary importance, and hence assumes important roles in Future Earth, SDGs, and other programmes for global sustainability or disaster risk reduction. This session relates to all these, and is intended to discuss crucial issues related with them and to seek right ways to implement needed integrated research for sustainable future in human geoscience perspective.

[HCG24-01] Enhancing Integrated Research for Sustainable Future - a human geoscience perspective

*Yukio Himiyama[1] (1.Emeritus Professor, Hokkaido University of Education)

[HCG24-02] Comprehensive research for land system science towards sustainable land management in Asia

*Okuro Toshiya[1] (1.Graduate School of Agricultural and Life Sciences, The University of Tokyo)

[HCG24-03] KLaSiCa Workshop to connect rural landscape in Asia through theater

*Ken-ichi Abe[1] (1.Research Institute for Humanity and Nature)

[HCG24-04] Do the Rich Suffer Less Damage from a Natural Hazard? A Case of the 2015 Nepal Earthquake

*Sato Takeshi[1], Santosh Rayamajhi[2], Tachibana Towa[3], Takeshi Sakurai[1] (1.Graduate School of Agricultural and Life Sciences, The University of Tokyo , 2.Institute of Forestry, Tribhuvan University, 3.Graduate School of Social Sciences, Chiba University)

[HCG24-05] **Assessment of regional eco-environmental vulnerabilities - - -A case study in Mongolia**

*Qinxue Wang[1] (1.National Institute for Environmental Studies)

Enhancing Integrated Research for Sustainable Future - a human geoscience perspective

*Yukio Himiyama[1]

1. Emeritus Professor, Hokkaido University of Education

Global environmental programmes have been re-structured under the framework of Future Earth, and Future Earth is playing increasingly important role in guiding and coordinating research for the world sustainability, and in contributing to the United Nation's Sustainable Development Goals (SDGs), which has also been impressively successful in mobilizing and leading the society to the more sustainable paths at global, regional, national and local levels. Human geoscience, which has been built on geoscience which studies dynamic nature and phenomena of the Earth including lithosphere, hydrosphere, atmosphere and biosphere, is uniquely committed to human sphere, where human and its various activities, the environment, global environmental problems and disasters all exist and human dimensions of global change is of primary importance, and hence assumes important roles in Future Earth, SDGs, and other programmes for global sustainability or disaster risk reduction. This session relates to all these, and is intended to discuss crucial issues related with them and to seek right ways to implement needed integrated research for sustainable future in human geoscience perspective.

Keywords: Future Earth, SDGs, Human Geoscience, Sustainability, Global Environmental Problem

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Comprehensive research for land system science towards sustainable land management in Asia

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Terrestrial land systems are now undergoing unprecedented levels of environmental modification by human activities, causing environmental problems at various scales. Especially in Asia, where 60% of the total population is concentrated, rapid population growth and economic growth have led to environmental disturbances and excessive resource use, while new social problems such as aging and declining population have emerged. Various problems are progressing at the same time, and a comprehensive solution for them is required. In order to solve the complex environmental problems that occur in the terrestrial land systems and realize a sustainable society, it is essential to understand terrestrial land systems through an approach that integrates social and natural sciences, based on a recognition that terrestrial land system is regarded as an interaction system between human and environmental systems (coupled human-environment system).
Research plan titled "Comprehensive Research for Sustainable Land System and Land Use in Asia", proposed by Global Land Programme (GLP) Japan Office and related communities, has been recently approved as one of Large Scale Research Project in Master Plan 2020 announced by Science Council of Japan. This project aims for elucidating and predicting terrestrial land system changes caused by land use and land cover change, and developing control methods for improving sustainability and efficient use of land resources through the integrated approach of land systems science. This project consists of three parts as follows; (1) to develop a Data Center for collecting, managing, analyzing, and publishing basic information regarding the coupled human-environment system, and a Knowledge Integration Center that promotes integration of outcomes, (2) to promote regional researches on biodiversity and ecosystem services, reduction of extreme weather phenomena and disaster risks, nitrogen cycle and sustainable resource use, urban and rural sustainability in the Asian region, and develop global discussions through understanding of Asian regions and relationships with other regions, and (3) to develop a program of education for sustainable development (ESD) for researchers, educators, citizens, and elementary and junior high schools and high schools as a framework to guarantee the promotion of ongoing activities and the social implementation of the outcomes in the future on a scale of Japan and Asia, and build a research and information network to promote collaboration among various stakeholders involved in policy making including researchers.
This paper introduces backgrounds and outlines of the project, related case studies in the Northeast Asia, and proposes future perspectives of researches and education which should be further developed, and implication to SDGs.

Keywords: social-ecologcial system, sustainable land management, biodiversity, ecosystem functioning

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KLaSiCa Workshop to connect rural landscape in Asia through theater

*Ken-ichi Abe[1]

1. Research Institute for Humanity and Nature

KLaSiCa, Knowledge, Learning, and Societal Change Alliance, is an international environmental education program to identify the conditions and factors that foster or impede societal transformations towards a sustainable way of life. The program will also study the capacity of social learning - a process that facilitates mutual learning between researchers and actors - to motivate and guide collective action. Engaged with the issue through the lenses of the social and natural sciences, arts, and humanities, the focus of this program lies in developing strategies for societal transformations that are underpinned by evidence-based research and theory.

Under this concept and aim of KLaSiCa, the workshop entitled “Reclaiming the Joys of Agriculture through Theatre: Connecting Rural Landscapes in Asia” was carried out in three countries, Japan, East Timor and the Philippines. This workshop aims to understand the joys of agriculture through theatrical expression, and discuss the possibility of agriculture in the future. The current agricultural practices in both developed and developing countries are based on too much on cost-benefit thinking and then should be changed into more sustainable ways.

Our final goal is to share our findings and ideas with wider communities in Asia. Agriculture has been misunderstood as outdated and 3D (Dirty, Dangerous and Demeaning) labor. It is also necessary to reconsider that we have been placed too much emphasis on economic efficiency in modern agriculture.

The target of this workshop is for high school students. They are the key to the future. The project is intended to give them an opportunity to think how the future agriculture can be with wider communities, learning from both senior and young farmers.

Agriculture is a way of living. People will not survive a day without farmers. This project aims also to raise awareness the importance of farmers for farmers themselves who support their own community since long time ago in the industry and the society. The challenge of the project is for the multigenerational community people in different regions to learn together and share innovative ideas, perspectives, and views.

Above-mentioned findings and thoughts are expressed by a theater presentation. In theatre presentation, stories are emphasized. The participants will undergo a process where they can clarify current situations in terms of agriculture and at the same time, imagine what their future would be if they were the farmers in their own community. Our theatre facilitators will guide the participants to create a theater presentation, expressing their messages.

It is not enough to tell the joy of agriculture only in words. Theatrical expression is more suitable to express it fully with movements, action, songs, dance and so on. Video recordings also help to share those images and thoughts with wider population. This is why we chose to use theatre. It is the nature of theatre to achieve sharing of ideas without being restricted by words.

The main output will be a theatre production from the high school students. Video recordings and images

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from the theatres will be archived in addition to a possible book and report publication. The process the participants will undergo is utmost important. A documentary will be prepared for interested people who would like to do the same in the future. This will in turn be scheduled and available via i-Tunes.

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Do the Rich Suffer Less Damage from a Natural Hazard? A Case of the 2015 Nepal Earthquake

*Sato Takeshi[1], Santosh Rayamajhi[2], Tachibana Towa[3], Takeshi Sakurai[1]

1. Graduate School of Agricultural and Life Sciences, The University of Tokyo , 2. Institute of Forestry, Tribhuvan University, 3. Graduate School of Social Sciences, Chiba University

Introduction

Practitioners and academics have reached a consensus that there are no natural disasters. Studies show that natural disasters are jointly caused by natural hazards and social problems, such as poverty and political dysfunctions. Several studies also show that preparedness against natural hazards increases with income levels. This association between poverty and preparedness against natural hazards may raise a serious issue in empirical analyses. The level of disaster damage is not only ascertained by the intensity of natural disasters but also by the characteristics of a household (HH).

However, taking into account the data at the micro level, since few studies statistically measured the association between social status (including the income level) and the damages from natural hazards, the effect of income on the level of disaster damage has not been accurately ascertained. This study tries to extend existing knowledge to clarify the impact of wealth on the damage from natural disasters.

Materials and methods

This study utilizes the index of the damages that HHs suffered during the 2015 earthquake (EQ) in Nepal. Nepal is located on a highly active seismic zone, and it was hit by a 7.8 magnitude earthquake on April 25, 2015. After the EQ, the Nepal government employed many engineers and assessed the damage on the private buildings, mainly private houses, in all the EQ hit districts. The Nepal Reconstruction Authority (NRA) has been entrusted with this damage data; by utilizing NRA’ s house damage data, this study provides evidence of the endogeneity of EQ damages in the following manner.

The study measures the gap between the magnitude of the EQ and the damage to the house; this gap should be zero if there are no impacts of HH characteristics. A correlation between HH characteristics, such as HH wealth and materials of buildings, and the damage level of the house would increase or decrease the damage caused depending on HH income level, even when the intensity of EQ is controlled. Subsequently, the study employs the peak ground acceleration (PGA) and the topographic slope using geographic information systems (GIS) to measure the aforementioned relationship. PGA is considered a major indicator for characterizing seismic hazard in engineering analysis.

To identify the wealthy HHs’ endogenous factors of the damage grade, we regress the damage grade on PGA, building materials (based on the building’ s strength), and HH characteristics.

Results

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NRA data show that the HH wealth has a certain correlation with the damage grade of EQ over a wide area. However, the results of the estimation using building materials and detailed HH data do not show a clear evidence that the HH wealth and damage of the EQ are correlated. Moreover, higher buildings were more damaged from the EQ. This result indicates that richer HH may not have taken care of the natural hazards in the study site and suffered the risk from the EQ. A significant increase in cash income through remittances did not reduce the damages to houses. Our results rather suggest that poor households suffered less from the 2015 EQ thanks to the “light” construction materials of their houses, such as mud and straw. At this income level, an increase in income does not work as a strong alleviator of natural disaster.

Keywords: Earthquake, Economics, Household Wealth, Nepal, PGA

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Assessment of regional eco-environmental vulnerabilities ---A case study in Mongolia

*Qinxue Wang[1]

1. National Institute for Environmental Studies

Eco-environmental vulnerability assessment is an important means to diagnose regional eco-environmental problems and identify key influential factors. It is also an important and indispensable part of eco-environment management and improvement. Since eco-environmental vulnerability involves many disciplines such as ecology, geography, land science and environmental science, etc. Some scholars think that vulnerability of the ecosystem is mainly determined by natural factors, and some think that vulnerability is related to the "utilization" of ecosystems by human beings. In short, eco-environmental vulnerability is a relative concept, and it is the result of the combined effect of natural and human factors. The major characteristics of eco-environmental vulnerability include vegetation degradation, loss of biodiversity, soil erosion, desertification, salinization, reduction of land productivity, increased frequency and intensity of disasters, and increased environmental pollution, etc., and there are obvious regional differences in the manifestations and influential factors.

The main influential factors of regional eco-environmental vulnerability can be summarized into the following three aspects: (1) Natural geographical conditions: in some regions such as the boundary area of desert, low vegetation coverage and poor stability of the ecosystem due to the influence of topographic, geological and climatic conditions directly lead to a vulnerable eco-environment; (2) Ecosystem sensitivity: in some regions such as the dry lands and permafrost areas, etc., since the ecosystem is very sensitive, the original ecological balance will be easily broken and very difficult to recover; (3) Human activity disturbance: in some regions such as the urban areas, intensive human activities lead to degradation of land, loss of biodiversity, environmental pollution and other problems, and eventually lead to the extremely easy deterioration of the ecological environment.

Mongolia is one of the largest inland country in arid and semi-arid areas. Based on the analysis of the formation mechanism of eco-environmental vulnerability, this study uses multi-source data and spatial analysis technology to systematically assess the eco-environmental vulnerability in Mongolia. The disturbance of human activities changes the stable state of the ecosystems, intensifies local and short-term changes, and becomes the main cause of regional ecological degradation. Overgrazing is the main cause of grassland degradation in human activities, especially in the surrounding areas of Ulaanbaatar city in the central part, where the overgrazing rate exceeds 50%. In addition, human economic activities such as exploitation of mineral resources and development of biological and tourism resources etc. have also brought serious damage to the grassland ecology, causing grassland degradation, wetland disappearance and desertification etc.

Based on the analysis of the formation mechanism of the vulnerable ecology in Mongolia, 10 evaluation indices including landform, climate, vegetation, and human disturbance are designed at three hierarchies, the ecological vulnerability in Mongolia and the spatial distribution characteristics thereof are evaluated. In terms of spatial distribution, the area of slightly and mildly vulnerable zones mainly distributed in the northern and western mountainous areas and southern desert areas. The area of moderately vulnerable zone mainly distributed in the steppe areas of east-central, south-central and northwestern Mongolia. The area of severely vulnerable and extremely severely vulnerable zones is obvious, mainly distributed in the

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surrounding areas of Ulaanbaatar city in the central part of the country, the surrounding areas of large-scale mining bases in the south and the edge of the deserts. Due to the vast area of Mongolia and the significant differences in regional climate changes, there are still too many uncertainties, which affected the vulnerability of ecosystems.

Keywords: Eco-environmental vulnerabilities, Overgrazing, Grassland degradation

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[E] Oral | H (Human Geosciences)：H-CG Complex & General

[H-CG25] Turbidity current: generation, morphodynamics and deposits

convener:Hajime Naruse(Department of Geology and Mineralogy, Graduate School of Science, Kyoto University), Robert Michael Dorrell(University of Hull), Miwa Yokokawa(Osaka Institute of Technology)

We invite research based on all kinds of approaches to understand turbidity currents such as field observation, physical and numerical experiments, mathematical analysis, and studies from rock records. Recent progress in research methodologies has greatly changed our understanding of dynamics of turbidity currents and relevant submarine geomorphology and stratigraphy. The integration of such new knowledge on turbidity currents is important not only for scientific interests but also for practical application such as risk assessment of natural hazards, and exploration of resources. We anticipate interdisciplinary discussions about turbidity currents and related sediment gravity flows.

Introduction

[HCG25-01] Autogenic foreset-bottomset transition trajectory: Experiment and theory

*Wonsuck Kim[1,2], Haein Shin[1] (1.Yonsei Univ., 2.Univ. of Texas)

[HCG25-02] Submarine topographic control on the distribution of supercritical-flow deposits: insights from the Middle Eocene deep-marine system, Ainsa-Jaca basins, Spanish Pyrenees

*Pauline H Cornard[1], Kevin Pickering[1] (1.University College London)

[HCG25-03] Flume experiments for Froude supercritical flow submarine fan: morphology and grain size distribution

*Kenya Ono[1], Hajime Naruse[2], Kazuki Kikuchi[2], Qifeng Yao[2], Zhirong Cai[2], Shunsuke Watanuki[1], Koji Ohata[2], Sojiro Fukuda[2,3], Kazushi Nakata[2], Miwa Yokokawa[4] (1.INPEX Corporation, 2.Kyoto University, 3.University of Hull, 4.Osaka Institute of Technology)

[HCG25-04] The scales and profiles of submarine cyclic steps

*Zhuyuan Wu[1], Norihiro Izumi[1] (1.Hokkaido University)

[HCG25-05] **The interplay of turbidity and contour currents: its representative products, flow dynamics, and significance**

★Invited Papers

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Autogenic foreset-bottomset transition trajectory: Experiment and theory

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In a lake environment, a delta can develop with three distinct depositional surfaces: Topset, foreset, and bottomset –all of which are connected with moving boundaries. Topset and foreset surfaces are connected at the shoreline, where the fluvial topset meets sea level. The subaqueous delta front is subdivided into foreset and bottomset at a slope break (henceforth foreset-bottomset break). The foreset develops dominantly by grain avalanche processes, while the bottomset develops with gravity flow.

Shoreline response to base level change has been studied extensively, and it has been found that shoreline trajectory in sedimentary records is a good stratigraphic indicator of base level change. However, the foreset-bottomset break and its trajectory stored in the stratigraphic record have not been thoroughly investigated. We present physical experiments and modeling results of how the trajectory of this moving boundary responds to base level rise. Under a constant base level, the foreset-bottomset trajectory shows three stages of the moving boundary migration: 1) initial aggradation with minor progradation, 2) strong progradation with minor elevation change, and 3) stable (slightly decelerating) progradation with declining elevation. Under constant base level rise at different rates, the foreset-bottomset trajectory shows 1) more distinct initial aggradation with higher base level rise rates, 2) stronger and faster progradation with lower base level rise rates, and 3) decelerated progradation with minor elevation changes.

The results from theoretical work and experimental verification of the theoretical model provides a unifying theory for the autogenic foreset-bottomset break migration. Based on a comparison of foreset-bottomset trajectory in the sedimentary record with the norm for the foreset-bottomset break migration, we can interpret clinoform development in lake basins under changes in environmental forcing.

Keywords: Autostratigraphy, Sediment Transport, Turbidity Current, Experiment, Delta

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Submarine topographic control on the distribution of supercritical-flow deposits: insights from the Middle Eocene deep-marine system, Ainsa-Jaca basins, Spanish Pyrenees

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Supercritical flows and their deposits have become central to the understanding of the architecture of deep-marine systems. Research has focused on the recognition criteria of supercritical-flow deposits (SFDs) using numerical modelling, flume-tank experiments, direct observations on active deep-marine systems and more recently from observations of ancient-deep-marine systems.

Here we link facies associations with SFDs observed in proximal submarine canyon-channel systems in the Middle Eocene Ainsa Basin, and in correlative lobes in the Jaca Basin. Two categories of supercritical-flow bedforms are defined: (i) erosional coarse-grained bedforms such as large- and small-scale cyclic-step deposits, and (ii) depositional fine-grained bedforms such as stable and unstable antidune and upper-plane bed deposits.

Quantitative analysis of SFD distribution shows a decrease from proximal-canyon to distal-lobe environments linked with a decrease in flow strength and velocity. Two surprising trends in the proportion of SFDs are observed: (i) the highest proportion of SFDs are in the lower-slope environment of the Ainsa Basin, and (ii) the proportion of SFDs from proximal to distal lobe environments shows no systematic changes.

From an interpretation of SFD distribution, three parameters are identified as playing a role on flow criticality: (i) flow confinement, (ii) seafloor gradient and (iii) basin geometry. We also recognize that the highest proportion of fine-grained sediments occurs with the highest abundance of SFDs. This relationship is linked to the preservation potential of SFDs and the amount of sediment bypass. Erosional, coarse-grained supercritical-flow bedforms are located in relatively confined settings with steep slopes and greater sediment bypass, whereas depositional fine-grained supercritical-flow bedforms occur in unconfined settings with lower seafloor gradients and good preservation potential.

We show that there is a trade-off between seafloor topography (confinement and gradient) and preservation potential, both playing a role in the formation and distribution of SFDs in deep-marine systems, and therefore, on the architecture of submarine fans.

Keywords: Supercritical-flow deposits, Seafloor topography, deep-marine system, flow confinement

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Flume experiments for Froude supercritical flow submarine fan: morphology and grain size distribution

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The Froude supercritical flow bedform has been commonly recognized as the upstream migratiing bedwaves in modern submarine fans. Also, in successions exposed at outcrops, we are able to interpret those bedforms by the dominance of scour and fill structures. These observations demonstrate their wider distribution than the previous recognition, which implies that the Froude supercritical flows significantly affect the depositional process on the submarine fan setting. However, their influence on the architecture and the grain size distribution in a lobe-complex scale remain uncertain. Thus, to understand the internal and external characteristics of supercritical bedforms by density flows, we started the first series of experiments using a 2D flume to observe the channel lobe transition zone (CLTZ), and then examined the sedimentary structures and detailed grain size segregation caused by the hydraulic jump of CLTZ. As the second phase of the experimental series, we expanded the setting into a 3D flume to observe the bedforms over the single lobe and grain size distribution. In each experiment, a surge of the turbidity current was generated by opening the valve for five seconds over a four-meter long tank, repeated by more than a hundred flows. We used the ten-centimeter wide flume for a 2D experiment and open flume (three-meter wide) for the 3D experiment. Sediment used in these experiments has broad grain size distribution, ranging from silt fine to medium sands.

The result of the 2D experiment showed that the occurrence of hydraulic jumps significantly controlled the resultant geomorphology and grain size segregation of deposits. Hydraulic jumps occurred sequentially from CLTZ forming the cyclic steps in one-meter long-wavelength after thirty surge-flows. The mean of grain-size segregation was controlled by those hydraulic jumps. The fraction of fine-grained sediment was significantly decreased at around the locations of hydraulic jumps.

The 3D experiment reproduced the single lobe structure from CLTZ after fifty surge-flows. The lobe is composed of one to two-centimeter high, and a few to ten-centimeter long multiple lobate sediment waves, also with local scour surfaces. The grain size distribution of the lobate deposit exhibits a similar trend with the 2D experiment. After more than a hundred surge-flows, however, the lobe evolves into the aggradational and flat-surfaced lobe only with grain-size segregation inside the channel-lobe transition, implying that the sediment waves were transitional features over the evolution of the single lobe.

The morphological similarity between the experimental results and observations of sediment wave, as well as CLTZ deposits exposed in the outcrops and modern sea floor, suggests that the Froude supercritical flow plays a similar role also in natural environments. Both experimental and ancient deposits show amalgamated stratigraphy but with the dominant erosional features. Also, our study demonstrates the Froude supercritical flow fan initiated from CLTZ is dominated by transitional structures such as the sediment waves exhibiting the autogenetic evolution.

Keywords: Froude supercritical flow, Submarine fan, Hydraulic jump

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The scales and profiles of submarine cyclic steps

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Froude-supercritical flow over an erodible bed is unstable and can form stable rhythmic bedform with long wave called cyclic steps. Cyclic steps are a series of upstream migrating steps which have the lee sides followed by stoss sides. It has been found that cyclic steps can be formed by turbidity currents which travel relatively long distance (long-runout turbidity currents). The flow is subcritical at the stoss side of the cyclic steps and it accelerates towards lee side end to become supercritical flow. The formation of cyclic steps formed by long-runout turbidity currents is presented in this study.

In this study, we assume an equilibrium state can be achieved in the high-concentrated lower layer near the bottom of long-run out turbidity currents. The high-concentrated layer can run out long distances and has little interaction with the upper layer. Then we integrate layer-averaged momentum and continuity equations along with the layer-averaged diffusion/dispersion equation of suspended sediment and the continuity equation of sediment (Exner equation) over the high concentrated lower layer. In the integration, the entrainment from the ambient sea water into the long-runout turbidity currents is negligible, since the Reynolds stress almost zero at the interface between the lower layer and the upper layer of long-runout turbidity currents.

The flow makes the transition from supercritical to subcritical regions through a hydraulic jump. The boundary conditions in this study are that the momentum is conserved before and after each hydraulic jump. Furthermore, the suspended sediment concentration is supposed to be continuous at the upstream and downstream sides of the hydraulic jump. The wavelength and wave height of cyclic steps are determined by the thickness of the high-concentration layer near the bottom. The thickness of this layer can be calculated by the fall velocity relative to the friction velocity, the slope of the ocean floor and the particle Reynolds number, and therefore it is reasonable to use the variables in the normal equilibrium state for the normalization.

We solve the two-point boundary value problem composed of the governing equations by the shooting method with the Newton-Raphson scheme. The calculation is started from the vicinity of the Richardson critical point to avoid singularities and it progresses towards upstream and downstream directions. Through calculation, we can generate the variations of suspended sediment concentration, layer-averaged velocity and wave height over one step wavelength. The profiles of cyclic steps depend on the Richardson number, the drag coefficient and the slope of the ocean floor. We could gain cyclic steps with various shapes depending on the parameters. The features of the obtained steps in the analysis bear an acceptable agreement with the field observations.

Keywords: Submarine bedform, cyclic steps, supercritical flow, long-runout turbidity currents

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The interplay of turbidity and contour currents: its representative products, flow dynamics, and significance

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A different type of deep-water channels characterized by unidirectional channel-growth trajectories, was recently recognized in northern South China Sea Slope (Gong et al., 2013), the Lowe Congo Basin (Gong et al., 2016), the offshore of Northern Mozambique (Fonnesu et al., 2020), and in many other deep-water basins. This type of submarine channels was termed unidirectionally migrating deep-water channels (UCs) by Gong et al. (2013) for the first time. Unidirectional channel migration is a depositional response to persistent actions of alongslope contour currents, while deep-water channels are conduits for downslope turbidity currents. UCs, thus, contain clear signals from both turbidity and contour currents.

Architecturally, UCs are characterized by unidirectional channel trajectories, and asymmetrical channel cross-sections with steep channel flanks developed towards channel migration, and short and relative straight channel courses. They are composed of different channel-complex sets, within each of which reworked turbidites in the lower part grade upward into muddy debris-flow deposits and, finally, into shale drapes. Hydraulically, we employed the concept of Wedderburn number (*W*) to quantify pycnocline response of turbidity flows to forcing events of contour currents in UCs recognized in the Lower Congo Basin. Bankfull turbidity flows in the Lower Congo UCs were computed to be supercritical [Froude number (*Fr*) of 1.11–1.38] and had velocities of 1.72–2.59 m/s. Contour currents with assumed constant velocities between 0.10 and 0.30 m/s flowing through their upper parts would result in pycnoclines between turbidity and contour currents, with amplitudes of up to 7.07 m. Such pycnoclines, in most cases, would produce Kelvin-Helmholtz (K-H) billows and bores that had velocities of 0.87–1.48 m/s and prograded toward the steep channel flanks by 4.0° to 19.2°. Their wavefronts with the strongest shocks and deepest oscillations would, therefore, occur preferentially along the steep channel flanks, thereby promoting erosion; on the other hand their wavetails with the weakest shocks and shallowest oscillations would occur preferentially along the gentle flanks, thereby promoting deposition. Such asymmetric intra-channel deposition, in turn, forced individual channels to consistently migrate toward the steep flanks, forming channels with unidirectional channel trajectories and asymmetrical channel cross-sections.

Our research on unidirectionally migrating deep-water channels provides two main contributions towards a better understanding of flow processes and sedimentation in submarine channels. First, our research success in documenting architecture and flow dynamics of a different type of deep-water channels, thereby contributing to a more compete picture of submarine channels. Second, our results suggest that pycnoclines between turbidity and contour currents could produce K-H billows and bores that impinged the steep channel flanks, therefore setting the tone in exploring further quantification of the interplay of oceanic contour currents and the sedimentology of turbidity currents.

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Keywords: unidirectionally migrating deep-water channels, Wedderburn number, Kelvin-Helmholtz billows and bores, the interplay of turbidity and contour currents, contour current-controlled sedimentation

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[E] Oral | H (Human Geosciences)：H-CG Complex & General

[H-CG25] Turbidity current: generation, morphodynamics and deposits

convener:Hajime Naruse(Department of Geology and Mineralogy, Graduate School of Science, Kyoto University), Robert Michael Dorrell(University of Hull), Miwa Yokokawa(Osaka Institute of Technology)

We invite research based on all kinds of approaches to understand turbidity currents such as field observation, physical and numerical experiments, mathematical analysis, and studies from rock records. Recent progress in research methodologies has greatly changed our understanding of dynamics of turbidity currents and relevant submarine geomorphology and stratigraphy. The integration of such new knowledge on turbidity currents is important not only for scientific interests but also for practical application such as risk assessment of natural hazards, and exploration of resources. We anticipate interdisciplinary discussions about turbidity currents and related sediment gravity flows.

[HCG25-06] Critical Transitions in Particulate Density Currents

★Invited Papers

*Benjamin Charles Kneller

[HCG25-07] **Laminar-turbulent transition in saturated granular free-surface flow**

*Sakai Yuichi[1], Norifumi Hotta[1] (1.Graduate School of Agricultural and Life Sciences, The University of Tokyo)

[HCG25-08] Statistical Analyses of Vertical Flow Profile show Turbidity Currents and Open-Channel Flow are Fundamentally Different

*Sojiro Fukuda[1], Elena Bastianon[2], Bill McCaffrey[3], Hajime Naruse[4], Robert Michael Dorrell[1] (1.Center for Environmental Fluid Dynamics, University of Hull, UK, 2.Energy and Environment Institute, University of Hull, UK, 3.Institute of Applied Geoscience, School of Earth and Environment, University of Leeds, 4.Department of Geology and Mineralogy, Graduate School of Science, Kyoto University, Japan)

[HCG25-09] Quantifying suspended sediment dynamics in a large-scale turbidity currents: Direct measurements from full scale flows

★Invited Papers

*Daniel R Parsons[1] (1.University of Hull, UK)

Discussion

Critical Transitions in Particulate Density Currents

*Benjamin Charles Kneller

Much effort has been expended on the differentiation of various types of particulate density current and the transitions between them, particularly that between flows with Newtonian and non-Newtonian (typically Herschel-Bulkley) rheologies. The deposits of such flows are classified as hybrid or transitional. Non-Newtonian behaviours have been associated with high fractions of cohesive material and with overall high density. The behaviour of high concentration non-cohesive flows has often been differentiated on the basis of a ‘Bagnold limit’, i.e. a grain concentration of roughly 9%. In fact there is no abrupt change from an an approximately Newtonian regime dominated by the properties of the interstitial fluid and with a stress/strain-rate dependency that is linear, to a grain-inertia regime in which grain collisions dominate, and where the stress/strain-rate dependency follows a power law; there is a transitional regime between Bagnold numbers of about 40 and 450 in which both play a part. Apart from grain concentration the Bagnold number is also dependent on the grain-size and shear rate. In other words, the behaviour of high-concentration dispersions (inertial/non-Newtonian, transitional, or macro-viscous/Newtonian) cannot be specified in terms of grain concentration alone. It is also likely to change from one regime to another as the shear strain rate changes. Lastly, dispersive pressure is likely to be a far more effective mechanism of grain support in the grain-inertia regime than in the macro-viscous regime, especially under high rates of shear. Changing rates of shear are thus a critical control on behavioural transitions in high-concentration particulate density currents.

The other critical transitions are those that relate to the passage of water from the ambient to the flow and vice versa, i.e. both entrainment into the flow, and detrainment from it. The transition from entraining flows to non-entraining flows (with and without Kelvin-Helmholtz instabilities, respectively) allows them to propagate long distances on the ocean floor without inflation and with little drag. The transition, involving increase in gradient Richardson number, is dependent principally upon gradient and mud content, either or both of which may change along the flow pathway.

Detrainment involves the loss of buoyant interstitial water from flows into colder or more saline ambient, via double-diffusive instabilities. This detrainment, if sustained over long enough distances, has the potential to transform hyperpycnal flows into ‘normal’ turbidity currents. High shear rates at the upper boundary suppresses these instabilities, either to be replaced by Kelvin-Helmholtz instabilities or, in the case of high gradient Richardson numbers, reducing fluid exchange in both directions, which might explain the propagation of some hyperpycnal flows over distances of 700 km.

Keywords: high-concentration, entrainment, detrainment

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Laminar-turbulent transition in saturated granular free-surface flow

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Flows of granular and fluid mixture driven by gravity are important sediment transport processes in subaerial and submarine environments. Their fluidity varies by grain size. Flows containing principally coarse grains are considered laminar and those featuring largely incohesive fine grains turbulent. When we focus on saturated granular free-surface flow, the transition from laminar to turbulent flow has been shown to depend on the ratio of flow depth to grain size (i.e., the relative flow depth). Flows with relative flow depths of approximately 10 are entirely laminar; those with relative flow depths over approximately 20 exhibit transitional flow behavior from entirely laminar to partially turbulent. This transitional flow has been investigated in a laboratory using resistance law and the vertical distribution of streamwise velocity. The flow exhibits a two-layer structure; the lower layer remains laminar but the upper layer becomes turbulent. However, transition modeling remains incomplete given the lack of data on the internal stresses associated with transitional flow. Here, we studied the laminar-turbulent transitions of saturated granular free-surface flow by measuring basal pore fluid pressures using flume tests.

We flowed saturated monodisperse granular materials over an open-channel rigid bed; we used sand particles of diameters 2.9, 2.2, 1.3, 0.8, 0.5, and 0.2 mm. When the flow attained a steady state, the flow depth and basal pore fluid pressure were measured using an ultrasonic sensor and pressure gages, respectively, and the basal total normal stress was estimated using the bulk density of the flow assessed at the downstream end. The relative flow depths ranged from 5 to 130.

Comparisons among the measured pore fluid pressures and the hydrostatic and total normal stresses indicated that a pore fluid pressure of 0.2 mm differed greatly from the hydrostatic pressure, equaling the total normal stress and indicating fully turbulent flow. In contrast, pore fluid pressures of 2.9, 2.2, and 1.3 mm were slightly higher than the hydrostatic pressures, indicating that the Reynolds stresses of the pore fluid due to strong shears imparted by the sediment particles were in play; flow was entirely laminar. Pore fluid pressures of 0.8 and 0.5 mm were intermediate between the hydrostatic and total normal stresses, indicating the transition from fully laminar to partially turbulent flow.

We investigated these transitions based on the non-dimensional number, which is similar to the Reynolds number for Newtonian fluid (the ratios of inertial to dynamic stresses due to both interparticle collisions and the Reynolds stresses of the pore fluid). This identified the critical non-dimensional number in terms of transition commencement. We describe transitional flow behavior using a two-layer model in which the position of the between-layer interface is estimated based on that critical non-dimensional number.

Keywords: Debris flow, Turbidity current, Granular flow, Turbulent flow, Pore fluid pressure

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Statistical Analyses of Vertical Flow Profile show Turbidity Currents and Open-Channel Flow are Fundamentally Different

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Over the past 100 years research into submarine sediment-laden buoyancy-driven flows, turbidity currents, have assumed that they are similar to open-channel flows. Here, we integrate 70 years of research into turbidity currents hydrodynamics, to show that the dynamics of turbidity currents are likely fundamentally different from open channel flow. We gathered the vertical velocity and density profile from available dataset of flume experiments of quasi-steady density currents and conducted statistical analyses. As resutls, we found that the stratification of velocity and density are well constrained by each other rather than by a specific flow parameters such as Froude number and Rouse number. Also the comparison between turbidity currents and fluvial rivers indicates that turbidity currents do not follow standard sediment-load transport models of open-channel flows, and thus that turbidity currents are not “rivers on the seafloor” as previously postulated. In open-channel flow the work-done keeping sediment in suspension, and thus sediment concentration, is directly proportional to flow power. Our results show this relationship does not hold for the turbidity currents. That experimental suspended sediment load is not directly proportional to flow power in turbidity currents, the historic Knapp-Bagnold constraint, opens new questions on sediment erosion, transport and deposition by buoyancy driven flows. The further analysis of flow parameters and vertical flow profile suggest a potential cause of this different trend of sediment-load transport model: the experimental turbidity currents, especially for the relatively dilute currents are unstable and cannot be regarded as quasi-equilibrium state. In other words, the sediment capacity might be strongly affected by whether a flow is erosional or depositional.

Keywords: Turbidity Currents, Flow Stratification, Sediment-load transport, Flow Power, Principal Component Analysis

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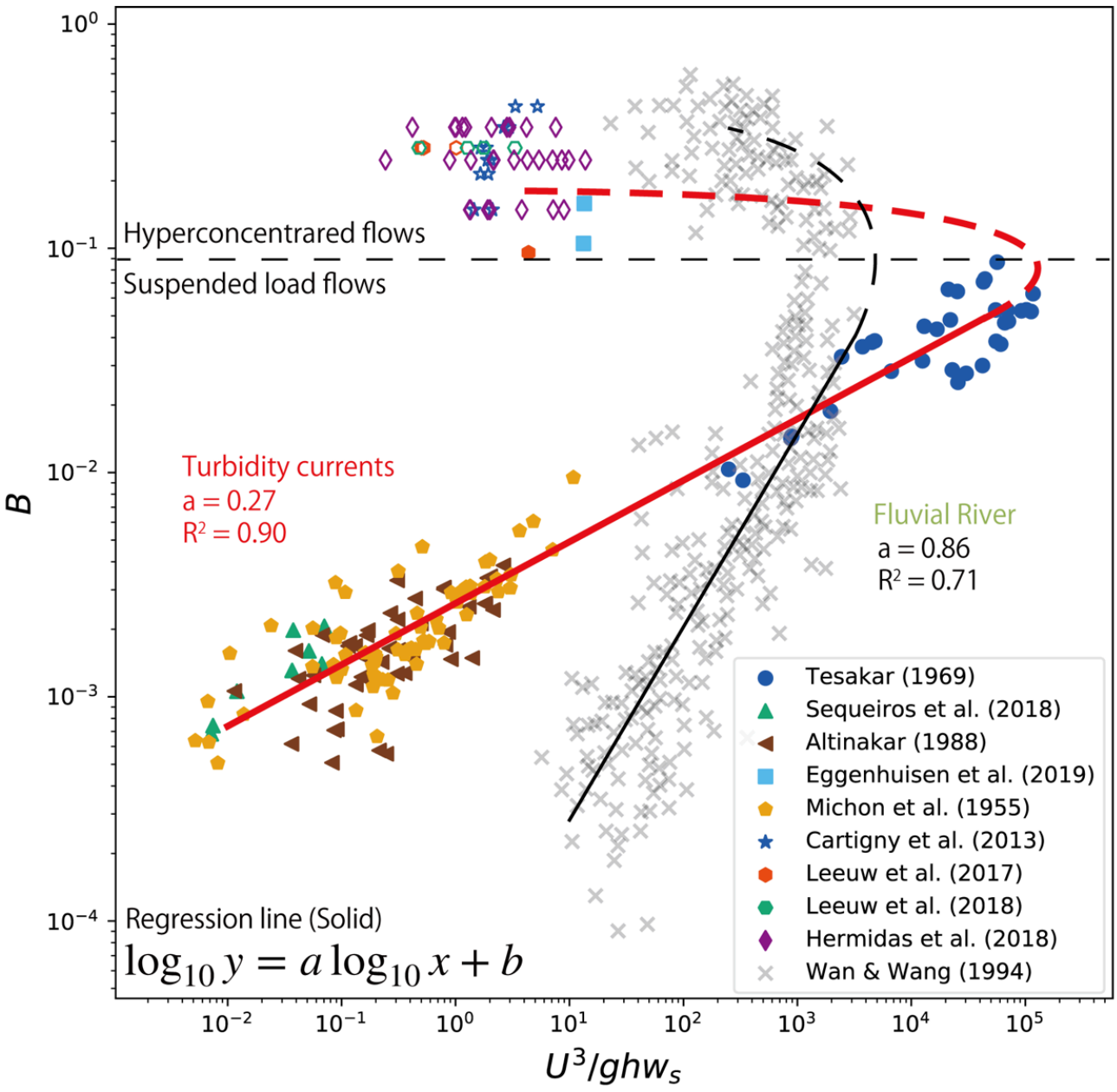

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Quantifying suspended sediment dynamics in a large-scale turbidity currents: Direct measurements from full scale flows

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Turbidity currents that transport sediment to the deep ocean deposit a greater volume of sediment than any other process on Earth. To date, only a handful of studies have directly measured turbidity currents, with flow durations ranging from a few minutes to a few hours. Our understanding of turbidity current dynamics is therefore largely derived from scaled laboratory experiments and numerical modelling. Recent years have seen the first field-scale measurements of depth-resolved velocity profiles, but sediment concentration (a key parameter for turbidity currents) remains elusive. Here, we present high resolution measurements of deep-water turbidity currents from a range of global sites, incluidng some of the world's largest submarine canyons. Direct measurements using acoustic Doppler current profilers (ADCPs) show that flows can last for many days at some sites, rather than hours, and the data provide the first quantification of concentration and grain size within deep-water turbidity currents. Velocity and backscatter were measured at sub-minute intervals by an ADCP suspended above the submarine channel floor. Novel inversion methods using multiple ADCP frequencies enabled quantification of sediment concentration and grain size within the flows. In some of the flows we are able to identify high concentrations of coarse sediment within a thin frontal cells, which outruns a thicker, trailing flow bodies. We are also able to indintfy the impact of large scale knickpoints on the flow dynamics. These data reveal some distinct divergenes from classical models and other field-scale measurements of turbidity currents and our results provide a new quantification of suspended sediment within flows and the interaction with the surrounding fluid.
Work presented here was through wide collaboration, incluidng with the Monteray Coordinated Canyon Experiment, the Bute Inlet Experiment and an ongoing Congo Canyon Project.

Keywords: Sediment transport, Turbidite, Flow, Congo canyon, Submarine canyon, Acoustic inversion

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[E] Oral | S (Solid Earth Sciences)：S-GD Geodesy

[S-GD01] Geodetic Infrastructure for Monitoring the Dynamic Earth: The Global Geodetic Observing System

convener:Basara Miyahara(GSI of Japan), Richard S Gross(NASA Jet Propulsion Laboratory)

The Global Geodetic Observing System (GGOS) measures the time-varying shape, rotation, and gravity field of the Earth, which provide accurate geodetic reference frames and enable us to understand various dynamic processes occurring on the Earth. The measurements are achieved with various geodetic techniques such as VLBI, SLR, GNSS, DORIS and gravity measurements. Many institutions in the world have developed their geodetic infrastructure to contribute to GGOS realization and devoted to research activities for Earth science. These activities are well coordinated and supported by the international scientific services of the International Association of Geodesy such as the International VLBI Service for Geodesy and Astrometry (IVS), the International Laser Ranging Service (ILRS), the International GNSS Service (IGS), the International DORIS Service (IDS), the International Gravity Field Service (IGFS), and so on. Through the coordination and support of these efforts, GGOS has fostered global collaboration and advocated stable production of geodetic products such as geodetic reference frames, earth rotation parameters and earth's gravity field models. This session will focus on reporting and discussing recent GGOS activities including geodetic data DOI working group, status of geodetic infrastructure and the results of data analysis for GGOS, and highlight the importance of geodetic observations to monitoring and understanding the dynamic Earth system for the benefit of science and society.

[SGD01-01] The Global Geodetic Observing System

*Basara Miyahara[1] (1.GSI of Japan)

[SGD01-03] GGOS External Relations Update: Using United Nations Frameworks to Promote International Cooperation and Geodetic Capacity Building in support of Disaster Risk Reduction and Resiliency

★Invited Papers

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[SGD01-04] GGOS Bureau of Networks and Observations: Network Infrastructure and Related Activities

*Michael R Pearlman[1], Carey E Noll[2], Dirk Behrend[3], Allison Craddock[4], Erricos Pavlis[5], Jérôme Saunier[6], Elizabeth Bradshaw[7], Riccardo Barzaghi[8], Daniela Thaller[9], Benjamin Maennel[10], Ryan Hippenstiel Hippenstiel[11], Roland Pail[12], Nicholas Brown[13] (1.Center for Astrophysics, Cambridge MA, United States, 2.NASA Goddard Space Flight Center, Code 61A, Greenbelt MD, United States, 3.NVI, Inc./NASA Goddard Space Flight Center, Greenbelt MD, United States, 4.Jet Propulsion Laboratory/California Institute of Technology, Pasadena, CA, United States, 5.University of Maryland, Baltimore MD, United States, 6.Institut Géographique National, St. Mande, France , 7.National Oceanography Centre, Liverpool, United Kingdom, 8.Politecnico di Milano, Milan, Italy, 9.Bundesamt fuer Kartographie und Geodaesie, Frankfurt, Germany, 10.GeoForschungsZentrum, Potsdam, Germany, 11.National Geodetic Survey, Silver Spring, MD, United States, 12.Technische Universitaet Muenchen, Munich, Germany, 13.Geoscience Australia, Canberra, Australia)

[SGD01-05] Activities of WG on DOIs in GGOS and Data DOI WG in GGOS Japan

★Invited Papers

*Yusuke Yokota[1], Basara Miyahara[3], Toshimichi Otsubo[4], Yasuhiro Murayama[5], Hiroshi Munekane[3], Tadashi Ishikawa[2] (1.Institute of Industrial Science, The University of Tokyo, 2.Hydrographic and Oceanographic Department, Japan Coast Guard, 3.Geospatial Information Authority of Japan, 4.Hitotsubashi University, 5.National Institute of Information and Communications Technology)

[SGD01-06] GGOS Japan's roles and activities as a GGOS Affiliate

*Toshimichi Otsubo[1], Basara Miyahara[2], Yusuke Yokota[3], Shinobu Kurihara[2] (1.Hitotsubashi University, 2.Geospatial Information Authority of Japan, 3.Institute of Industrial Science, the University of Tokyo)

The Global Geodetic Observing System

*Basara Miyahara[1]

1. GSI of Japan

The Global Geodetic Observing System (GGOS) of the International Association of Geodesy (IAG) provides the basis on which future advances in geosciences can be built. By considering the Earth system as a whole (including the geosphere, hydrosphere, cryosphere, atmosphere and biosphere), monitoring Earth system components and their interactions by geodetic techniques and studying them from the geodetic point of view, the geodetic community provides the global geosciences community with a powerful tool consisting mainly of high-quality services, standards and references, and theoretical and observational innovations. The mission of GGOS is: (a) to provide the observations needed to monitor, map and understand changes in the Earth’ s shape, rotation and mass distribution; (b) to provide the global frame of reference that is the fundamental backbone for measuring and consistently interpreting key global change processes and for many other scientific and societal applications; and (c) to benefit science and society by providing the foundation upon which advances in Earth and planetary system science and applications are built. The goals of GGOS are: (1) to be the primary source for all global geodetic information and expertise serving society and Earth system science; (2) to actively promote, sustain, improve, and evolve the integrated global geodetic infrastructure needed to meet Earth science and societal requirements; (3) to coordinate with the international geodetic services that are the main source of key parameters and products needed to realize a stable global frame of reference and to observe and study changes in the dynamic Earth system; (4) to communicate and advocate the benefits of GGOS to user communities, policy makers, funding organizations, and society. In order to accomplish its mission and goals, GGOS depends on the IAG Services, Commissions, and Inter-Commission Committees. The Services provide the infrastructure and products on which all contributions of GGOS are based. The IAG Commissions and Inter-Commission Committees provide expertise and support for the scientific development within GGOS. In summary, GGOS is IAG’ s central interface to the scientific community and to society in general. The whole figure of GGOS and its recent focus will be presented in the presentation.

Keywords: geodetic reference frame, International Association of Geodesy, earth's gravity field, earth rotation

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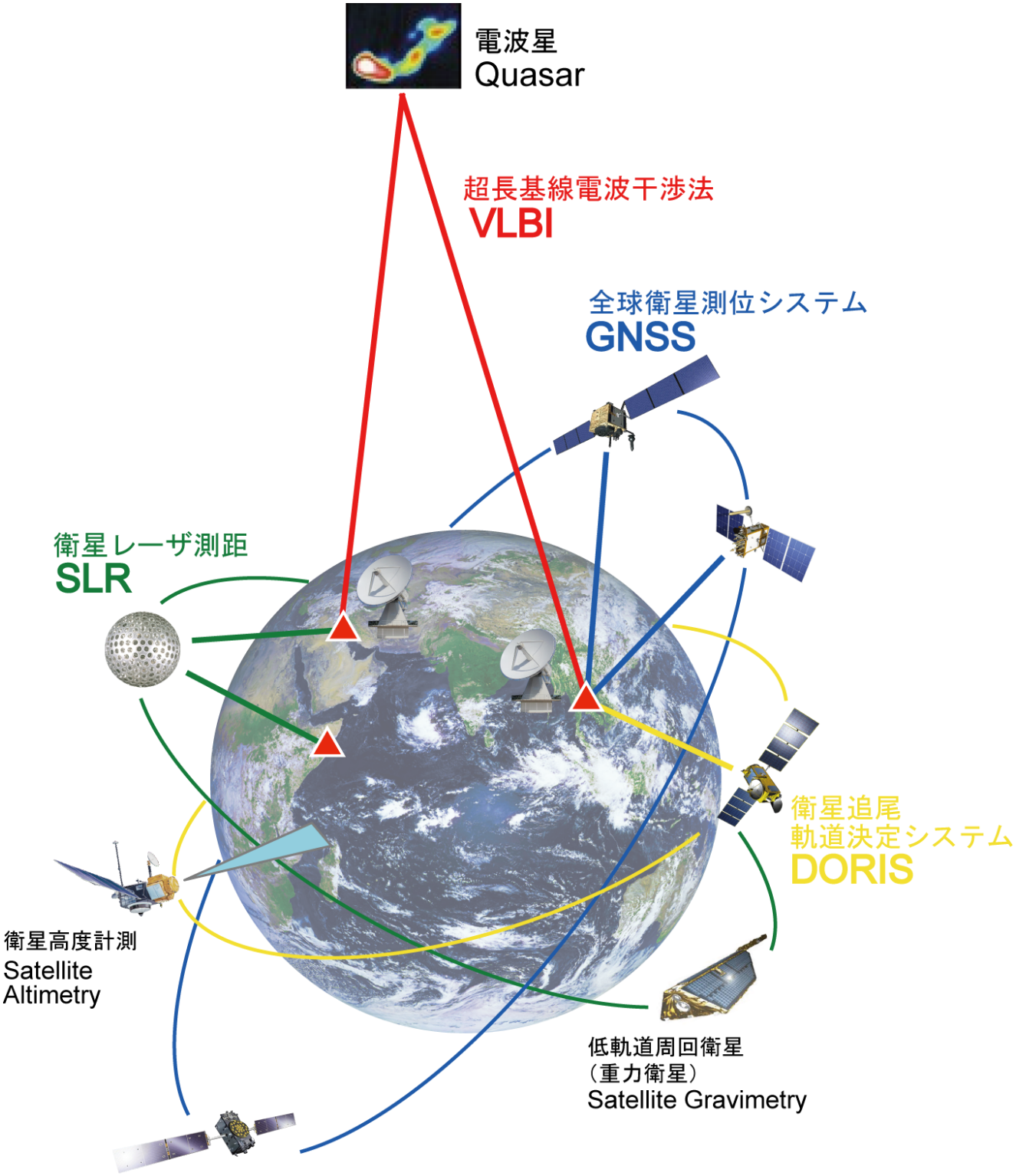

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GGOS External Relations Update: Using United Nations Frameworks to Promote International Cooperation and Geodetic Capacity Building in support of Disaster Risk Reduction and Resiliency

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This presentation will highlight the importance of international cooperation for capacity building to address disaster risk reduction, as well as establishing the United Nations Global Geodetic Reference Frame. Multilateral and international forums supporting geodesy and Earth observations will be introduced. We will focus on recent achievements by the International GNSS Service and the IAG Global Geodetic Observing System in advocating, coordinating, and building capacity in international forums. We also discuss recent outcomes of the 2017 GNSS Tsunami Early Warning System Workshop (GTEWS 2017) held in Sendai, Japan in July 2017, during which academics assessed what resources would be required to develop real-time GNSS throughout the Pacific Rim.

Emphasis will be placed on the applicability of United Nations frameworks, including the Sendai Framework for Disaster Risk Reduction, Sustainable Development Goals, and the UN GGIM-World Bank Integrated Geospatial Information Framework, as tools for communicating the relevance and importance of geodesy to a broader audience as well as potential funding sources.

Keywords: GNSS, Sendai Framework, IGS, GGOS, Capacity Building, Capacity Development

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GGOS Bureau of Networks and Observations: Network Infrastructure and Related Activities

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The GGOS Bureau of Networks and Observations works with the IAG Services (IVS, ILRS, IGS, IDS, IGFS, and PSMSL) to advocate for the expansion and upgrade of space geodesy networks for the maintenance and improvement of the reference frame and other applications, as well as for the integration with other techniques, including absolute gravity and sea level measurements from tide gauges. New sites are being established following the GGOS concept of “core” and co-location sites, and new technologies are being implemented to enhance performance in data yield as well as accuracy. The Bureau continues to meet with organizations to discuss possibilities, including partnerships, for new and expanded participation. The GGOS Network continues to grow as new stations join every year.

The Bureau holds meetings frequently, providing the opportunity for representatives from the services to meet and share progress and plans, and to discuss issues of common interest. It also monitors the status and projects the evolution of the network based on information from the current and expected future participants. Of particular interest at the moment is the integration of gravity and tide gauge networks and the forthcoming establishment of the new absolute gravity reference frame.

The IAG Committees and Joint Working Groups play an essential role in the Bureau activity. The Standing Committee on Performance Simulations and Architectural Trade-offs (PLATO) uses simulation and analysis techniques to project future network capability and to examine trade-off options. The Committee on Data and Information is working on a strategy for a GGOS metadata system for data products and a more comprehensive long-term plan for an all-inclusive system. The Committee on Satellite Missions is working to enhance communication with the space missions, to advocate for missions that support GGOS goals and to enhance ground systems support. The IERS Working Group on Site Survey and Co-location (also participating in the Bureau) is working to enhance standardization in procedures, outreach and to encourage new survey groups to participate and improve procedures to determine systems’ reference points, a crucial aid in the detection of technique-specific systematic errors.

We will give a brief update on the status and projection of the network infrastructure of the next several years, and the progress and plans of the Committees/Working Group in their critical role in enhancing data product quality and accessibility to the users.

Keywords: Space Geodesy, Reference Frames, GGRF, Global Geodetic Observing System, Co-located Geodetic Techniques

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Activities of WG on DOIs in GGOS and Data DOI WG in GGOS Japan

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GGOS is the framework that integrates various geodetic observation information such as GNSS, VLBI, SLR, DORIS, and gravity. The data, operating organizations, and international governing bodies under its umbrella are diverse. The quality and quantity of not only data but also raw data differ in each framework. For example, RINEX files, which are raw data of GNSS, are in MB order in one day even at a sampling rate of 1 Hz or more, but raw data of VLBI reaches the TB order which makes them difficult to save and distribute. How to manage and maintain a huge amount of data from such observation networks with different properties is a common issue in the current geosciences.

GGOS Japan established the Data DOI Working Group in 2019 to discuss the assignment of DOIs to data with the aim of proper distribution of these diverse data, objective evaluation and permanent management of the data. Also in 2019, the Working Group on DOIs was set up at GGOS, a superordinate organization of GGOS Japan. The agenda common to both WGs is to deal with the quality and quantity of different data and to deal with various situations that differ depending on the manager.

These WGs are discussing the future handling of geodetic data by large institutes (NASA GSFC, UNAVCO, GSI, ...). Since not only the quality of data but also the data management system and organizational guidelines are different in each organization, it is difficult to create rules that take all of these into consideration, so we are considering how to respond to each data quality. In the future, we aim to discuss the handling of data acquired by individuals and create a guideline in about two to three years after organizing the current issues.

What is important in both WGs is that data DOI alone is not enough to cover the differences, and a framework of data papers is needed in the future. Data paper publications must be important in the future, as the details, circumstances, and scientific validity will be the responsibility of the data manager / observer who understands the data most.

Keywords: GGOS, data DOI, data paper

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GGOS Japan's roles and activities as a GGOS Affiliate

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1. Hitotsubashi University, 2. Geospatial Information Authority of Japan, 3. Institute of Industrial Science, the University of Tokyo

GGOS Japan, formerly known as GGOS Working Group of Japan, was established in 2013 to strengthen the collaboration among the space-geodesy-related agencies in Japan. Its core members consist of a chair, a secretary, a lead of the outreach working group, a lead of the DOI working group and representatives of five core techniques: VLBI, SLR, GNSS, DORIS and gravity. It is largely supported by tens of people in Japan and also by its parent entity, IAG subcommittee in Japan.

It has been positioned in GGOS as the first GGOS Affiliate since 2017 and we strived to get connected to international organizations.

This presentation will cover our achievement such as assembling our site list, hosting various domestic/international meetings, planning a special issue in a domestic journal, producing its leaflet and website. GGOS Japan also provides online and offline forums for timely issues, such as assigning Data DOI to geodetic dataset, planning local tie for ITRF2020, etc.

Keywords: GGOS (Global Geodetic Observing System), Space Geodesy

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[E] Oral | S (Solid Earth Sciences)：S-GD Geodesy

[S-GD01] Geodetic Infrastructure for Monitoring the Dynamic Earth: The Global Geodetic Observing System

convener:Basara Miyahara(GSI of Japan), Richard S Gross(NASA Jet Propulsion Laboratory)

The Global Geodetic Observing System (GGOS) measures the time-varying shape, rotation, and gravity field of the Earth, which provide accurate geodetic reference frames and enable us to understand various dynamic processes occurring on the Earth. The measurements are achieved with various geodetic techniques such as VLBI, SLR, GNSS, DORIS and gravity measurements. Many institutions in the world have developed their geodetic infrastructure to contribute to GGOS realization and devoted to research activities for Earth science. These activities are well coordinated and supported by the international scientific services of the International Association of Geodesy such as the International VLBI Service for Geodesy and Astrometry (IVS), the International Laser Ranging Service (ILRS), the International GNSS Service (IGS), the International DORIS Service (IDS), the International Gravity Field Service (IGFS), and so on. Through the coordination and support of these efforts, GGOS has fostered global collaboration and advocated stable production of geodetic products such as geodetic reference frames, earth rotation parameters and earth's gravity field models. This session will focus on reporting and discussing recent GGOS activities including geodetic data DOI working group, status of geodetic infrastructure and the results of data analysis for GGOS, and highlight the importance of geodetic observations to monitoring and understanding the dynamic Earth system for the benefit of science and society.

[SGD01-08] The Next Generation Lunar Retroreflector and Lunar Laser Ranging

*Douglas G Currie[1], Dennis Wellnitz[1], Chensheng Wu[1], Giovanni Delle Monache[2], Simone Dell'Agnello[2], Bradford Behr[1] (1.University of Maryland, College Park, 2.INFN-LNF, Frascati, Italy)

[SGD01-09] Determination of geopotential value over Japan for contribution to the International Height Reference Frame

*Koji Matsuo[1] (1.GSI of Japan)

[SGD01-11] Integrated Space Geodetic Study of the 2019 Typhoon Hagibis: Signatures in Troposphere, Lithosphere, and Ionosphere

★Invited Papers

*Kosuke Heki[1], Wei Zhan[2], Syachrul Arief[1] (1.Department of Earth and Planetary Sciences, Faculty of Science, Hokkaido University, 2.The First Monitoring and Application Center, China Earthquake Administration, Tianjin, China)

[SGD01-12] Accuracy evaluation of a crustal deformation model with velocity in terms of maintaining the Japanese geodetic datum

*Yu Takagi[1], Kensuke Kokado[1], Yasuhiro Koso[1], Hiromi Yamao[1], Takashi Tsutsumi[1], Masao Iwata[1] (1.GSI of Japan)

The Next Generation Lunar Retroreflector and Lunar Laser Ranging

*Douglas G Currie[1], Dennis Wellnitz[1], Chensheng Wu[1], Giovanni Delle Monache[2], Simone Dell'Agnello[2], Bradford Behr[1]

1. University of Maryland, College Park, 2. INFN-LNF, Frascati, Italy

Fifty years ago, during the Apollo 11 mission, Buzz Aldrin deployed our first retroreflector array. To this day, our Lunar Laser Ranging (LLR) program continues to operate the retroreflector arrays and produce new and unique science. However, the combination of a flat array of 100 Cube Corner Retroreflectors (CCRs) and the lunar librations result in the most significant uncertainty in our current range measurements. To address this, NASA, within the Lunar Surface Instrument and Technology Payloads (LSTIP) program is supporting the University of Maryland, College Park to create three Next Generation Lunar Retroreflectors (NGLRs). Our NGLRs will support an improvement in a given range measurement by up to a factor of 100, depending upon the hardware and procedures of the LLR Observatories. A discussion of the role of the NGLR in the Lunar Geophysical Network (LGN) that will be proposed for the New Frontiers 5 solicitation will also be considered. The current designs for LSITP and NGL will be reviewed, with a discussion of some of challenges and their resolution. Addressing the science advances that are expected, several areas of lunar and gravitational physics will be reviewed, including the Lunar Fluid Core, the Excessive Tidal Dissipation, the Lunar Moments of Inertia, the Love Numbers, the Retroreflector Coordinates, the Physical Libration, the Flattening of CMB and the Weak Equivalence Principle and GravitoMagnetic Effects.

Keywords: Lunar Laser Ranging, Next Generation Lunar Retroreflector, Lunar Physics, Gravitation and General Relativity

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Determination of geopotential value over Japan for contribution to the International Height Reference Frame

*Koji Matsuo[1]

1. GSI of Japan

The International Height Reference Frame (IHRF) is a vertical coordinate system referred to the global mean sea level surface (W0), realized based on globally unified standards and conventions. The motivation of IHRF is to realize a society that the global heights (orthometric height, normal height, ellipsoidal height, etc.) are available with centimeter accuracy, as well as to accurately monitor minute global changes such as global sea level rise. The initiative of IHRF was issued as a resolution at the International Union of Geodesy and Geophysics (IUGG) 2015 meeting, and the first version of IHRF (IHRF2019) will be released soon. IHRF2019 consists of 165 reference stations in the world, three of which (Wakkanai, Ishioka, and Osumi) exist in Japan. In this study, we introduce the details of the current IHRF stations in Japan and report the estimated gravitational potential values over Japan with an eye on the future densification of the IHRF stations in Japan.

Keywords: Height reference system, Geoid, Gravity

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Integrated Space Geodetic Study of the 2019 Typhoon Hagibis: Signatures in Troposphere, Lithosphere, and Ionosphere

*Kosuke Heki[1], Wei Zhan[2], Syachrul Arief[1]

1. Department of Earth and Planetary Sciences, Faculty of Science, Hokkaido University, 2. The First Monitoring and Application Center, China Earthquake Administration, Tianjin, China

Strong typhoons hit the Japanese Islands repeatedly in 2019 autumn. Here we study one of these typhoons (2019 #19 Hagibis, 915 hPa, 86 casualties) that made landfall in central Japan on Oct.12 during the Rugby World Cup tournament, using three different space geodetic approaches to study multiple spheres, i.e. tropospheric water vapor, ionospheric electron content, and lithospheric deformation due to stormwater load. The first approach is the recovery of Precipitable Water Vapor (PWV) using the zenith wet delays (ZWD) estimated by the dense GNSS array in Japan GEONET (GNSS Earth Observation Network). Because atmospheric water vapor concentrates in relatively low altitudes, high humidity is often difficult to recognize in ZWDs when the surface altitude is high. To overcome the difficulty, we reconstructed ZWDs, converted to sea-level values, by spatially integrating the tropospheric delay gradient (azimuthal asymmetry of water vapor) vectors. We also calculated convergence of such delay gradients, equivalent to water vapor concentration (WVC) index proposed by Shoji (2013). We found that extreme rainfall occurs where both reconstructed ZWD and the WVC index are high. Next, we studied vertical crustal movements associated with the water load brought by the typhoon, using the two solutions of the GEONET station coordinates, one from the official F3 solution and the other from the UNR data base. After applying a network filter to remove common mode errors, we confirmed subsidence down to ~2 cm in multiple regions where severe flood occurred, e.g. in Izu-Peninsula, Coastal region of Fukushima, and Nagano (see attached figure). Such subsidence was observed to recover with a time constant of 1-2 days reflecting rapid drain of rainwater to ocean due to large topographic slope and proximity to the sea. We could not identify, however, crustal uplift due to the low atmospheric pressure at the center of the typhoon. At last, we look for ionospheric disturbances possibly excited by the typhoon Hagibis as changes in the ionospheric total electron content (TEC) measured using Quasi-Zenith Satellite System (QZSS) tracked by the GEONET stations. Geostationary satellite (PRN07) of QZSS enables us to monitor ionosphere above the Japanese Islands continuously and are useful in detecting ionospheric disturbances above Japan.
In the attached figure, we show subsidence of GNSS stations in Japan on 2019 Oct. 12 due to stormwater load (right) and vertical coordinate time series of selected stations (left). They are all based on the F3 solution of the GEONET GNSS stations after removal of common mode errors.

Keywords: Typhoon Hagibis, GNSS, water vapor, crustal deformation, surface load, ionospheric disturbance

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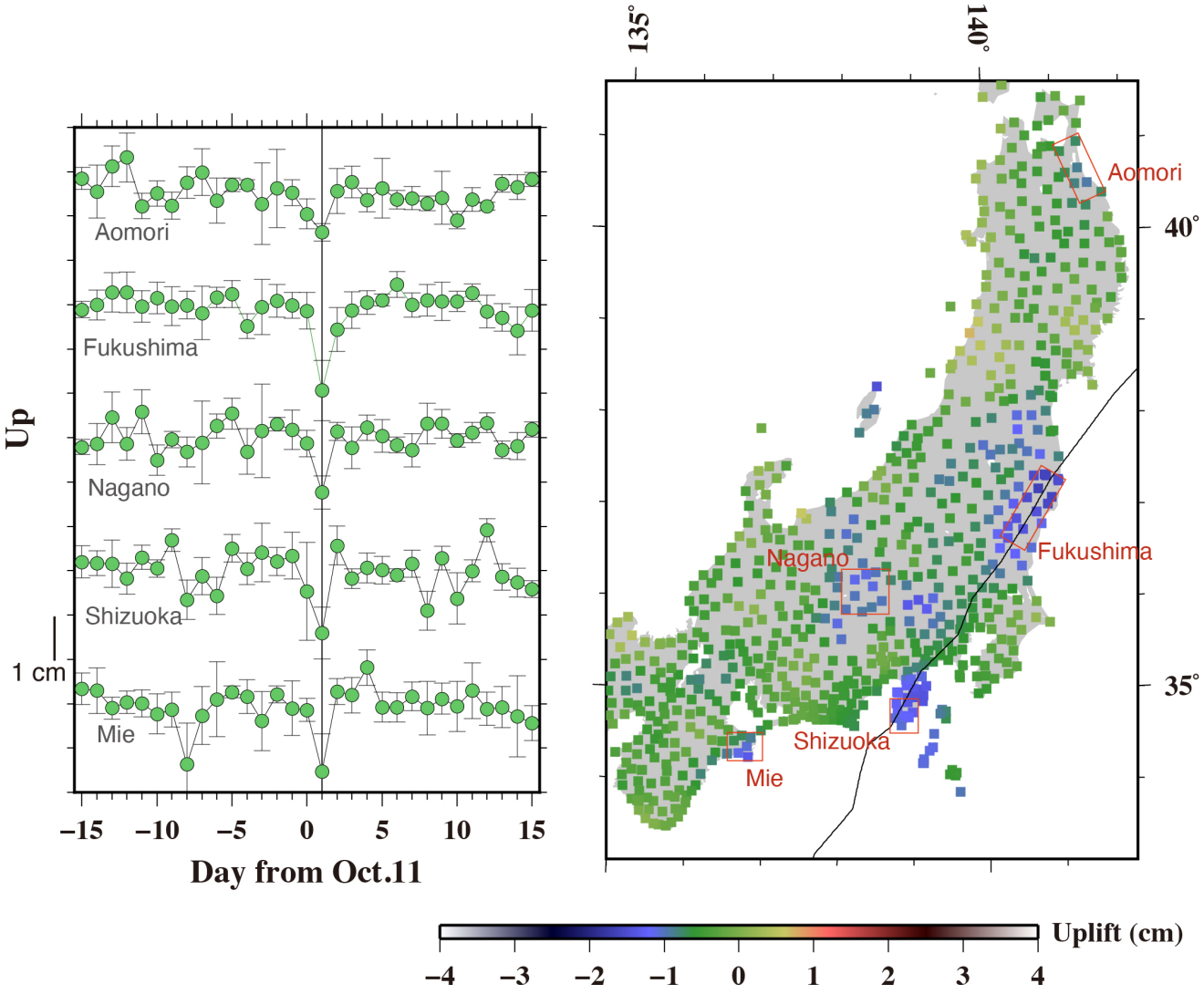

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Accuracy evaluation of a crustal deformation model with velocity in terms of maintaining the Japanese geodetic datum

*Yu Takagi[1], Kensuke Kokado[1], Yasuhiro Koso[1], Hiromi Yamao[1], Takashi Tsutsumi[1], Masao Iwata[1]

1. GSI of Japan

Geospatial Information Authority of Japan (GSI) introduced semi-dynamic correction in the field of surveying in 2010 (Hiyama et al., 2010) to reduce the effect of the strain due to steady-state crustal deformations such as caused by plate motion so that the accuracy of Japanese geodetic datum, a static datum, is maintained. In semi-dynamic correction, the effect of the strain that has accumulated from the reference epoch of the datum to the current epoch is corrected by using the crustal deformation model constructed with the use of the data of about 1,300 GNSS Continuously Operating Reference Stations (CORSs). The model, representing the accumulated crustal deformation at each point of the latitude-longitude grid whose spacing is about 5 km, are obtained by interpolation of the CORS' s coordinate differences between the 1st of January in every year and the reference epoch by means of Kriging method (Tanaka et al., 2007). In order to accurately correct the effect of the strain accumulating over time, it is updated every year.
As mentioned above, the present model has been applied exclusively to the field of surveying, in which relative positioning technique is used. Recently, however, more and more satellite positioning communities, especially real-time precise positioning service providers, other than those in the surveying field are starting to use the deformation model, as recent technical development enables us to obtain accurate coordinates more easily than ever before. A crustal deformation model that can correct the effect of the accumulating crustal deformation constantly and accurately is needed in order to use the coordinates obtained by highly accurate satellite positioning together with geospatial information based on the geodetic datum, as in the case of overlaying the positioning results on maps. The present model, however, cannot accurately reproduce the crustal deformation such as the post-seismic deformation observed after the 2011 off the Pacific coast of Tohoku earthquake, or 2011 Tohoku-oki earthquake.
This study aims to develop a crustal deformation model that can reproduce crustal deformation including post-seismic deformation more accurately in order to provide the geodetic datum that can work with precise positioning. Although Tobita (2016) and others used models with logarithmic and exponential functions to represent post-seismic deformation, a sufficient period of data is needed to estimate reasonable time constants and coefficients for those functions. On the other hand, a model with simple velocity, which is derived from the difference of coordinates between two epochs divided by the time, can be readily constructed compared to the above models. In this study, we make model with logarithmic and exponential functions and one with simple velocity, and evaluate to what degree these models can reproduce the actual crustal deformation observed after the 2011 Tohoku-oki earthquake. In this presentation, we will report the results of the evaluation and discuss the effectivity and limitations of the model with simple velocity from the point of view of maintaining the geodetic datum.

Keywords: geodetic datum, crustal deformation, post-seismic deformation, GNSS Continuously Operating Reference System, semi-dynamic correction

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[E] Oral | S (Solid Earth Sciences)：S-SS Seismology

[S-SS03] Seismological advances in the ocean

convener:Takashi Tonegawa(Research and Development center for Earthquake and Tsunami, Japan Agency for Marine-Earth Science and Technology), Takeshi Akuhara(Earthquake Research Institute, University of Tokyo), Pascal Audet(University of Ottawa), Taka'aki Taira(Berkeley Seismological Laboratory, University of California, Berkeley)

[SSS03-01] Millimeter-scale tsunami of an M6 earthquake observed by the nearest-field pressure gauge array: a fault modeling and stress drop estimation

★Invited Papers

*Tatsuya Kubota[1], Tatsuhiko Saito[1], Wataru Suzuki[1] (1.National Research Institute for Earth Science and Disaster Resilience)

[SSS03-02] Seismic velocity structure along the Japan trench inferred from ambient noise and teleseismic surface waves observed by S-net

*Ryota Takagi[1], Akira Ishigami[1], Genti Toyokuni[1], Ryosuke Azuma[1], Mare Yamamoto[1] (1.Research Center for Prediction of Earthquakes and Volcanic Eruptions, Graduate School of Science, Tohoku University)

[SSS03-03] Seismic ambient noise interferometry applied to dense OBS array of off Ibaraki region

*Lina Yamaya[1], Kimihiro Mochizuki[1], Takeshi Akuhara[1], Kiwamu Nishida[1], Tsuyoshi Ichimura[1], Kohei Fujita[1], Takuma Yamaguchi[1], Takane Hori[2] (1.Earthquake Research Institute, University of Tokyo, 2.Japan Agency for Marine-Earth Science and Technology)

[SSS03-04] Lithospheric structure beneath the extinct Mid-Ocean-Ridge in South China Sea: Constraints from passive-source OBS data

*Ting Yang[1], Ba Manh Le[1], Chenguang Liu[3], Mei Xue[2] (1.Southern University of Science and Technology, 2.Tongji University, 3.First institute of oceanography, MNR, China)

[SSS03-05] Development of seismic inversion tool for flat and isotropic layered structures in the ocean (SEIS-FILO)

*Takeshi Akuhara[1] (1.Earthquake Research Institute, The University of Tokyo)

[SSS03-06] Inverting OBS compliance signals for oceanic crust and sediment velocity structure using mixture density neural networks

*Stephen Glenn Mosher[1], Zach Eilon[2], Pascal Audet[1] (1.University of Ottawa, 2.University of California Santa Barbara)

Millimeter-scale tsunami of an M6 earthquake observed by the nearest-field pressure gauge array: a fault modeling and stress drop estimation

*Tatsuya Kubota[1], Tatsuhiko Saito[1], Wataru Suzuki[1]

1. National Research Institute for Earth Science and Disaster Resilience

Tsunamis associated with major (M > 7) offshore earthquakes are often recorded by offshore ocean-bottom pressure gauges and have been used to estimate the fault models and to understand the mechanics of earthquake faulting (e.g., Satake et al. 2013; Gusman et al. 2015; Heidarzadeh et al. 2016; Kubota et al. 2019). However, because the offshore stations were too few and remote from the earthquake hypocenters, it is challenging to record tsunamis due to moderate (M ~6) earthquakes with reasonable quality. To constrain the fault parameters for such moderate earthquakes, it is required to use stations near the source. Recently, a new, wide and dense pressure gauge network, called the Seafloor Observation Network for Earthquakes and Tsunamis along the Japan Trench (S-net), was constructed by the National Research Institute for Earth Science and Disaster Resilience (NIED) (Kanazawa et al. 2016). This network observed tsunamis with amplitudes of less than one cm associated with an Mw 6.0 earthquake off Sanriku on August 20, 2016, which occurred at the northern edge of the rupture area of the 1896 Sanriku tsunami earthquake (Kanamori, 1972; Tanioka & Satake, 1996). This study uses these millimeter-scale tsunami records to estimate the finite fault model and examines its relationship with other interplate earthquake phenomena.

First, we applied a band-pass filter with a passband of 100–1000 s to the raw records. When the traces were aligned according to the station locations, the westward propagation of tsunamis with the velocity of ~0.1 km/s could be recognized. The step-like signals were also observed at several stations near the epicenter. At the site S4N10, a station closest to the epicenter (~10 km), an abrupt pressure increase of ~20 hPa was observed. Takagi et al. (2019) examined records from the co-located accelerometer at S4N10 during this earthquake and found the sensor at S4N10 was rolled with a rotation angle of 5.72°. This suggests that these step-like signals are irrelevant to tsunami nor crustal deformation.

We then inverted the record to estimate the initial sea-surface height distribution (i.e., tsunami source). As a result, the tsunami source had a spatial extent of ~40 km and was located ~10 km to the west of the GCMT solution. In addition, when using only the remote stations (> ~100 km), the horizontal location was similar; however the initial height distribution was broader and the total volume of the displaced seawater was almost double. This suggests the horizontal location could be reasonably constrained only from the remote stations but the near-field data is essential to obtain the higher-resolution fault models, as pointed out by Inazu & Saito (2014) and Kubota et al. (2019).

We finally constrained the rectangular fault model with a uniform slip across the fault, based on the S-net tsunami data. We obtained a seismic moment $M_0 = 1.4 \times 10^{18}$ Nm (Mw 6.0) and a stress drop of $\Delta\sigma = 1.5$ MPa. The estimated stress drop value seems not so small as those of tsunami earthquakes such as the 1896 Meiji Sanriku earthquake ($\ll$ ~1 MPa, e.g., Kanamori and Anderson, 1975) even if we consider the uncertainty of the stress drop estimation ($\Delta\sigma >$ ~ 0.7 MPa). We also found the estimated fault was unlikely to overlap with regions where slow earthquakes are active, such as low-frequency-tremors and very-low-frequency-earthquakes (e.g., Matsuzawa et al. 2015; Nishikawa et al. 2019; Tanaka et al. 2019).

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This study demonstrated that the detectability of a millimeter-scale tsunami and the constraints on earthquake source parameters of moderate earthquakes are dramatically increased by the S-net’s new dense and widely distributed tsunami network. We expect that this new array records more tsunamis due to minor-to-moderate offshore earthquakes. This will enable us to elucidate the spatial variation of the stress drops, or mechanical properties, along the plate interface with much higher resolution than previously possible.

Keywords: S-net, Ocean bottom pressure gauge, Tsunami, Interplate earthquake, Fault modeling, Stress drop

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Seismic velocity structure along the Japan trench inferred from ambient noise and teleseismic surface waves observed by S-net

*Ryota Takagi[1], Akira Ishigami[1], Genti Toyokuni[1], Ryosuke Azuma[1], Mare Yamamoto[1]

1. Research Center for Prediction of Earthquakes and Volcanic Eruptions, Graduate School of Science, Tohoku University

The Japan trench subduction zone has intense seismic activity including regular and slow earthquakes. Although the structural heterogeneity may provide a hint to better understand the mechanisms controlling slip behavior on the plate interface, the seismic velocity structure, especially shear wave velocity, in the forearc region beneath the ocean was poorly constrained. The present study aims to estimate the seismic velocity structure at the offshore region of the Japan trench subduction zone using the recently developed S-net ocean bottom seismic network. We analyzed surface waves of ambient seismic noise and teleseismic earthquakes to broaden the frequency range of analysis. For the ambient noise records, we conducted the cross-correlation technique for three-year accelerometer records from August 2016 to August 2019 to extract inter-station Green’ s functions of surface waves. After applying an instrument noise reduction method, we successfully extracted Rayleigh and Love waves at the frequencies above 0.04 Hz and measured phase velocities in 0.04-0.1 Hz. The phase velocities at 0.06 Hz show the along-strike variations: relatively low velocities off the northern and southern Tohoku regions; high velocities off the central Tohoku and eastern Hokkaido regions. The relatively high and low velocity regions correspond to the regions where slow earthquakes are active and inactive, respectively. For the teleseismic surface waves, we applied a spatial gradient based tomographic method called Eikonal tomography. We imaged the phase velocity maps of Rayleigh wave in 0.025-0.04 Hz. At 0.03 Hz, we found a spatial correlation between slip areas of past large earthquakes and high velocity region. Because the Rayleigh and Love waves at these frequencies are sensitive to seismic velocity within the upper plate and oceanic crust, the structural heterogeneity around the plate interface may result in the different slip behaviors on the plate interface.

Keywords: S-net, Seismic velocity structure, Subduction zone, Japan trench, Surface wave, Ambient noise

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Seismic ambient noise interferometry applied to dense OBS array of off Ibaraki region

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Off Ibaraki region is located at the southern end of the focal area of the 2011 off the Pacific coast of Tohoku Earthquake (Tohoku Earthquake). A dense network of 32 ocean bottom seismometers (OBSs) was deployed at this region with a station interval of about 6 km from October 2010 (11 OBSs started from February 2010) to October 2011. A large number (> 10,000) of aftershocks following the 2011 Tohoku earthquake were detected by this network. However, precise determination of these hypocenters and focal mechanisms is challenging due to uncertainties of seismic properties of thick sediment layers beneath the seafloor. The P-wave velocity structure has been reasonably constrained by active-source seismic surveys (Mochizuki et al., 2008), but the S-wave velocity structure is still unrevealed despite its importance.

To constrain the S-wave velocity of the shallower portion, we apply the ambient noise interferometry to the short-period OBS data in this study. After dividing the data into ten-minute segments, we deconvolve the data with instrumental response function, remove trends, and discard data dominated by seismic events. Then, we apply a one-bit normalization and spectrum whitening. Finally, we calculate cross-correlations for vertical-vertical, radial-radial, and transverse-transverse components to retrieve Green's functions.

We measure average phase velocity in the array using spatial auto-correlation method (Aki, 1957; Nishida et al., 2008). The phase velocities of the fundamental Rayleigh, the first-higher Rayleigh, and the fundamental Love modes are 0.5 to 2.5 km/s (in the frequency range of 0.1 to 0.3 Hz), 0.8 to 1.5 km/s (0.17 to 0.3 Hz), and 0.5 to 2.0 km/s (0.25 to 0.1 Hz), respectively. Next, we infer the 1-D average S-velocity isotropic structure by non-linear inversion, whose sensitivity is mainly ~5 km. The results show ~1000 m thick sediment with S-wave velocity of 300–1000 m/s immediately beneath the seafloor. At last, we apply band-pass filter with frequency range of 0.125 Hz and measure travel-time anomaly of the phase velocity in each frequency range, following Nagaoka et al. (2012). We apply non-linear inversion (Rawlinson & Sambridge, 2003) and find low-velocity anomalies in the deeper of the northern part and in the shallower of the center part.

Keywords: ambient noise interferometry, sedimental layer, S-velocity structure

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Lithospheric structure beneath the extinct Mid-Ocean-Ridge in South China Sea: Constraints from passive-source OBS data

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The extinct Mid-Ocean-Ridge (MOR) and the seamount chain above it in the central sub-basin of the South China Sea (SCS) represent a unique type of global MOR systems, in which magmatic processes continued for many million years after the ridge has been abandoned. Here we present a 3-D shear velocity model of this ridge using seismograms recorded at two passive-source Ocean Bottom Seismograph (OBS) array experiments in the SCS basin. The model is derived by inversing phase velocities of Rayleigh waves at 8 periods in the range of 18 –50 s, which are sensitive to the structure to 80 km deep. The model shows a high-velocity lid beneath the extinct ridge, which is ~ 15 km thicker than the prediction of the cooling model of the oceanic lithosphere. The anomalously thick lithosphere can be explained by the melt-extracted mantle, consistent with a low-density gravitational anomaly across the ridge confirmed by both observation and modeling. A low-velocity anomaly (1 –2 %) below the lid is also imaged, likely suggesting the presence of a high temperature of ~135 K at those depths. A low-velocity stripe on the subducting SCS slab beneath the Luzon Island coincides with the location of the MOR, indicating there exists a tearing along the subducted MOR in the upper mantle.

Keywords: OBS, Rayleigh waves, mid-ocean-ridge

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Development of seismic inversion tool for flat and isotropic layered structures in the ocean (SEIS-FILO)

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Seismological studies have approximated the Earth’ s structure using the stratification of flat and isotropic layers. Such one-dimensional models are suitable for single-station measurements, including receiver functions, surface wave dispersion curves, and H/V ratios, and have been widely used to illuminate a wide range of structures from shallow basin to deep mantle structures. Recently a growing number of studies come to use more sophisticated methods (e.g., full-waveform inversion) for modeling laterally heterogeneous structures of the Earth. Nevertheless, the modeling by one-dimensional structure will not lose its position because of the less computational cost and no need for dense seismic instrument deployments. Especially for the ocean area, insufficient coverage by station networks will force to use such single-station methods.

Here, I present a computer program package termed SEIS-FILO (seismic inversion tool for flat and isotropic layered structures in the ocean). The software performs transdimensional inversion of receiver functions and surface wave dispersion curves, with the effects of the seawater column fully considered. The state-of-the-art Bayesian probabilistic sampling method known as reversible-jump Markov-chain Monte Carlo is used, where the number of model parameters (i.e., the number of layers) is automatically selected based on the data complexity. The parallel tempering technique is also implemented to enhance the conversion rate. The source codes are written in a modern Fortran programming style (i.e., objective-oriented programming) for a low-maintenance and easy expansion in the future.

Currently, the software undergoes alpha testing: independent/joint inversions of receiver functions and fundamental Rayleigh wave dispersion curves are possible to perform. This alpha version is available at the GitHub repository (https://github.com/akuhara/SEIS_FILO).

Keywords: Transdimensional inversion, Receiver function, Surface wave , Ocean-bottom seismometer, Software

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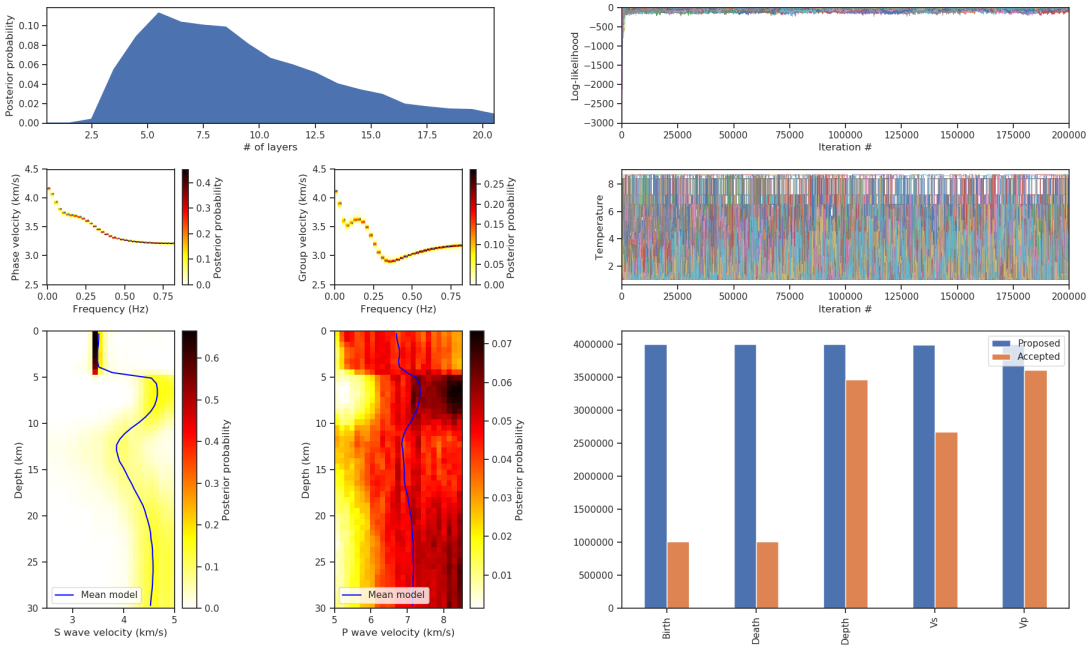

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Inverting OBS compliance signals for oceanic crust and sediment velocity structure using mixture density neural networks

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Extremely long wavelength infra-gravity waves propagating along the ocean surface induce a loading of the seafloor, which elastically deforms in response to associated pressure changes in the overlying water column. This phenomenon is known as seafloor compliance and is often considered to be a source of noise contaminating ocean-bottom seismometer (OBS) data. However, OBSs equipped with pressure gauges are able to exploit compliance signals for structural imaging. In particular, seafloor compliance signals are most sensitive to the shear modulus, and therefore, are sensitive to the shear wave velocity (Vs) structure of the sediment column and uppermost crust.

The non-linear inverse problem of predicting shallow 1D Vs profiles from compliance signals has been addressed in several previous studies, often through the use of linearizing techniques. In this study we explore the possibility of instead solving for Vs structure through the use of a neural network, specifically a mixture density network. Mixture density networks are extensions of standard neural networks that are able to approximate arbitrary probability density functions, including ones that are highly multi-modal (i.e., strongly non-linear). In detail, trained mixture density networks are able to map *M*-dimensional variables to (posterior) probability functions of *N*-dimensional observations by expressing these arbitrarily complex functions as a mixture of multiple *M+N* dimensional Gaussians. Using this framework, the posterior probability distribution of the network output can be computed for any input. In our context this means that once a network has been trained, probabilistic 1D Vs profiles can be computed given any observed compliance data. In this study we restrict our focus to synthetic signals generated for sensors at deep water sites (depths > 1 km) and we parametrize Vs structures using cubic splines down to 3 km, below which a half-space is assumed. We test the feasibility of this method by training a mixture density network on 100,000 synthetically generated compliance signals, and report its effectiveness in recovering shallow elastic structure. This work holds promise for widespread application across the hundreds of recent and planned OBS deployments across the world’ s oceans as it is a fast and effective means to image oceanic structures.

Keywords: Machine Learning, Inverse Problems, OBS

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[E] Oral | S (Solid Earth Sciences)：S-SS Seismology

[S-SS03] Seismological advances in the ocean

convener:Takashi Tonegawa(Research and Development center for Earthquake and Tsunami, Japan Agency for Marine-Earth Science and Technology), Takeshi Akuhara(Earthquake Research Institute, University of Tokyo), Pascal Audet(University of Ottawa), Taka'aki Taira(Berkeley Seismological Laboratory, University of California, Berkeley)

Seismic observations in the oceans have been steadily increasing in the last two decades due to continued deployments and recent advances in temporary arrays and permanent (cabled) networks including seismometers, hydrophones, and pressure gauges. The use of ocean data on the seafloor and in the seawater has compelled the community to create/modify data processing techniques, with exciting new findings on, e.g., seismicity, wave phenomena, seismic structures from active and passive surveys, and underwater phenomena. Some of these studies may be related to environmental seismology in the ocean. The purpose of this session is to share recent advances in seismology from data obtained in the oceans, including new seismicity and seismic velocity, progress in instrumentation, data processing on active and passive seismic approaches, characterization of ambient noise, e.g., microseisms and infragravity waves, as well as challenges in suppressing contamination from ocean-related noise.

[SSS03-07] Seafloor seismology with Distributed Acoustic Sensing in Monterey Bay

★Invited Papers

*Nate Lindsey[1,2], Jonathan Ajo-franklin[4,2], T. Craig Dawe[3], Lise Retailleau[1], Biondo Biondi[1], Lucia Gualtieri[1] (1.Stanford University, 2.Lawrence Berkeley National Laboratory, 3.Monterey Bay Aquarium Research Institute, 4.Rice University)

[SSS03-08] Marine seismic observation by Distributed Acoustic Sensing using seafloor cable off Sanriku for long-term monitoring

*Masanao Shinohara[1], Tomoaki Yamada[1], Takeshi Akuhara[1], Kimihiro Mochizuki[1], Takeo Kasajima[2], Takahiro Arioka[2], Masayuki Hamakawa[3], Shunsuke Kubota[4] (1.Earthquake Research Institute, University of Tokyo, 2.Fujitsu Laboratories Ltd., 3.Fujitsu Limited, 4.YK Giken Co., Ltd.)

[SSS03-09] Strain release by “rapid” aseismic slip at the Izu-Bonin trench

*Yoshio Fukao[1], Hiroko Sugioka[5], Aki Ito[1], Takashi Tonegawa[1], Mikiya Yamashita[4], Hajime Shiobara[2], Tatsuya Kubota[3], Tatsuhiko Saito[3] (1.Japan Agency for Marine-Earth Science & Technology, 2.University of Tokyo, 3.National Research Institute of Earth Science and Disaster Resillence , 4.National Institute of Advanced Industrial Science and Technology, 5.Kobe University)

[SSS03-10] Glacier tremors revealed by Ocean Bottom Seismometer in Greenland

*Evgeny A. Podolskiy[1], Yoshio Murai[2], Naoya Kanna[1], Shin Sugiyama[3] (1.Arctic Research Center, Hokkaido University, 2.Institute of Seismology and Volcanology, Hokkaido University, 3.Institute of Low Temperature Science, Hokkaido University)

[SSS03-11] Distribution of long period seismic "hum" sources following large storms in the north Pacific and their relation to infragravity waves

Satish Maurya[1,2], *Taka'aki Taira[1], Barbara Romanowicz[1,3] (1.Berkeley Seismological Laboratory, University of California, Berkeley, 2.Department of Earth Sciences, Indian Institute of Technology Bombay, 3.Collège de France, Paris)

[SSS03-12] Ambient noise field and temporal changes on ambient noise auto/cross-correlogram at the sea bottom inferred from ocean-bottom seismic and pressure arrays

*Yoshihiro Ito[1], Miyuu Uemura[1], Spahr C. Webb[2], Kimihiro Mochizuki[3], Stuart Henrys[4] (1.Disaster Prevention Research Institute, Kyoto University, 2.Lamont Doherty Earth Observatory, Columbia University, 3.Earthquake Research Institute, The University of Tokyo, 4.GNS Science)

Seafloor seismology with Distributed Acoustic Sensing in Monterey Bay

*Nate Lindsey[1,2], Jonathan Ajo-franklin[4,2], T. Craig Dawe[3], Lise Retailleau[1], Biondo Biondi[1], Lucia Gualtieri[1]

1. Stanford University, 2. Lawrence Berkeley National Laboratory, 3. Monterey Bay Aquarium Research Institute, 4. Rice University

Emerging distributed fiber-optic sensing technology coupled to existing subsea telecommunications cables enable access to meterscale, multi-kilometer aperture, broadband seismic array observations of ocean and solid earth phenomena. In this talk, we report on two multi-day Distributed Acoustic Sensing (DAS) campaigns conducted in 2018 and 2019 with the Monterey Accelerated Research System (MARS) observatory tether cable. In both experiments, a DAS instrument located on shore was connected to a fiber inside the buried MARS cable and recorded a ~10,000-component, 20-kilometer-long, strain-rate array. We use the 8 TB DAS dataset to address three questions:

1. How can seafloor DAS earthquake records inform offshore seismic hazard assessments? Offshore seismic hazards are poorly characterized despite dense coastal populations. The MARS DAS array captured multiple unaliased earthquake recordings, which document phase conversions and abrupt S-wave delays of 0.25 s at mapped (and unmapped) faults that transect the cable. Minor earthquakes in Northern California produce seismic waves in the range 0.5 - 50 Hz, which interact with submarine faults lying just offshore. Spectral ratios and wavefield synthetics are used to explore how seismic waves from well-characterized earthquakes interact with poorly-characterized subsea faults.

2. How are ocean microseisms and other coastal processes recorded by subsea DAS? Horizontal seabed ambient noise recorded with the MARS DAS array matches the expected dispersion of primary microseisms (f~0.05-0.15 Hz) induced by shoaling ocean surface waves, but at a higher band than onshore observations. Separation of incoming and outgoing waves recorded over the DAS array validates the Longuet-Higgins-Hasselmann theory that bi-directional ocean wind-waves undergo nonlinear wave interaction, producing secondary microseisms (f~0.4-1.5 Hz), even when the outgoing energy is observed to be <1% of the incoming energy. Continuous wavelet transforms of sea state observations from buoys, onshore broadband seismometers, and subsea DAS provide insight into the physics of microseism generation and ocean-solid earth coupling. Additionally, DAS provides observation of post-low-tide tidal bores (f~1-5 Hz), storm-induced sediment transport (f~0.8-10 Hz), infragravity waves (f~0.01-0.05 Hz), and breaking internal waves (f~0.001 Hz) consistent with previous point sensor observations in Monterey Bay.

3. How is the coastal seafloor structure organized from shore to shelf break? The northern continental shelf of Monterey Bay is comprised of allochthonous Cretaceous granite overlain by marine sediments of varying thickness, and is crosscut by abandoned (and subsequently filled) paleochannels. Noise interferometry applied to the full MARS DAS dataset in the 0.25 - 5 Hz range retrieves Scholte waves, which are dispersive and coherent over 2 - 6 kilometers. We apply fundamental mode dispersion (1.5D) imaging to subarray noise correlations in order to understand the sediment thickness distribution across the shelf. Our model is compared with recent seismic reflection profiling conducted by the USGS California Seafloor Mapping Program.

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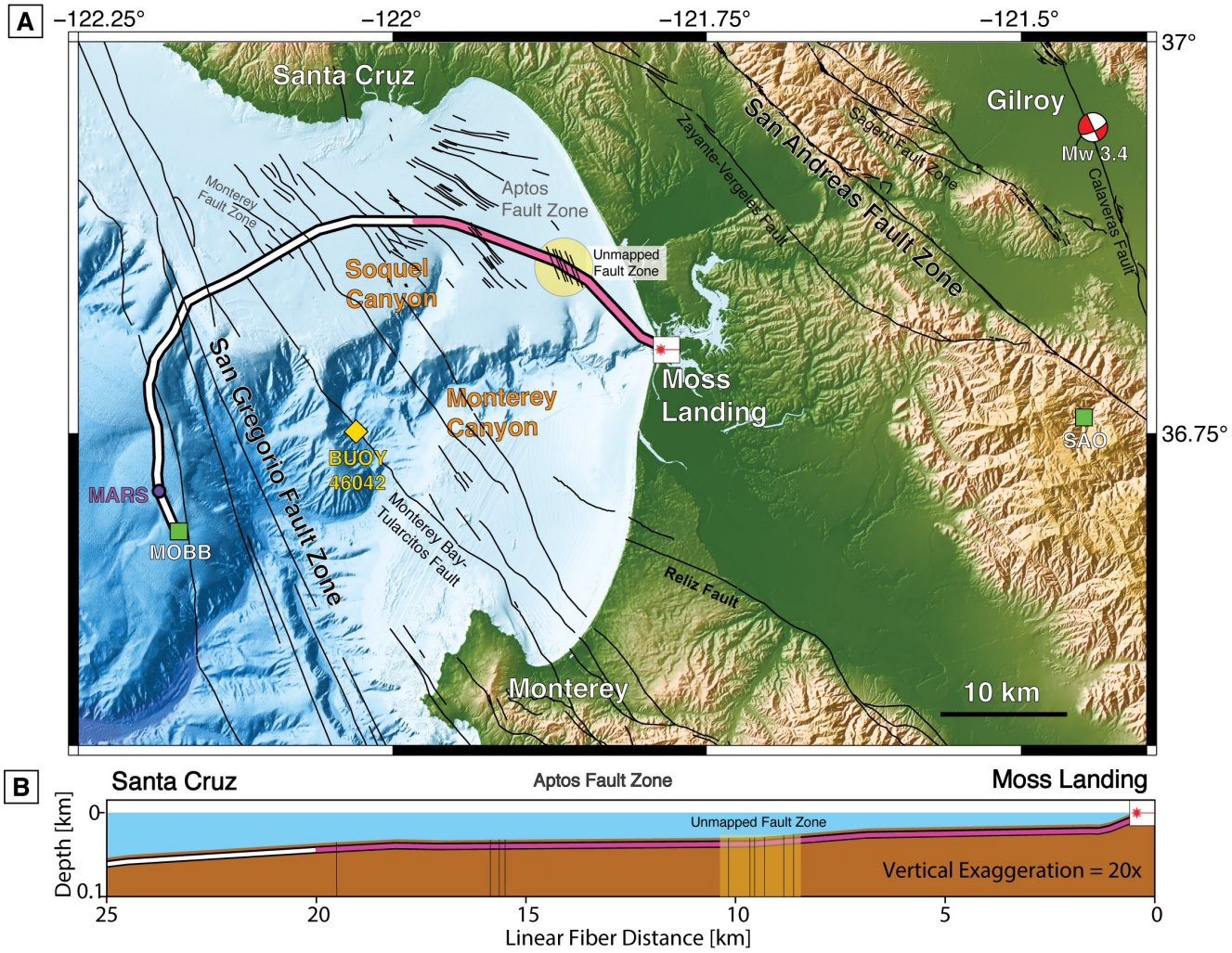
Keywords: fiber-optic, microseism, distributed acoustic sensing



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Marine seismic observation by Distributed Acoustic Sensing using seafloor cable off Sanriku for long-term monitoring

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1. Earthquake Research Institute, University of Tokyo, 2. Fujitsu Laboratories Ltd., 3. Fujitsu Limited, 4. YK Giken Co., Ltd.

Distributed Acoustic Sensing (DAS) measurement is one of optical fiber sensing technologies and utilizes an optical fiber itself as a sensor. Seismic observation using DAS technology becomes popular because spatially high-density data can be obtained. In the DAS measurement, a coherent laser pulse with short duration is transmitted continuously to a single mode optical fiber, and backscattered light is observed. When a small deformation of a fiber occurs by a vibration near fiber, a pattern change of the backscattered light is observed. Travel time of light and pulse length correspond to distance of measurement point and spatial resolution, respectively. In 1996, a seafloor seismic tsunami observation system using an optical fiber cable was deployed off Sanriku by Earthquake Research Institute, the University of Tokyo. Six spare (dark) optical fibers are included in the system for future extension. We performed DAS measurement using a spare fiber of the Sanriku system in February 2019. An interrogator was installed in the landing station temporarily, data were recorded continuously for 100 km length with gauge lengths of 10 m or 40 m and sampling frequency of 500 Hz. Channel interval was 5 m. Consequently, we obtained data with 20,000 channels. A recording period was approximately two days. Additional observation using a different interrogator was performed to confirm the performance of the DAS measurement in June, 2019. As a result, earthquakes including small local earthquakes occurring near the cable system, and deep earthquakes were recorded.

It is recognized that the DAS measurement using a seafloor cable with an optical fiber is useful for earthquake observation in marine environment. However, we have obtained temporally short dataset. To monitor seismic activity on seafloor, a long-term observation is needed. In addition, to understand the characteristics of the DAS measurement for earthquake observation, we need more dataset. Therefore, an experimental measurement for the long-term observation was carried out. The objective of this measurement, we made the measurement as long as possible. The recording period basically depends on a capacity of a recording device. We made a success of a continuous DAS measurement for approximately two weeks. The DAS measurement using the Sanriku seafloor cable system was started on 18th November 2019, and the measurement was finished on 2nd December 2019. We set the same recording parameters as those of the measurement in February 2019. To reduce a total amount of dataset, a total length of the measurement was set to 48 km for the first day and extended to 70 km after the second day. A total capacity of the dataset reaches 15 TB for two weeks. Many earthquake including deep earthquakes are also recorded by the DAS measurement. We will start development of a data processing and recording system for long-term monitoring using the obtained data.

Keywords: Seafloor optical cabled observation system off Sanriku, Distributed Acoustic Sensing (DAS) measurement, Long-term high-density seafloor seismic observation

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Strain release by “rapid” aseismic slip at the Izu-Bonin trench

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Abstract

No great earthquakes have been historically documented at the Izu-Bonin Trench, where subduction is believed to be taken up largely by aseismic slip, although the detail of the slip process has been poorly known. We deployed an array of ocean bottom pressure gauges and a broadband ocean bottom seismometer with a differential pressure gauge inward of the northern Bonin Trench for a year from May 2015 (Fig.1). The array recorded pressure changes associated with the sudden uplift/subsidence of the seafloor caused by the nearby Mw6.0 thrust earthquake (01/Sep/2015), and the consequent generation and propagation of sea surface disturbance (tsunami) (Fig.1). The records were inverted for the slip distribution of the mainshock (Fig.1). The inversion result was consistent with the seismic moment of the reported CMT solution, indicating that the mainshock was an ordinary event, not a tsunami earthquake. The records in a longer time window, however, showed the co-occurrence of aseismic slip with a characteristic time on the order of 5000 s (Fig.2). The similar aseismic slip recurred 3.5 days after the mainshock which was abruptly accelerated upon the occurrence of a small aftershock (Fig.3). Both of the aseismic events occurred mainly on the deeper extensions of the coseismic slip. The total seismic moment of the mainshock and two aseismic events was more than an order of magnitude larger than that of the mainshock, while the resultant stress drop was similar to that of the mainshock (~1 MPa). “Rapid” aseismic slip (a characteristic time of ~5000 s with a relatively low stress drop of ~1 MPa) may be a phenomenon that bridges the gap between geodetic SSEs (slow slip events) (a few days or longer in duration with stress drops of 0.01 to 0.1 MPa) and seismic earthquakes (a few minutes or shorter in duration with stress drops of 1 to 10 MPa). This new mode of slip may play a significant role at the Izu-Bonin Trench and possibly in other Mariana-type trenches.

Figure captions:

Figure 1. Top right: Source region and reported focal mechanisms of the Mw6.0 earthquake of 01/Sep/2015 near the Izu-Bonin trench and the location of the APG (Absolute pressure gauge) array. The slip distribution at the source is the result of the tsunami waveform inversion from the APG data. **Bottom right:** Cross-section across the trench showing the seismologically estimated plate boundary with the presumed hypocenter and mechanism of the Mw6.0 earthquake on it. The site distribution of the array is also shown. **Left:** Lowpass-filtered, tide-removed pressure record at station B10 showing the seafloor uplift and the consequent tsunami due to the Mw6.0 mainshock. The observed and synthetic traces are shown in black and red, respectively. The M5.6 foreshock which took place 1 min before the mainshock is not taken into account in the synthetic calculation.

Figure 2. Lowpass-filtered, tide-removed pressure records at eight stations of the APG array over a time window of 80000 s including the 01/Sep/2015 earthquake in the middle. The records show co-seismic and post-seismic vertical displacements of the seafloor, based on which the co-seismic slip and post-seismic slip along the plate boundary are estimated, including the characteristic time of the post-seismic slip. The resultant model curves of seafloor displacement are compared with the observed

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records.

Figure 3. Tide-removed pressure records at eight stations of the APG array over a time window of 80000 s including the 05/Sep/2015 small aftershock in the middle. The records show aseismic uplifts of the seafloor which are apparently accelerated upon the occurrence of the small aftershock. The aseismic slip along the plate boundary is estimated and the resultant model curves of seafloor displacement with the characteristic times different before and after the small aftershock are compared with the observed records.

Keywords: Ocean bottom seismology, Tsunami, Aseismic slip, Ocean bottom pressure observation

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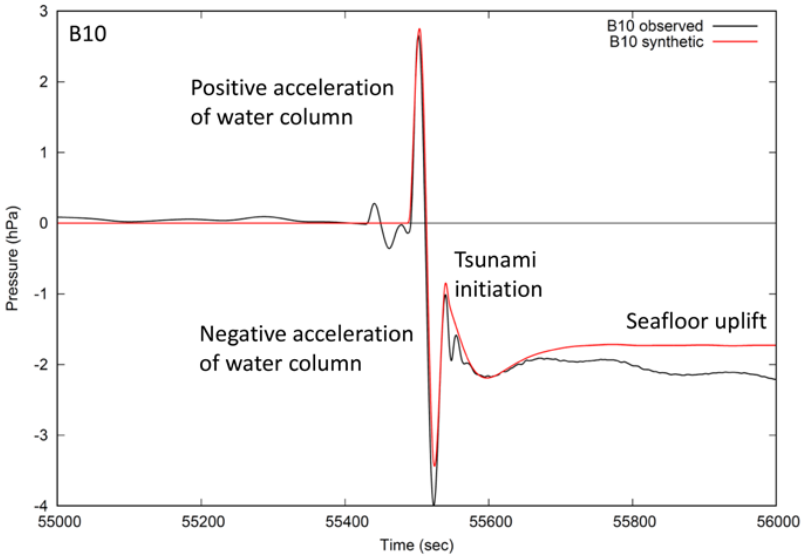
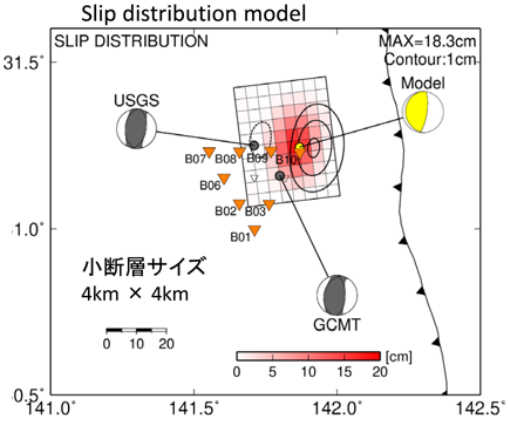
Figure 1

Comparison of observed and synthetic pressure records at B10



Slip distribution model



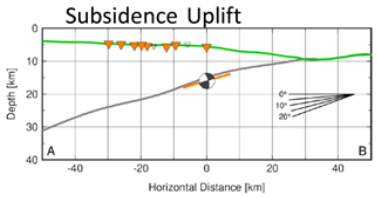
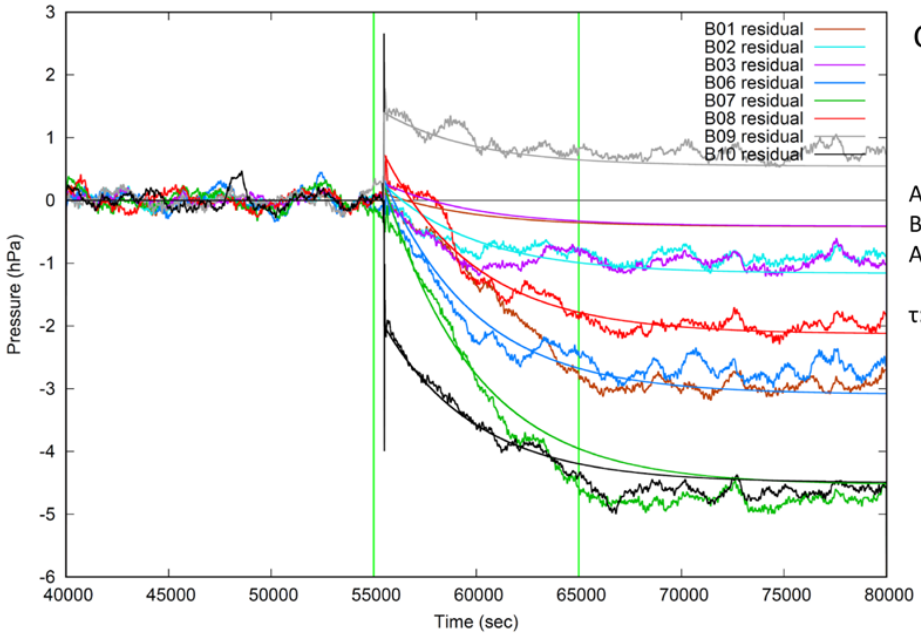


Figure 2

Seafloor uplift due to post-seismic slip



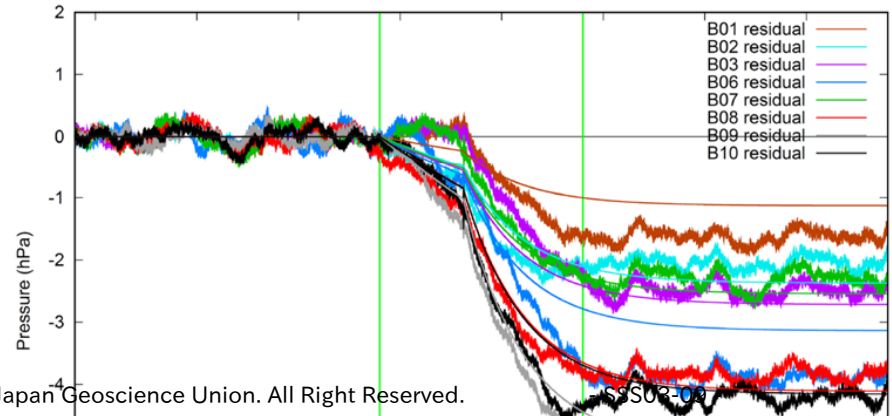
Curve fitting by

$$f(t) = A + B(1 - e^{-\frac{t}{\tau}})$$

A: Coseismic seafloor displacement
B: Post-seismic seafloor displacement
A+B: Resultant seafloor displacement
= Baseline offset
τ: Time constant of aseismic slip
Here, τ = 4500 s.

Figure 3

Seafloor uplift due to aftershock-associated aseismic slip



Pre-aftershock stage

$$f(t) = A\left(1 - e^{-t/\tau 1}\right)$$

$0 \le t \le t1$

Post-aftershock stage

$$f(t) = A\left(1 - e^{-t1/\tau 1 - (t-t1)/\tau 2}\right)$$

$t1 \le t$

t1=4100 s: Aftershock origin time

Here, τ1 = 18000 s, τ2 = 3000 s,

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Glacier tremors revealed by Ocean Bottom Seismometer in Greenland

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On the one hand, our understanding of glacier basal sliding is currently one of the least certain aspects in models used to predict the future evolution of glaciers and, therefore, the rates of global sea level rise. On the other hand, less than 20 years ago careful attention to weak seismic tremor led to a discovery of a nonvolcanic episodic tremor and slip (ETS), which has revolutionized our understanding of subduction zones. Glacier basal sliding is at least three orders of magnitude faster (~500 m per year vs. 0.1 m per year), making it reasonable to suggest that a family of similar seismological phenomena could be expected and analogies with tectonic subduction established.

However, *in situ* observations in remote polar regions are limited, difficult, and challenging due to harsh and extremely noisy conditions. For example, seismic sensors installed directly on ice surface are subjected to intense cracking noise, can melt out, loose level or simply be destroyed due to crevassing and mechanical loss of ice (known as iceberg calving). Moreover, on-rock installations have to be positioned aside from the glacier of interest and require significant technical preparations for protecting the stations from polar conditions and animals, which are usually difficult due to limited resources and lack of any infrastructure.

In summer 2019, for elucidating co-seismic glacial processes, we overcame these fundamental limitations by conducting the first Ocean Bottom Seismometer (OBS) experiment for cryospheric research in Greenland. Specifically, we manually deployed an OBS system (i.e., 3D geophone, hydrophone, and thermometer) to ~250 m depth at about 600 m from the calving front of a Greenlandic marine-terminating glacier (Bowdoin Glacier). Such configuration implied that the receiver was coupled directly to the sliding interface of the glacier. This unique campaign was integrated into a comprehensive international expedition to Bowdoin Glacier, with various geophysical observations simultaneously made directly on ice, in the fjord, and rock outcrops nearby (e.g., GPS and seismic arrays, time-lapse photography, UAV mapping, and etc).

Our analysis shows very intense seismic activity, encompasses a major calving event with iceberg disintegration above the OBS, and suggests a presence of a distinct diurnal tremor signal which is apparently correlated with a horizontal ice speed of the glacier (~1 m per day). In this truly inter-disciplinary contribution, we present the experiment, provide our preliminary interpretation of the continuous tremor as evidence of sliding at the ice-rock interface, and discuss possible alternatives, which could be of interest to a vast community of geoscientists.

Keywords: Ocean Bottom Seismometer, seismic tremor, cryoseismology, Greenland, Arctic, Hydroacoustics

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Distribution of long period seismic "hum" sources following large storms in the north Pacific and their relation to infragravity waves

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The earth's low frequency "hum" originates primarily in the oceans and is generated through interaction of infragravity waves with the seafloor. The infragravity waves themselves are produced by non-linear interaction between ocean waves generated by storms. We investigate the spatially and temporally varying distributions of sources of the Earth's low-frequency seismic hum at high space-time resolution during a seismically quiet 7-day period in December 2015 in which two large storms with different reaches propagate across the North Pacific Ocean. Our beamforming and array analyses obtained for a Cascadia storm are consistent with the conceptual model of Rhie and Romanowicz (2006, G-Cubed) in which sources of seismic hum are generated progressively, as infra-gravity waves propagate away from the impact location of the storm on the west coast of North America, along the coast and toward the open ocean. Our result suggests that the distribution of Earth's hum sources strongly depends on the propagation characteristics of the corresponding storms. We discuss these results in the light of more recent data (winter of 2018-2019) during which the dense AACSE (Alaska Amphibious Community Seismic Experiment) was deployed off-shore Alaska together with on-shore USArray broadband stations in Alaska, providing the opportunity to investigate the relationship of Pacific storms and "hum", as recorded on offshore buoys, absolute/differential pressure gauges and broadband seismometers together with land-based broadband seismic arrays in Alaska and California.

Keywords: Infragravity waves

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Ambient noise field and temporal changes on ambient noise auto/cross-correlogram at the sea bottom inferred from ocean-bottom seismic and pressure arrays

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The interactions of wind with the ocean surface, ocean wave with acoustic wave, acoustic wave with seismic wave below the sea bottom, and the interplay among them drive important energy flows from the atmosphere to the lithosphere. Uncertainty remains regarding the origin of wind-related noise in the ocean and its coupling to seismic noise below the sea floor. Seismic interferometry is a powerful tool that uses microseisms, or ambient noise within solid earth, to monitor temporal seismic velocity change by referring to the auto/cross-correlation as a Green’s function at the sites, and its temporal change. The most important assumption when detecting seismic velocity changes with seismic interferometry is that mutually uncorrelated noise sources are distributed randomly in space and time without any temporal changes in their density and intensity in a fully diffuse wave field. An effect of temporal variation on the ambit noise field to the retrieval of Green’s function is, however, not fully understood, nor is how reliable temporal changes in interferogram noise are, especially when accompanied by large earthquakes and slow slip events. Here, we show relationships among the temporal changes of sea surface wave, acoustic wave, and seismic wave fields, which are observed in ocean bottom pressure gauges and seismometer arrays installed in New Zealand. The temporal variation in the power spectrum obtained from continuous ocean bottom seismometer and pressure records near 200 mHz correlates with the temporal variation in wind speed above the sites, particularly during wind turbulence of more than 5 m/s. The temporal fluctuation in the ocean bottom pressure caused by the ocean surface wave field correlates to that of a microseism near 200 mHz. The temporal variations in the power spectrum from both continuous ocean bottom pressures and microseisms in the 200–800 mHz range show a positive correlation. After calculating the auto/cross-correlation functions (ACF/CCF) from ambient noise in a 200–800 mHz pass band every 6 h, the temporal variation in the correlation between the ACF/CCFs is investigated every 6 h. The temporal variation in the ACF/CCFs correlates with the time derivative of the temporal changes in the power spectrum amplitude of both the bottom pressure and the microseism rather than the temporal changes in the amplitude of the power spectrum. This suggests that the temporal change that occurs in the seismic interferogram owing to ambient noise, is mostly controlled by the temporal change in the ocean wave field undergoing fluctuations by the atmospheric turbulence over the sea surface. The temporal variations in the noise field in space and time may break the assumption on seismic interferometry, and eventually make the apparent temporal change in interferogram noise.

Keywords: seismic interferometry, ambient noise, temporal variation

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[E] Oral | S (Solid Earth Sciences)：S-SS Seismology

[S-SS04] Strong Ground Motion and Earthquake Disaster

convener:Kazuhiro Somei(Geo-Research Institute), Yasuhiro Matsumoto(Kozo Keikaku Engineering)

Strong ground motion has social impacts as it induces earthquake disasters. We solicit contribution on any seismological topics related to strong ground motion that includes, but are not limited to, source processes, wave propagation, and site effects. We also welcome contribution on earthquake related disaster mitigation.

Introduction

[SSS04-01] Separation of High-frequency Source and Path Effects from South Africa Mine Data

*James Mori[1], Hiroshi Ogasawara[2] (1.Earthquake Hazards Division, Disaster Prevention Research Institute, Kyoto University, 2.Faculty of Science and Engineering, Ritsumeikan University)

[SSS04-02] Site effects at strong motion stations in Shizuoka prefecture, Japan, and its application for validating the underground velocity model

*Tomotaka Iwata[1], Hayato Shimazu[2], Kimiyuki Asano[1], Kazuhiro Somei[3], Shigeki Senna[4] (1.Disaster Prevention Research Institute, Kyoto University, 2.Graduate School of Science, Kyoto University, 3.Geo-Research Institute, 4.National Research Institute for Earth Science and Disaster Resilience)

[SSS04-03] Small-aperture Microtremor Array Surveys in the Southern Part of the Kyoto Basin and Northern Part of the Nara Basin, Japan

*Kimiyuki Asano[1], Tomotaka Iwata[1], Haruko Sekiguchi[1] (1.Disaster Prevention Research Institute, Kyoto University)

[SSS04-04] Microtremor observation in the tsunami inundation predicted area in Hokuriku Region: Preliminary resutls from observed data in Suzu city, Ishikawa prefecture

*Michihiro Ohori[1] (1.Research Institute of Nuclear Engineering, University of Fukui)

[SSS04-05] Subsurface velocity structure of Saga Plain and Shiroishi Plain, Kyushu, Japan, estimated by microtremor array survey

*Masayuki Yoshimi[1], Michiko Shigefuji[2], Tatsuo Kanno[2], Ryosuke Noma[2], Hiro Nimiya[1] (1.Geological Survey of Japan, AIST, 2.Faculty of Human-Environment Studies, Kyushu University)

Separation of High-frequency Source and Path Effects from South Africa Mine Data

*James Mori[1], Hiroshi Ogasawara[2]

1. Earthquake Hazards Division, Disaster Prevention Research Institute, Kyoto University, 2. Faculty of Science and Engineering, Ritsumeikan University

Using seismic data recorded in deep South Africa mines at stations with close distances to earthquakes, we examined waveforms to try and separate the source and path contributions in the high-frequency radiation. We studied the waveforms from small events recorded at several closely spaced stations, and also studied the waveforms from closely spaced events at single stations. We used cross correlations of the waveforms over a range of frequencies from 2 to 20 hz, to estimate the degree of similarity of the recorded data.

This dataset provides an excellent opportunity to investigate the high-frequency characteristics of the seismic waveforms because stations are located at distances of several hundred meters to a few kilometers and installed on hard rock sites at 1 to 3 km depth in the mine, which minimizes the site effects. We also compared the waveforms from the subsurface mine stations with stations located on the surface.

Preliminary results indicate that for the lower frequencies, there is relatively more contribution from the source effects, while at higher frequencies the path effects are larger. High frequency content due to both the source and path are likely related to the wavelengths of the geological heterogeneities of the region.

Keywords: South Africa Mine, High-frequency , Earthquakes

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Site effects at strong motion stations in Shizuoka prefecture, Japan, and its application for validating the underground velocity model

*Tomotaka Iwata[1], Hayato Shimazu[2], Kimiyuki Asano[1], Kazuhiro Somei[3], Shigeki Senna[4]

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Estimation of site effect on ground motion is one of the fundamental issues for seismic hazard assessment. The spectral inversion method is applied to separate source, propagation-path, and site effects from strong motion data (e.g. Iwata and Irikura, 1988). In this study, we estimated site effects of strong motion observation stations in Shizuoka prefecture. We use totally 166 strong motion stations including K-NET, KiK-net and JMA, together with SMAD and Seismic intensity stations in Shizuoka prefecture from the SK-net. The number of events is 501, occurring in the period from March 1996 to July 2019, and the total number of event and station pairs is 8440. We assume the site effect of KiK-net SZOH24 is 2 for all frequency range. We also assume different Q-values of the propagation-paths in the Eastern and the Western areas with a border of the Itoigawa-Shizuoka Tectonic line. The obtained site effects of K-NET and KiK-net stations were compared to those by other studies and those were agreed well. One of the important usages of the obtained site effects is to discuss the basin velocity models, comparing those with theoretical amplification factors using subsurface velocity models in the study area, e.g., J-SHIS (Fujiwara et al., 2009, 2012), and the basin model by Wakai et al. (2019) for discussing the performance of these models.

Keywords: Spectral inversion, Site effects, SK-net, Strong motion data, Basin velocity model

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Small-aperture Microtremor Array Surveys in the Southern Part of the Kyoto Basin and Northern Part of the Nara Basin, Japan

*Kimiyuki Asano[1], Tomotaka Iwata[1], Haruko Sekiguchi[1]

1. Disaster Prevention Research Institute, Kyoto University

The Nara-Bonchi-Toen Fault Zone forms the eastern margin of the Kyoto and Nara basins. The Kyoto and Nara basins are mostly filled by the Plio-Pleistocene Osaka Group. Holocene alluvium and terrace deposits covering over the Osaka Group distributed along the Kizu and Uji rivers. The thickness of alluvium layers in the Kyoto Basin is thought to be less than 20 m based on analysis of a boring database (e.g. Kansai Geoinformatics Council, 2002). Improvement on the velocity structure model from the superficial alluvium layers to the seismic bedrock is quite important for advanced strong motion prediction for future earthquakes from nearby source faults. As a part of Comprehensive Research Project for the Nara-Bonchi-Toen Fault Zone funded by the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan, we have carried out various kind of geophysical surveys to investigate the velocity structure in the Kyoto and Nara basins.

Miniature to small aperture microtremor array surveys are carried out at many sites in the southern part of the Kyoto prefecture to obtain information on S-wave velocity of shallow subsurface sedimentary layers (Fig.1). The number of surveyed sites is 57 as of Feb. 18, 2020, and the field work is undergoing to cover the whole area of the Nara and Kyoto basins. We carried out miniature and small equilateral triangle array observations at each measurement site except several sites where a small array observation could not be carried out. The circumradius is 0.6 m for a miniature array, and the circumradius for a small array depends on site in a range from 6 to 8 m. A portable integrated microtremor observation system HAKUSAN JU410 was installed at each apex of the equilateral triangle and the center of circumscribed circle. The microtremor was recorded continuously more than 15 minutes at a sampling rate of 200 Hz after amplified by 100 times (200V/G).

The vertical component of the observed microtremor were analyzed to obtain the spatial autocorrelation (SPAC) coefficients (Aki, 1957). The spatial autocorrelation function was calculated in the frequency domain, and the Fourier spectrum was smoothed by the technique of Konno and Ohmachi (1998). The phase velocity dispersion curve was estimated by the extended SPAC method (Ling and Okada, 1993; Okada, 2003).

The one-dimensional S-wave velocity structure model for each measurement site was estimated by assuming that the observed phase velocity dispersion curve as the fundamental mode of the Rayleigh wave using the Markov chain Monte Carlo method. The velocity structure model of deep sedimentary layers (Vs >= 550 m/s) and the upper crust was given referring to the existing three-dimensional velocity structure models J-SHISV2 (Fujiwara et al., 2012), and the velocity structure model from the lower crust to upper mantle was referred to JIVSM (Koketsu et al., 2012). The obtained S-wave velocity structure model will be discussed in terms of spatial distribution of low-velocity layers with referring to surface geology and boring data information.

H/V spectra was also estimated from three-component records of the observed microtremors. The observed peak frequency of H/V spectra is shown in Fig.1. The H/V peak frequency is 0.3–0.4 Hz in the southern part of the Kyoto Basin including the Ogura-ike reclaimed land. It is relatively high (~1 Hz) in Kyotanabe where the boundary of the Kyoto and Nara basins is geologically identified. The sites around the Narayama Hills have the H/V peak frequency of 0.4–0.5 Hz, indicating the existence of thick Osaka Group sediments.

Acknowledgement: This work was conducted as a part of Comprehensive Research Project for the

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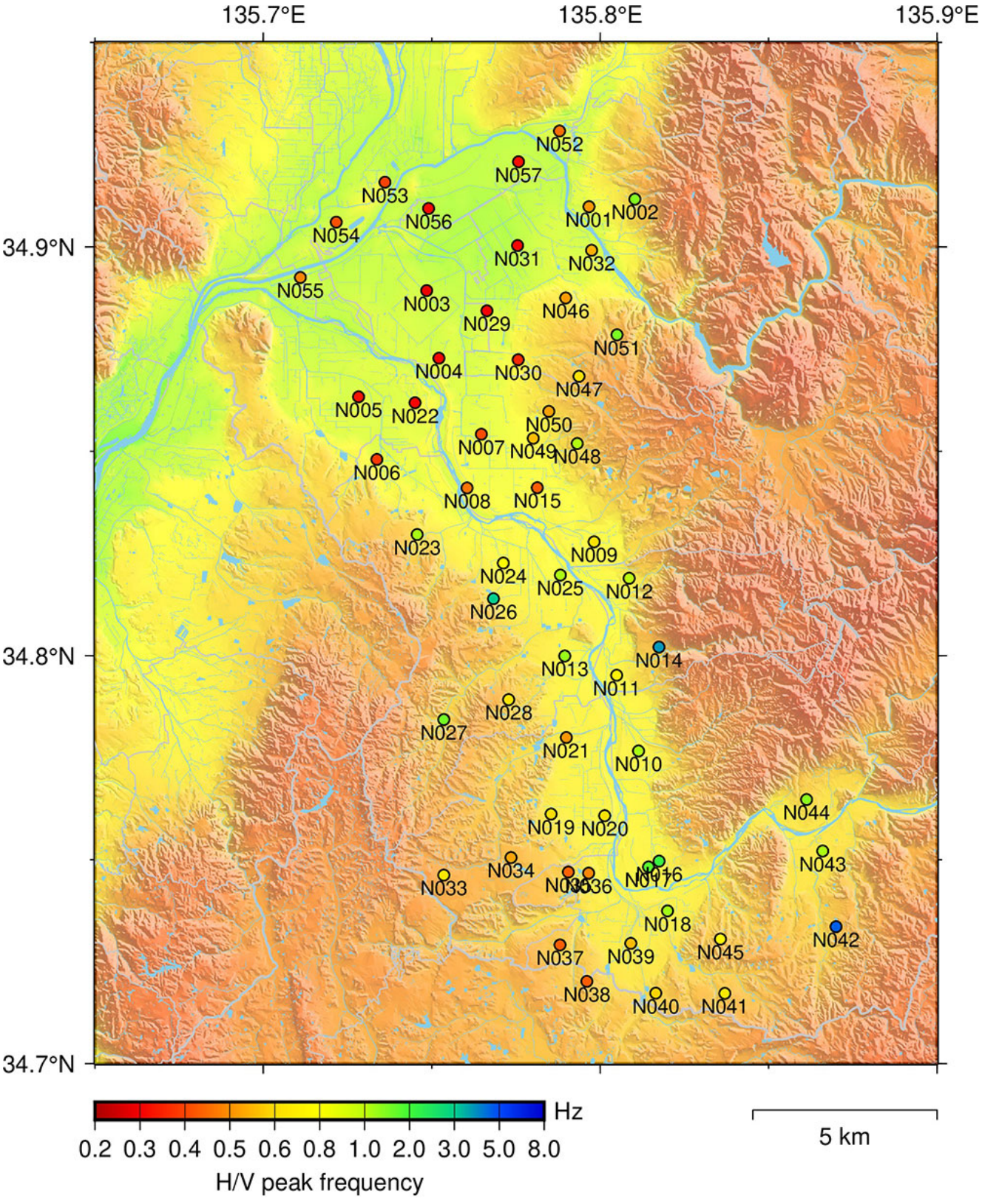
Nara-Bonchi-Toen Fault Zone of the Ministry of Education, Culture, Sports, Science and Technology, Japan.

Keywords: microtremor array survey, velocity structure model, Kyoto basin, Nara basin



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Microtremor observation in the tsunami inundation predicted area in Hokuriku Region: Preliminary resutls from observed data in Suzu city, Ishikawa prefecture

*Michihiro Ohori[1]

1. Research Institute of Nuclear Engineering, University of Fukui

Compared with the Pacific coast, the Japan Sea coast has experienced few tsunami disasters, especially in the Hokuriku region, where the seismicity is low; however, disaster prevention awareness is also low. To promote practical disaster prevention education by making full use of lessons learned from the tsunami disaster following the 2011 Tohoku Earthquake, it is crucial to deepen our understanding of a devastating tsunami following strong ground shaking and relevant damage from an earthquake. In our previous study, focusing on the Hokuriku region in Japan (Fukui, Ishikawa, and Toyama prefectures), we conducted a tsunami simulation and examined the resulting tsunami hazard map. Three potential faults of Mw7.6 earthquake were selected to generate the tsunami. Also, using a simplified method, ground shaking and liquefaction rates were evaluated to gain insight into tsunami hazard in relation to strong ground motion. In particular, attention was focused on Suzu City in Ishikawa prefecture as a region where the damage resulting from a tsunami is especially devastating. Furthermore, the costal lowland, which represents the primary inundation area of the city, has high seismic intensity and liquefaction occurrence rate. To escape damage resulting from the tsunami, it is important to evacuate to a safe place as soon as ground shaking ends; however, to ensure the safety of the evacuation route, safety measures against earthquake shaking are also important. In this study, I conducted microtremoer measuremetns at about 80 sites along a costal area in Suzu City and preliminary resutls were presented. This study was partly supported by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan, under its Earthquake and Volcano Hazards Observation and Research Program.

Keywords: microtremor measurements, Hokuriku region, tsunami innundation predicted area

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Subsurface velocity structure of Saga Plain and Shiroishi Plain, Kyushu, Japan, estimated by microtremor array survey

*Masayuki Yoshimi[1], Michiko Shigefuji[2], Tatsuo Kanno[2], Ryosuke Noma[2], Hiro Nimiya[1]

1. Geological Survey of Japan, AIST, 2. Faculty of Human-Environment Studies, Kyushu University

We conducted microtremor array surveys to estimate S-wave velocity structure beneath the Saga Plain and Shiroishi Plain, Saga prefecture, Kyushu, Japan. Previous microtremor arrays performed along a P-wave reflection survey line have shown that the basement depth of the Saga Plain changes at the northern marginal fault zone of the Saga Plain and increases toward the Ariake Sea up to 1 km depth in the coast (Yoshimi et al., 2019, Yoshimi & Shigefuji, 2019) . On the November 2019, we performed microtremor array observation in the western part of the Saga plain and whole Shiroishi plain at eight sites: in the center of Saga city, southern part of Saga city, western part of Saga city, Ogi city, and four places in Shiroishi town (including KiK-net station SAGH05). Eight set of three-component velocity microtremor (Tokyo Sokushin SE-321, natural period 10 seconds) were used for the observation. To cover wider range of the wavelength, five to six arrays with different radius were set for each site. The maximum radius ranges 510m to 1100m. Vertical component of the microtremor data are analyzed with the SPAC method (Okada, 2003) to obtain phase velocity. By averaging phase velocities of every triangle array, unified phase velocities of Rayleigh wave are obtained for each site. Then, 1D S-wave velocity (Vs) structure of each array site was estimated from the observed phase velocity with the inversion technique using a GA method. We found that the velocity structure of the western part of the Saga plain is similar to that of the central part. Details will be shown in the presentation.

Keywords: S-wave velocity structure, phase velocity, northern marginal fault zone of the Saga Plain, ambient noise

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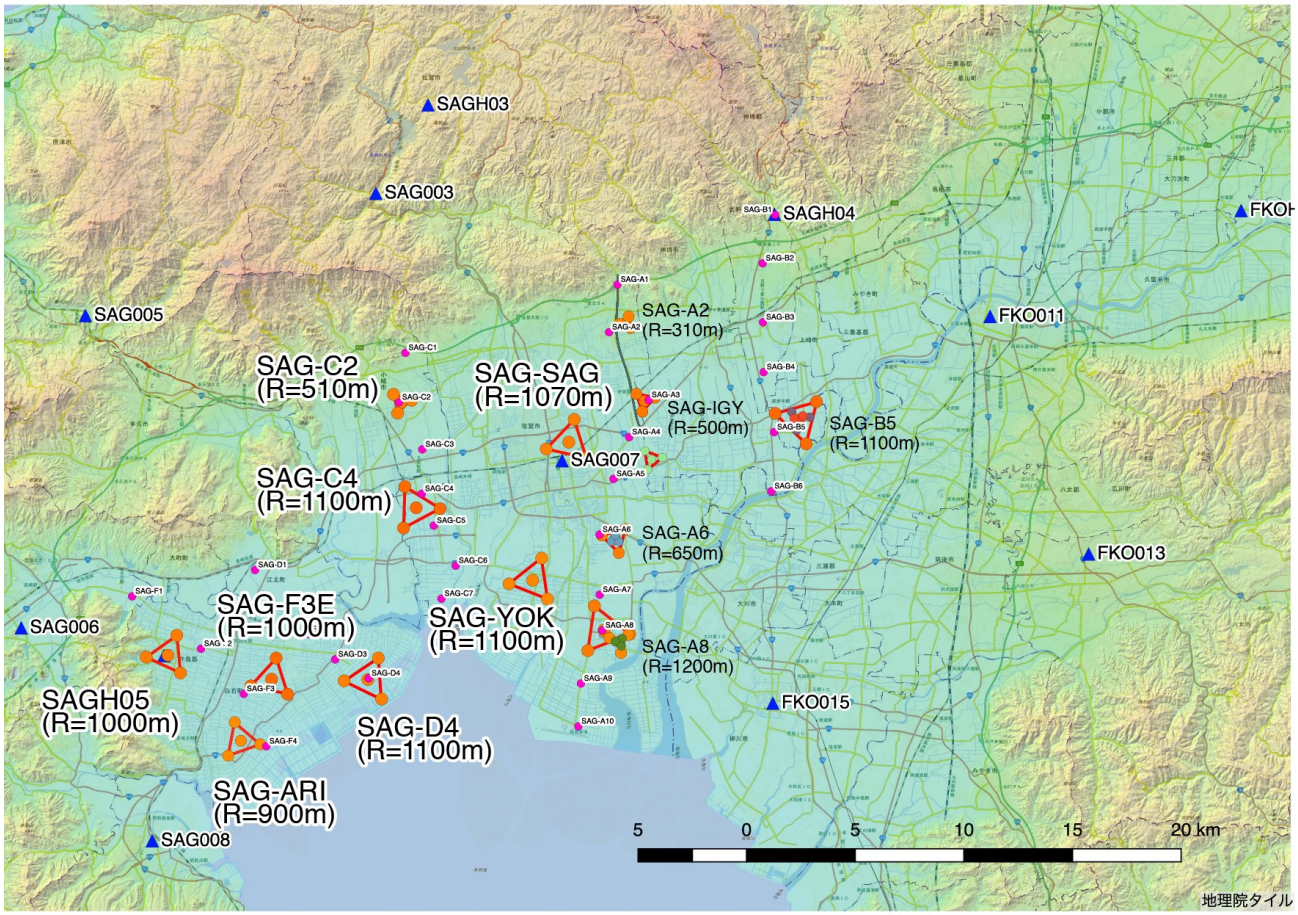

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[E] Oral | S (Solid Earth Sciences)：S-SS Seismology

[S-SS04] Strong Ground Motion and Earthquake Disaster

convener:Kazuhiro Somei(Geo-Research Institute), Yasuhiro Matsumoto(Kozo Keikaku Engineering)

Strong ground motion has social impacts as it induces earthquake disasters. We solicit contribution on any seismological topics related to strong ground motion that includes, but are not limited to, source processes, wave propagation, and site effects. We also welcome contribution on earthquake related disaster mitigation.

[SSS04-06] Estimation of shallow 3D S-wave velocity structure by applying surface-wave tomography using MeSO-net

*Hiro Nimiya[1,2], Tatsunori Ikeda[2], Takeshi Tsuji[2] (1.National Institute of Advanced Industrial Science and Technology, 2.Kyushu University)

[SSS04-07] Comparison of subsurface models derived from different physical quantities in the inversion based on microtremors and earthquake motions

*Kentaro Motoki[1], Kenichi Kato[1] (1.Kobori Research Complex)

[SSS04-08] Impact of Seismic Velocity Change on Ground Motion Modeling

*Hiroe Miyake[1], Taka'aki Taira[2], Li-Wei Chen[2] (1.Earthquake Research Institute, University of Tokyo, 2.Berkeley Seismological Laboratory, University of California, Berkeley)

[SSS04-09] Validation of S-wave velocity structure of sedimentary layers of the Kanto basin using strong motion records applied to seismic interferometry

*Kosuke Chimoto[1], Hiroaki Yamanaka[1] (1.Tokyo Institute of Technology)

[SSS04-10] Comparison of PGA and PGV at the S-net and land stations for the 2016 Mw7 off Fukushima earthquake

*Yadab Prasad Dhakal[1], Wataru Suzuki[1], Takashi Kunugi[1], Takeshi Kimura[1], Shin Aoi[1] (1.National Research Institute for Earth Science and Disaster Resilience (NIED))

Discussion

Estimation of shallow 3D S-wave velocity structure by applying surface-wave tomography using MeSO-net

*Hiro Nimiya[1,2], Tatsunori Ikeda[2], Takeshi Tsuji[2]

1. National Institute of Advanced Industrial Science and Technology, 2. Kyushu University

The estimation of S-wave velocity structure is essential to predict damage caused by earthquakes. Especially in the Tokyo metropolitan area, the earthquake hazard assessment has a significant meaning. Since the Tokyo metropolitan area located in the large-scale thick sedimentary Kanto basin and the population is centralized, the large damage due to earthquake is expected. However, it is difficult to conduct large-scale seismic exploration for the 3D velocity model construction due to heavy traffic and limited space in this area. Thus, constructing high-resolution 3D S-wave velocity structures of the Kanto basin is a challenging task. For this purpose, we performed surface-wave tomography on the Metropolitan Seismic Observation network (MeSO-net), which is deployed centered on Tokyo. It is suit for constructing 3D S-wave velocity structures in urban area since the surface wave can be extracted without active sources by applying seismic interferometry. In this study, we first computed cross-correlation of ambient noise to extract surface waves propagating between pair of stations. Then, we estimated surface-wave dispersion curves by applying a frequency domain method. Calculation in frequency domain simplifies estimation of dispersion curves. In this study, we developed iterative phase-velocity picking algorithm to estimate stable dispersion curves. We then estimated the 3D S-wave velocity structure by applying a direct surface-wave tomography method. This surface-wave tomography method can estimate S-wave velocity directly with 3D sensitivity kernels updated iteratively. Our result shows the S-wave velocity structure from surface to 2.5 km depth. The results show very low velocity which can reflect the thick sedimentary basin throughout the entire area. In the shallow part, we observed the low velocity anomaly corresponding to the soft sediments in low elevation area. In the deeper part, we observed the low velocity anomaly which is consistent with a trend of the pre-Neogene basement rock distribution. Our velocity model can also contribute to disaster management and assessment.

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Comparison of subsurface models derived from different physical quantities in the inversion based on microtremors and earthquake motions

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1. Kobori Research Complex

1. Introduction

We can make a subsurface model using horizontal to vertical spectral ratio (HVSR) of earthquake motions at single point on the ground surface based on diffusion wave field theory (Kawase et al., 2011). In addition, we can keep the accuracy of the subsurface model by combining a receiver function (RF) even at a thick sedimentary site (Motoki et al., 2016). If the subsurface model can be estimated from records at single point on the ground surface with sufficient accuracy, it can be applied to thousands of stations deployed nationwide, which will lead to the advancement to make a comprehensive model. It is important to confirm the validity of the subsurface models in comparison with the results of other geophysical surveys, such as PS logging and microtremor array exploration. In this report, for the KiK-net Atsuma station IBUH03, we estimated the subsurface model by individual inversions and joint inversions with HVSR, RF, and microtremor exploration. We evaluated which model could be properly represented from the reproducibility of the earthquake motions.

2. Method and data

We calculated HVSR and RF using the records at the ground surface of IBUH03. The phase velocity by microtremor exploration was referred to Kogawa et al. (2019). We inversed the subsurface models using the hybrid heuristic method (Yamanaka, 2007). The model with the smallest error was adopted as the estimated model. At the time of inverse analysis, we individually used HVSR, RF, and phase velocity. We also jointly used RF, HVSR and the phase velocity. Vs and Vp were constrained so that Vs and Vp were not lower than those of the upper layer.

3. Inversion result

Compared with the PS logging model, the models derived from the phase velocity had a slightly slower Vs, and the other model had a slightly faster Vs. For the depth of seismic bedrock, the models were estimated in the range from 5,000 m to 7,500 m, similar to J-SHIS model. Regarding the difference between the single and the joint inversion, there was no significant difference in the deep subsurface model when HVSR was added to RF. When the phase velocity was added, the substrate depth became shallower.

4. Validation of subsurface models using earthquake motions

For the validation, goodness of fit (GOF) by Anderson (2004) was applied with three indicators; the first one is the transfer function between the vertical array; second one is the accuracy of the simulation at the ground surface; the last one is the propagation time from the downhole to the ground surface. In the simulation, we estimated the earthquake motions at the ground surface by the one-dimensional wave propagation theory with the input records at the borehole. Then GOF in response spectra is calculated. The propagation time was calculated based on the seismic interferometry, and the observed time was compared with the vertical S wave travel time of the model.

We found that the GOF resulted in two different group on the reproducibility of earthquake motions. First group was that the amplitude of the transfer function and the response spectrum of the ground record

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were highly reproducible. Second group was that the phase of the transfer function and the propagation time were highly reproducible. For the first group, the single model with HVSR and the joint model with HVSR and RF were inverted. For the second group, the single model with phase velocity and the joint model with all quantities were included. There were no models that satisfy both groups simultaneously, primarily due to the effect of irregular boundary of sedimental layers, which is our task to be solved.

Keywords: Horizontal to vertical spectral ratioo, Receiver function, Phase velocity, Inversion of subsurface models

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Impact of Seismic Velocity Change on Ground Motion Modeling

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Temporal change of seismic velocity is well observed after strong shaking of large earthquakes. Seismic velocity drop is generally observed, indicating possible stress change due to water-saturated cracks and related reasons. It resulted in larger seismic intensity than conventional seismic hazard estimates. This impact is also expected to ground motion modeling and time-dependent seismic hazard assessment to the 1923 Kanto earthquake sequence with the mainshock and more than five M7-class aftershocks, the 2011 Tohoku earthquake sequence with the mainshock and three M7.5-calss aftershocks, and the Nankai Trough megathrust sequence associate with the M8 events with two-year delay in 1944 and 1946 and two-day delay in 1854. In addition, as seen in the 2016 Kumamoto earthquake sequence and the 2019 Ridgecrest earthquake sequence, the mainshock with largest ground motion is associate with the foreshock with strong shaking.

We quantitatively investigate the impact of seismic velocity change on ground motion modeling. Using the coda interferometry method by Chen et al. (2017), the seismic velocity change more than 5% with respect to the average S-wave velocity was observed for both the 2003 Tokachi-oki earthquake and the 2018 Hokkaido Eastern Iburi earthquake at the KiK-net IBUH03 station (e.g., Taira et al., 2019; Chen et al., 2020). The seismic velocity drop occurred near surface between the sensors at uphole and at downhole with 153 m deep with S-wave velocity of 520 m/s. We estimate the seismic velocity drop made the increment of 0.15 at maximum on the JMA seismic intensity scale. Since the increment of seismic intensity is proportional to the input ground velocity at the engineering bedrock, the temporal velocity change is not negligible in time-dependent seismic hazard assessment for aftershock forecasting with significant ground motion, and has a potential to over the threshold as a final push.

Keywords: seismic hazard, ground motion, velocity change

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Validation of S-wave velocity structure of sedimentary layers of the Kanto basin using strong motion records applied to seismic interferometry

*Kosuke Chimoto[1], Hiroaki Yamanaka[1]

1. Tokyo Institute of Technology

By using ground motion records, the seismic interferometry is applied to estimate the Green’s function and it is used for the estimation of the depth to the layer discontinuity. The strong ground motion is also used to estimate the depth to the seismic bedrock (e.g., Yoshimoto et al., 2009; Watanabe et al., 2011). We have also applied this technique to estimate the Green’s function of the sedimentary layers which has multiple reflected waves in the Shimousa area of the Kanto basin.

Since there is a lot of strong motion observation station in the Kanto basin and many of its records are available. MeSO-net is one of the strong motion networks operated in the Kanto basin (NIED, 2019). We then applied the seismic interferometry to those records and estimated Green’s function in the Kanto basin. For the autocorrelation analysis of seismic interferometry, we used transverse components of whole strong motion records. The bandpass filter and spectral whitening were also applied before autocorrelation (Oren and Nowack, 2017; Chimoto and Yamanaka, 2019).

Along the observation line of the MeSO-net from Hidaka to Asahi, we compared the autocorrelation functions with the theoretical Green’s function. We calculated the Green’s function theoretically by using the integrated underground model of Kanto area provided by J-SHIS (NIED, 2019). The travel time of significant reflected wave from seismic bedrock compares favorably with that calculated theoretically in the Shimousa region. The trend of arrival times of reflected wave along the line was same as the Yoshimoto et al. (2009).

Not only the reflected wave from the bedrock, the autocorrelation function has several arrivals from other layer boundaries and multiple reflected waves as well. We understand the validity of the structure model from this comparison. This comparison can also be done to other observation lines in the Kanto basin, we also investigated the north-south line from Fujisawa to Tsukuba.

Keywords: autocorrelation, seismic interferometry, strong ground motion, Kanto basin, Green's function

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Comparison of PGA and PGV at the S-net and land stations for the 2016 Mw7 off Fukushima earthquake

*Yadab Prasad Dhakal[1], Wataru Suzuki[1], Takashi Kunugi[1], Takeshi Kimura[1], Shin Aoi[1]

1. National Research Institute for Earth Science and Disaster Resilience (NIED)

The 2016 Mw 7.0 off Fukushima earthquake was the largest earthquake that occurred in the off Tohoku region after the deployment of the Seafloor observation network for earthquake and tsunami along the Japan Trench (S-net). One hundred and twenty-five stations of five segments of S-net except for the outer rise segment, which was not in operation during the earthquake, successfully recorded the seismic motions during the earthquake. We processed the strong-motion recordings at land (K-NET and KiK-net) and ocean bottom (S-net) stations for comparing peak ground acceleration (PGA) and peak ground velocity (PGV) for the abovementioned earthquake. One main difference between the land and S-net stations is that the sensors at S-net stations can undergo larger coseismic rotations compared to those on the land stations (Takagi et al. 2019, Nakamura and Hayashimoto 2019) for large PGAs. However, it has been found that the X-axis is more stable compared to the other two axes. Therefore, we selected the PGA of X-component for the S-net stations and lager PGA of two horizontal components for land stations for the comparison. We compared the PGA and PGV values with the attenuation curves using the equations in Si and Midorikawa (1999). We computed the fault distance using the model by Kubo et al. (2016). We found that the PGAs at the land (soil site condition) and S-net stations were generally explained well by the attenuation curve with small mean errors at distances smaller than 200 km (Fig. a). On the other hand, the attenuation was faster at the land stations than that at the S-net stations at larger distances. We adjusted the PGVs at the land stations for reference site condition of Vs30 of about 600 m/s following the procedure explained in Si and Midorikawa (1999), and compared the values with the attenuation curve. Again, we found that the PGVs on land were generally explained well by the attenuation curve within the expected error margins. On the other hand, the observed values at the S-net stations were larger by a factor of about three at distances < 200 km and by a factor of about four at distances > 200 km on average (Fig. b). Due to the lack of S-wave velocity information at the S-net sites, by using trial and error approach, we found that the Vs30 value of about 100-125 m/s, assumed identical at all sites (the simplest case), was needed to produce the mean error similar to that at land stations at distances within 200 km. A comparison of the PGVs after adjustment for the Vs30 value of 110 m/s is shown in Fig. b. The low Vs30 value used in the correction generally corresponds to the Vs30 values at some of the KiK-net stations, such as at Atsuma, Edosaki, Aso, and so on. However, the observations were larger than the mean predictions by a factor of about 1.5 on average at distances > 200 km even after the correction by the Vs30 value. It requires further examination to explain the difference at larger distances, such as the effect of sediment thickness and propagation path effect. We have been analyzing the data for a suite of earthquakes in the region, and report the results in the future papers.

Keywords: S-net, Attenuation, Ground motion prediction equation, Vs30, K-NET, KiK-net

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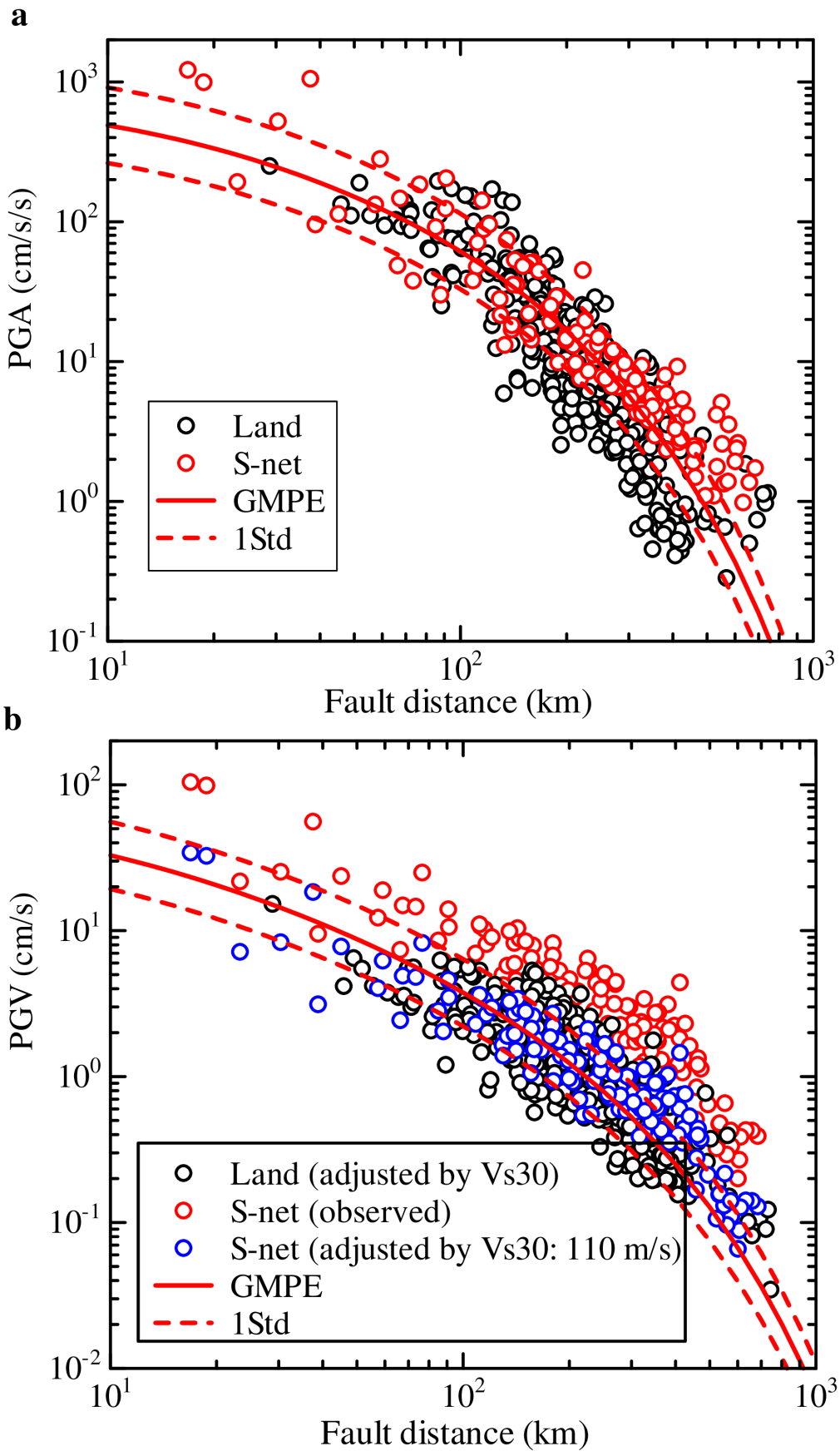

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[E] Oral | S (Solid Earth Sciences)：S-SS Seismology

[S-SS04] Strong Ground Motion and Earthquake Disaster

convener:Kazuhiro Somei(Geo-Research Institute), Yasuhiro Matsumoto(Kozo Keikaku Engineering)

Strong ground motion has social impacts as it induces earthquake disasters. We solicit contribution on any seismological topics related to strong ground motion that includes, but are not limited to, source processes, wave propagation, and site effects. We also welcome contribution on earthquake related disaster mitigation.

[SSS04-11] Source scaling and stress drop for the 2018 Hokkaido Eastern Iburi earthquake sequence estimated by the S-wave coda spectral ratio method

*Kazuhiro Somei[1], Kimiyuki Asano[2], Tomotaka Iwata[2], Ken Miyakoshi[1], Takashi Akazawa[1] (1.Geo-Research Institute, 2.Disaster Prevention Research Institute, Kyoto University)

[SSS04-12] Estimation of the strong motion generation area (SMGA) during the 2018 Hokkaido eastern Iburi earthquake

*Susumu Kurahashi[1], Kojiro Irikura[1] (1.Aichi Institute of Technology)

[SSS04-13] Strong ground motions from deep earthquakes in Hokkaido and attenuation structure of island arc

*Yasumaro Kakehi[1] (1.Graduate School of Science, Kobe University)

[SSS04-14] Simulation of near-fault ground motion for the 2016 Kumamoto earthquake (Mj7.3) considering the surface rupture geometry

*Asako Iwaki[1], Nobuyuki Morikawa[1], Hiroyuki Fujiwara[1], Takashi Kumamoto[2], Yurie Okuma[2], Hinata Kimura[3] (1.National Research Institute for Earth Science and Disaster Prevention, 2.Faculty of Science, Okayama University, 3.Graduate School of Environmental Studies, Nagoya University)

[SSS04-15] Modeling procedure of fault rupturing with detailed information of surface traces for predicting strong motions and permanent displacements

*Kazuo Dan[1], Saruul Dorjpalam[1], Atsuko Oana[2], Kensuke Arai[2], Hiroyuki Fujiwara[3], Nobuyuki Morikawa[3] (1.Ohsaki Research Institute, Inc., 2.Shimizu Corporation, 3.National Research Institute for Earth Science and Disaster Resilience)

[SSS04-16] Waveform inversion with empirical Green's functions for the source rupture process of the mainshock of the 2019 Ridgecrest earthquake sequence

*SHUANGLAN WU[1], Atsushi Nozu[1], Yosuke Nagasaka[1] (1.PORT AND AIRPORT RESEARCH INSTITUTE)

Source scaling and stress drop for the 2018 Hokkaido Eastern Iburi earthquake sequence estimated by the S-wave coda spectral ratio method

*Kazuhiro Somei[1], Kimiyuki Asano[2], Tomotaka Iwata[2], Ken Miyakoshi[1], Takashi Akazawa[1]

1. Geo-Research Institute, 2. Disaster Prevention Research Institute, Kyoto University

Source scaling and variation in stress drops play an important role not only in understanding source physics but also in advancing strong ground motion prediction because stress drop is an essential source parameter to control the high frequency ground motion amplitude. We estimated corner frequencies and stress drops for the 2018 Hokkaido Eastern Iburi earthquake sequence based on the S-wave coda spectral ratio method (Somei et al., 2014) to elucidate the source scaling and factor for variation in stress drops.

We analyzed 54 events (M_w 3.6-6.6) including the mainshock in the 2018 Hokkaido Eastern Iburi earthquake sequence. We collected ground motion records observed at KiK-net and F-net stations located in Hokkaido and Aomori prefectures. For KiK-net stations, we used acceleration time histories recorded by downhole strong motion sensors. For F-net stations, we used velocity time histories recorded by both strong motion and broadband seismographs. We followed the procedures of Somei et al. (2014) to process the data. The source spectral ratio for one station was obtained by the amplitude spectral ratio between large and small event records. For calculating the amplitude spectra, we used the S-wave coda portions in the same lapse time window between the event pair as the analyzed time window. In order to guarantee the commonality of decay curves in the time windows between the event pair, we examined the decay ratios of RMS envelopes in S-wave coda for six narrowband frequency ranges. The observed source spectral ratios were well explained by the ω^{-2} source spectral model, and we could estimate the corner frequencies for large and small events by grid search method. For comparisons, we also obtained the source spectral ratios from the observed spectral ratios for direct S-waves. We could clearly see the source spectral ratios derived from S-wave coda are much more stable by station to station than those derived from direct S-wave portions.

Assuming a circular clack fault model, the stress drop could be estimated from the seismic moment and the source radius (Eshelby, 1957). The source radius could be related to the corner frequency (Brune, 1970, 1971). In this study, the seismic moment of each event was fixed at the value provided by its F-net moment tensor solution. Stress drops for all 54 events spanned from 0.08 to 6.18 MPa. The stress drops of the mainshock (M_w 6.6) and the averaged value for all the aftershocks are 6.18 and 0.40 MPa, respectively. The stress drops of aftershocks do not exceed that of mainshock, which is the same result as that of Somei et al. (2014). Stress drops for the 2018 Hokkaido Eastern Iburi earthquake sequence are in the variation of those for past inland crustal earthquakes in Japan (Somei et al., 2014) although the stress drop of the mainshock is slightly larger than those of the other large inland crustal events. To investigate the factors of variations in stress drops independent of seismic moment, we examined possible correlations between stress drop and some tectonic effects such as regionality, focal mechanism, and source depth. Although there are no obvious correlations of stress drops with regionality and focal mechanism, we could see the dependence of source depth on stress drops for the aftershocks of the 2018 Hokkaido Eastern Iburi earthquake sequence.

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Acknowledgements: Strong motion data from KiK-net and F-net were provided by the National Research Institute for Earth Science and Disaster Resilience (NIED), Japan. Broadband seismograms and moment tensor solutions were provided from F-net, NIED. The JMA unified earthquake catalog was produced by JMA in cooperation with the Ministry of Education, Culture, Sports, Science and Technology (MEXT).

Keywords: The 2018 Hokkaido Eastern Iburi earthquake sequence, S-wave coda spectral ratio, Corner frequency, Source scaling, Stress drop

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Estimation of the strong motion generation area (SMGA) during the 2018 Hokkaido eastern Iburi earthquake

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1. Aichi Institute of Technology

On 6 September 2018, an Mw 6.6 earthquake occurred in Hokkaido Eastern Iburi, Japan. Strong ground motion with a maximum 7 on Japan Meteorological Agency (JMA) seismic-intensity scale struck Atsuma in Eastern Iburi and south-east Hokkaido, causing 42 death, about 462 collapsed houses and about 1570 partially destroyed houses (Fire and Disaster Management Agency, 2018). The hypocenter of this earthquake determined by the JMA is located as deep as 37km beneath the western part of the Hidaka Collision Zone where an arc–arc collision system in Hokkaido Island is placed. The characteristics of strong ground motions from this earthquake occurring in deep crust are needed to compare with those from shallow crustal earthquake in other regions in Japan.

The K-NET and KiK-net strong-motion observation networks operated by Japan’s National Research Institute for Earth Science and Disaster Prevention (NIED) recorded strong ground motions at 473 stations during the 2018 Hokkaido Eastern Iburi earthquake. The peak ground acceleration of 1796.4 gal and 1504.8 gal (absolute values calculated from the three components) were measured at K-NET stations HKD127 (Oiwake) and KiK-net stations IBUH01 (Oiwake), respectively, with almost the same hypocentral distance of 44.9km. Figure 1 shows a map view of aftershock distribution and the locations of observed stations and observed records.

The strong motion generation area (SMGA) source model during the 2018 Hokkaido eastern Iburi earthquake (Mw6.6, depth: 37km) was estimated by the empirical Green’s function method (EGFM) using strong motion data in 0.5-10Hz. First, a source fault model of the mainshock was assumed with three segments from aftershock distribution and observed waveforms consisting of three wavepackets. A rupture starting point of each SMGA was determined from the onset of each wavepacket seen in the observed records assuming the source fault plane. Second, two aftershocks (EGF events) are used as the empirical Green’s functions. One is for SMGA1 and SMGA3 the other is for SMGA2 because source mechanisms are different between SMGA1 and SMGA3, although almost the same between SMGA2. The stress parameters and area of the EGF events were estimated from corner frequencies calculated by the source spectral ratios of the mainshock to the EGF events. Third, the synthetic motions from the mainshock are estimated for assumed SMGA models using the EGFM. The best-fit SMGA source model was obtained to minimize the residuals between the observed and synthetic waveforms.

As a result, the best-fit SMGA source model consists of three SMGAs (SMGA1-3) located in the northern segment, the southern segment and the central segment, respectively. The stress parameter of each SMGA is 20-25MPa and slightly higher than those of general crustal earthquakes. The combined area of SMGAs is 68km^2 and deviates a bit smaller from the relationship between the combined area of asperities and seismic moment by Miyakoshi et al. (2019) standing for a higher stress parameter. Finally, we estimated the stress parameters of 35 aftershocks (Mw3.5-Mw4.9) occurring in and around the source area of the mainshock using their corner frequencies from the source spectral ratio method. The stress parameter of the mainshock is slightly higher than those of the aftershocks. The stress parameters of the aftershocks were not particularly high, although they occurred deeper than the other crustal earthquakes.

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Keywords: The 2018 Hokkaido eastern Iburi earthquake, strong motion generation area, empirical Green’ s function method

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Strong ground motions from deep earthquakes in Hokkaido and attenuation structure of island arc

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High-density strong ground motion data by NIED K-NET and KiK-net are analyzed to investigate the relation between the ground motions by deep earthquakes in Hokkaido and the attenuation structure of island arc. In this study, the strong ground motions from the following three events are analyzed: (1) 2020 Southeast Off Nemuro Peninsula earthquake (Mw 5.4, 96.0km depth, intraslab earthquake), (2) 2007 Mid-eastern Iburi earthquake (Mw 5.5, 126.18km, intraslab earthquake), and (3) 2015 East Off Aomori Prefecture earthquake (Mw 6.1, 66.07km, interplate earthquake). In northeastern Japan, a clear feature that the accelareation amplitudes in the backarc side are smaller than those in the forearc side is commonly seen among the three events. This is because of the low-Q medium of the volcanic front and the backarc side (e.g. Kakehi (2015)). On the other hand, spatial distribution of strong ground motions in Hokkaido is more complex. In case of event 1, large acceleration amplitudes are seen only within the eastern side of the Hidaka moutains, and the those in the western area of the Hidaka moutains are small though it is in the forearc side. This feature, small acceleration amplitudes in the western side of the Hidaka mountains, is also seen in event 2 and 3.The Hidaka mountains is an area of arc-arc collision (called "Hidaka collision zone"), and the underground structure (including attenuation structure) in the area is very complex. Previous studies (Kita et al. (2014) , Nakamura and Shiina (2019)) reported that Hokkaido has a low-Q area in the western side of Hidaka collision zone though the area is in the forearc side. The area with small acceleration amplitudes seen for the three events is intepreted to be caused by the attenuation of high-frequency seismic waves propagating through this low-Q area in the forearc side. Thus, in Hokkaido, more complex distribution of strong ground motion is seen than in northeastern Japan because of the existence of low-Q area in the forearc side, in addition to the clear contrast of attenuation structrue between the forearc and backarc sides.

Keywords: strong ground motion, attenuation structure, island arc, Hokkadio, Hidaka collision zone

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Simulation of near-fault ground motion for the 2016 Kumamoto earthquake (Mj7.3) considering the surface rupture geometry

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1. National Research Institute for Earth Science and Disaster Prevention, 2. Faculty of Science, Okayama University, 3. Graduate School of Environmental Studies, Nagoya University

The 2016 Kumamoto earthquake occurred along the Futagawa and Hinagu fault zones, causing several tens of kilometers of surface rupture with fault displacement up to 2 m. Associated with this earthquake strong ground motion and severe building damage were observed n the vicinity of the fault. It has been revealed that the conventional strong motion prediction method in Japan (“recipe”, HERP 2017) substantially underpredicted the observed moment magnitude as well as the amplitudes of the near-fault ground motion. In addition, a single-planar buried fault can hardly reproduce the detailed spatial distribution of near-fault ground motion and fault displacement.

In order to contribute to local seismic-risk reduction in regions with active faults, it is necessary to update the ground-motion prediction method and to construct seismic hazard maps with higher resolution focused more on near-fault regions.

In this study, we attempted to construct a kinematic fault rupture model for ground-motion prediction of this earthquake that incorporates the observed surface rupture geometry in the shallow part connected with multi-segment planar faults in deeper region (> 2 km depth). The fault model is represented by 100-m-interval point sources in the deterministic ground-motion simulation by 3D finite-difference method, in which the target frequency range is set to 1 Hz and lower. We use the detailed 3D velocity model around Kumamoto plain by Senna et al. (2018) combined with J-SHIS V2 velocity model.

We particularly focus on the distinctive strong motion and densely distributed building damage in the vicinity of the surface rupture in Mashiki town. The effects of the geometry and parameterization of the kinematic source model by comparison of our simulation results with the observed features.

Acknowledgment: Part of this work was supported by JSPS KAKENHI 18H03601.

Keywords: 2016 Kumamoto earthquake, near-fault ground motion, surface rupture

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Modeling procedure of fault rupturing with detailed information of surface traces for predicting strong motions and permanent displacements

*Kazuo Dan[1], Saruul Dorjpalam[1], Atsuko Oana[2], Kensuke Arai[2], Hiroyuki Fujiwara[3], Nobuyuki Morikawa[3]

1. Ohsaki Research Institute, Inc., 2. Shimizu Corporation, 3. National Research Institute for Earth Science and Disaster Resilience

We explained a modeling procedure of fault rupturing with detailed information of surface traces for predicting strong motions and permanent displacements.An example was shown for the 2016 Kumamoto earthquake, Japan. Figure 1 shows the seismic fault model (deep fault) obtained by Oana *et al.* (2019) and earthquake surface fault observed by Shirahama *et al.* (2016). Figure 2 shows an example of connecting the seismic fault (Futagawa segment) with the segment f01 of the earthquake surface faults. Figure 3 shows the slip-velocity time functions on the fault. Here, we assumed that the peak velocity on the shallow fault was a half the peak velocity on the seismic fault (deep fault). Figures 4 and 5 shows the calculation results of ground displacements.

Keywords: inland crustal earthquake, fault-rupturing model, surface fault trace, strong ground motion prediction, permanent displacement prediction, 2016 Kumamoto earthquake

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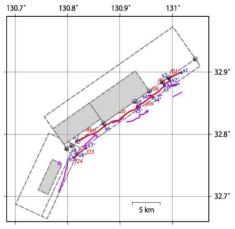


図 1　2016 年熊本地震の Ouna *et al.* (2019) による震源断層と Shirahama *et al.* (2016) による地表地震断層

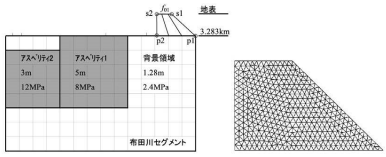
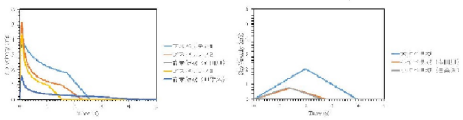
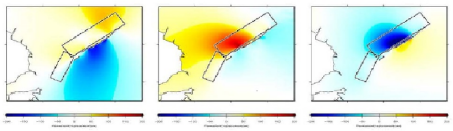


図 2　2016 年熊本地震の震源断層と地表地震断層 *f01* を結んだ例



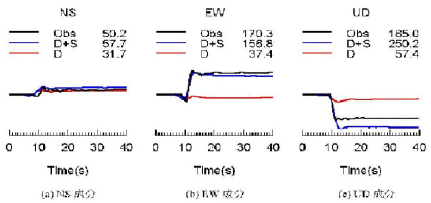
(a) 震源断層　(b) 活断層

図 3　2016 年熊本地震のすべり速度時間関数



(a) NS 成分　(b) EW 成分　(c) UD 成分

図 4　計算で得られた 2016 年熊本地震の永久変位分布（a: 布田川セグメントのみモデル化）



(a) NS 成分　(b) EW 成分　(c) UD 成分

図 5　各観測点における変位波形（単位は cm）の比較

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Waveform inversion with empirical Green's functions for the source rupture process of the mainshock of the 2019 Ridgecrest earthquake sequence

*SHUANGLAN WU[1], Atsushi Nozu[1], Yosuke Nagasaka[1]

1. PORT AND AIRPORT RESEARCH INSTITUTE

The 2019 Ridgecrest earthquake sequence with M_w 7.1 mainshock hit the Eastern California Shear Zone (ECSZ) in July 2019, which was the first event exceeding M_w 7.0 in California since the occurrence of the 1999 Hector Mine earthquake. The mainshock caused near-fault ground motions exceeding 0.5 G and 70 cm/s. It highly required clarification of the source rupture process and the generation mechanism of strong ground motions of the earthquake. In this study, the rupture process of the mainshock was investigated from waveform inversions of strong-motion data in the frequency range of 0.2-2.0 Hz. In the inversion scheme, the empirical Green’ s functions (EGFs) were adopted to avoid possible uncertainties caused by the assumption of subsurface velocity structures, and to handle relatively higher frequency ranges of strong ground motions typically up to 2.0 Hz as well, which are of great importance from engineering points of view. Our preferred slip model suggested that the main rupture of the M_w 7.1 event was confined in a region approximately 40 km in length, within which two large slip regions were identified: the primary large slip region with a maximum slip of approximately 3.0 m was centered ~ 3 km NW of the hypocenter, which was slightly shallower than the hypocenter, and a secondary large slip region was centered ~ 23 km SE of the hypocenter. A relatively small rupture velocity of 2.2 km/s was identified. Then, the reliability and robustness of our preferred source model were examined by different combinations of EGF events, which resulted that the locations of the large slip regions are not significantly affected by the selection of the EGF events. Moreover, using the preferred source model, we synthesized ground motions at strong-motion stations that were not used in the inversion analyses. The synthetic waveforms could capture the main phases of the observed waveforms, indicating the validity of the major spatio-temporal characteristics of the slip model. Additionally, our preferred slip model is generally consistent with some of the other models based on different data sets focusing on a lower frequency range (generally lower than 0.5 Hz). In particular, our preferred model is consistent with the result of the subevent modeling of strong-motion and teleseismic data (Ross *et al.*, 2019). The results imply that the generation process of strong ground motions of the Ridgecrest mainshock did not involve significant frequency-dependent nature at least up to 2.0 Hz.

Keywords: the mainshock of the 2019 Ridgecrest earthquake sequence, waveform inversion, empirical Green’ s function, strong ground motions, rupture process

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[E] Oral | S (Solid Earth Sciences)：S-SS Seismology

[S-SS04] Strong Ground Motion and Earthquake Disaster

convener:Kazuhiro Somei(Geo-Research Institute), Yasuhiro Matsumoto(Kozo Keikaku Engineering)

Strong ground motion has social impacts as it induces earthquake disasters. We solicit contribution on any seismological topics related to strong ground motion that includes, but are not limited to, source processes, wave propagation, and site effects. We also welcome contribution on earthquake related disaster mitigation.

[SSS04-17] A point source model considering the directivity effect

*Yosuke Nagasaka[1], Atsushi Nozu[1] (1.Port and Airport Research Institute)

[SSS04-18] Supplementing Vs30 and Z1.0 with H/V Fourier Spectral Ratios and Spatial Correlation for Predicting Site Effect

*Shu-Hsien Chao[1], Che-Min Lin[1], Chun-Hsiang Kuo[1], Jyun-Yan Huang[1] (1.National Center for Research on Earthquake Engineering)

Discussion

Discussion

Discussion

A point source model considering the directivity effect

*Yosuke Nagasaka[1], Atsushi Nozu[1]

1. Port and Airport Research Institute

In strong ground motion simulations, we often assume that strong ground motions are generated from an extended area on the fault plane, which is called an asperity. Spacio-temporal distribution of slip is considered by dividing the asperity into small subfaults and superposing motions from them. One of the problems of this method is the existence of artificial fall-off frequencies due to coherent interference of small motions, which is not clear in observed records. These frequencies depend on the asperity size and the manner of the division. Countermeasures have been developed to avoid this problem and to make synthetic spectra follow the omega-square model, for example, by introducing random rupture velocity.

In this study, we propose a simpler solution to this problem using the pseudo point-source model and two newly introduced parameters to model the directivity effect. The pseudo point-source model is a simple source model that follows omega-square model and have shown good agreements with observations for past large earthquakes. However, this model did not consider the directivity effect, which is an important factor of strong ground motions especially for crustal earthquakes.

One of the newly introduced parameters is the direction of the rupture propagation. The other represents the magnitude of the directivity effect. Since apparent rupture duration depends on the direction of the rupture propagation and the relative location of the site from the source, we represent the directivity effect by a corner frequency model of these two parameters. The model is designed to be smooth with respect to the target orientation. Using the model, we can synthesize strong ground motions with directivity effect without unnatural spectral fall-offs. We apply this method to the 2007 Chuetsu-oki earthquake, in which the directivity effect was clear. In addition, we investigate the effect of asperity shape on the directivity effect by comparing our model with characterized source model.

Keywords: strong ground motion simulation, point source model, directivity, corner frequency

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Supplementing Vs30 and Z1.0 with H/V Fourier Spectral Ratios and Spatial Correlation for Predicting Site Effect

*Shu-Hsien Chao[1], Che-Min Lin[1], Chun-Hsiang Kuo[1], Jyun-Yan Huang[1]

1. National Center for Research on Earthquake Engineering

In this study, we propose a methodology to involve H/V Fourier spectral ratios from strong motion data and ambient motion data individually as well as spatial correlation in GMPE directly to improve the prediction of the site effect. We illustrate it by developing a Vs30&Z1.0 based GMPE supplemented with spatial correlation and H/V Fourier spectral ratios of strong motion data collected from 628 strong motion stations. Then we develop an another Vs30&Z1.0 based GMPE supplemented with spatial correlation and H/V Fourier spectral ratios of ambient motion data collected from 112 stations collocated with 112 strong motion stations. The standard deviation of site-to-site variability can be reduced up to 90% while considering spatial correlation and H/V Fourier spectral ratios for both cases. The spatial distribution of the station terms predicted from 3699 stations with H/V Fourier spectral ratios of ambient motion data shows consistent spatial distribution of the station terms predicted from 721 strong motion stations by using the proposed models. The site-to-site variability of the stations with inferred Vs30 is similar with the site-to-site variability of the stations with measured Vs30 while considering spatial correlation and H/V Fourier spectral ratios. This study provides a good basis to improve the prediction of the site effect for a target site without available strong motion data by measuring H/V Fourier spectral ratios of ambient ground motion from micro-tremor.

Keywords: H/V Fourier Spectral Ratios, Spatial Correlation, Ground Motion Prediction Equation, Site Effect

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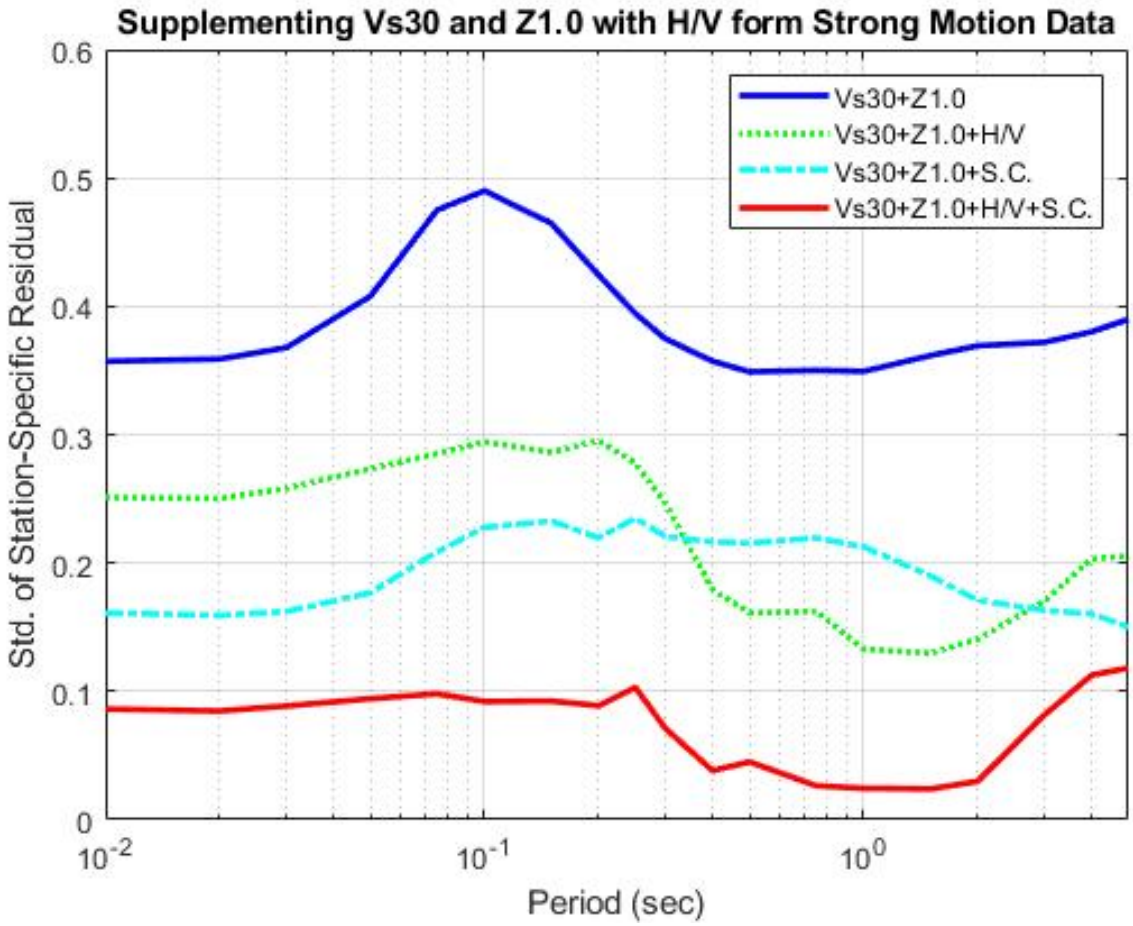

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[E] Oral | S (Solid Earth Sciences)：S-SS Seismology

[S-SS05] Innovative data analysis methods for characterization of seismicity

convener:Francesco Grigoli(ETH Zurich Swiss Federal Institute of Technology Zurich), Bogdan Enescu(Department of Geophysics, Kyoto University), Aitaro Kato(Earthquake Research Institute, the University of Tokyo), Yosuke Aoki(Earthquake Research Institute, University of Tokyo)

In the last two decades the number of high quality seismic instruments being installed around the world has grown exponentially and likely will continue to grow in the coming decades. This led to a dramatic increase in the volume of available seismic data and pointed out the limits of the current standard routine seismic analysis, often performed manually by seismologists. Exploiting this massive amount of data is a challenge that can be overcome by using new generation, fully automated and noise-robust seismic processing techniques. In the last years, waveform-based detection and location methods have grown in popularity and their application has dramatically improved seismic monitoring capability. Moreover, machine learning techniques, which are dedicated methods for data-intensive applications, are showing promising results in seismicity characterization applications, opening new horizons for the development of innovative, fully automated and noise-robust seismic analysis methods. Such techniques are particularly useful when working with data sets characterized by large numbers of weak events, with low signal-to-noise ratio, such as those collected in induced seismicity, seismic swarms and volcanic monitoring operations. This session aims to bring to light new methods that can be applied to large data sets, either retro-actively or in (near) real-time, to characterize seismicity (i.e., perform detection, location, magnitude and source mechanisms estimation) at different scales and in different environments. We thus encourage contributions that demonstrate how the proposed methods help improve our understanding of earthquake and/or volcanic processes.

[SSS05-01] Deep Learning for Earthquake Monitoring

★Invited Papers

*Weiqiang Zhu[1], S. Mostafa Mousavi[1], Kai Sheng Tai[2], Yongsoo Park[1], Yen Joe Tan[1], William Ellsworth[1], Gregory C. Beroza[1] (1.Department of Geophysics, Stanford University, 2.Computer Science Department, Stanford University)

[SSS05-02] Deep Learning (& classification models) performance in aftershock prediction

★Invited Papers

*Marco Broccardo[1,2], Arnaud Mignan[2,3] (1.Institute of Risk and Uncertainty, University of Liverpool , 2.Swiss Seismological Service, ETH Zürich, Switzerland, 3.Institute of Risk Analysis, Prediction and Management, Academy for Advanced Interdisciplinary Studies, Southern University of Science and Technology, Shenzhen, China)

[SSS05-03] Statistical learning and denoising for multivariate seismic data streams

*Andrey Lokhov[1] (1.Los Alamos National Laboratory)

[SSS05-04] Testing foreshock hypothesis against the ETAS model: why is it so difficult?

*Jiancang Zhuang[1] (1.Institute of Statistical Mathematics)

[SSS05-05] Analyses of the temporal change in size distribution of the earthquakes without using “moving window”

*Kohei Nagata[1] (1.Meteorological Research Institute)

Deep Learning for Earthquake Monitoring

*Weiqiang Zhu[1], S. Mostafa Mousavi[1], Kai Sheng Tai[2], Yongsoo Park[1], Yen Joe Tan[1], William Ellsworth[1], Gregory C. Beroza[1]

1. Department of Geophysics, Stanford University, 2. Computer Science Department, Stanford University

Seismic networks are continuously recording seismic data around the world. These data contain rich information about earthquake processes, but traditional auto-processing algorithms can not fully extract this information. Fortunately, the existence of large manually labeled data sets provides us an excellent opportunity for developing deep-learning algorithms for earthquake monitoring. Deep learning is an effective, data-driven way to build a nonlinear map from a high-dimensional input distribution to a target distribution of interest. In this work, we present some of our recent efforts in developing deep-learning models to denoise, detect, pick, cluster, and associated earthquakes. These new algorithms and rapidly evolving deep-learning techniques can improve earthquake catalog generation and thus provide a much clearer and more detailed picture of earthquake processes.

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Deep Learning (& classification models) performance in aftershock prediction

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Deep Learning is growing rapidly, as stand-alone research not only in data science but also in classical natural sciences, where it has been shown to have considerable predictive power in many highly complex phenomena. This is supported by the superior performance of Deep Learning in identifying and recognizing patterns from large data sets. A key strength of Deep Neural Networks (DNN) is that there is no requirement for feature extraction, effectively eliminating any subjective feature engineering. However, it is still a challenge (and generally a subjective choice) to design the architecture and topology of the network (i.e., the number of nodes and layers). Given the superior predictive power and flexibility of the method, it is not surprising that DNNs are also becoming popular in statistical seismology. In fact, the combination of the latest data acquisition techniques, together with Deep Learning, is giving new hope for earthquake prediction, a challenge that is still considered impossible by the majority of the scientific community.

Recently, there has been growing interest in using DNN to predict the spatial distribution of aftershocks following a major seismic event. There are two main reasons for this interest: first, it is a problem of great importance both from a scientific point of view and for seismic risk assessment and management; second, there are extensive collections of aftershock events that make the use of a data-driven approach attractive. In this perspective, the most widespread trend is to turn the problem of aftershock prediction into a classic classification problem. In particular, the volume surrounding the main aftershock event is divided into cells. Next, the input is defined by stress or kinematic variables for each single cell, and the output is either 1 or 0. In particular, a value of 1 is given (only) if there is at least one aftershock inside the cell. In these classification problems, performance is usually measured by the Area under the Receiver Operational Characteristics (AUC-ROC) curves. This approach has been used to define DNN even though it has been shown that their performance is not superior to a simple logistic regression. However, this binary aftershock classification generates unbalanced data sets with the vast majority of cells containing zeros. The problem, therefore, becomes a small event detection, and, in these cases, AUC-ROC curves may not be the appropriate metric to evaluate the performance of a classifier.

This talk examines the area under the Precision-Recall Curves (which proved to be more appropriate for imbalanced data sets) to assess the performance of the different classifiers in the context of aftershock forecasts. Then, given these evaluations, we carefully examine the use of different stress-based metrics for aftershock classification, showing that their predictive power is related to convex combinations of tensor stress elements and not to specific physical patterns.

Keywords: Deep Learning, Aftershock prediction, Machine Learning

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Statistical learning and denoising for multivariate seismic data streams

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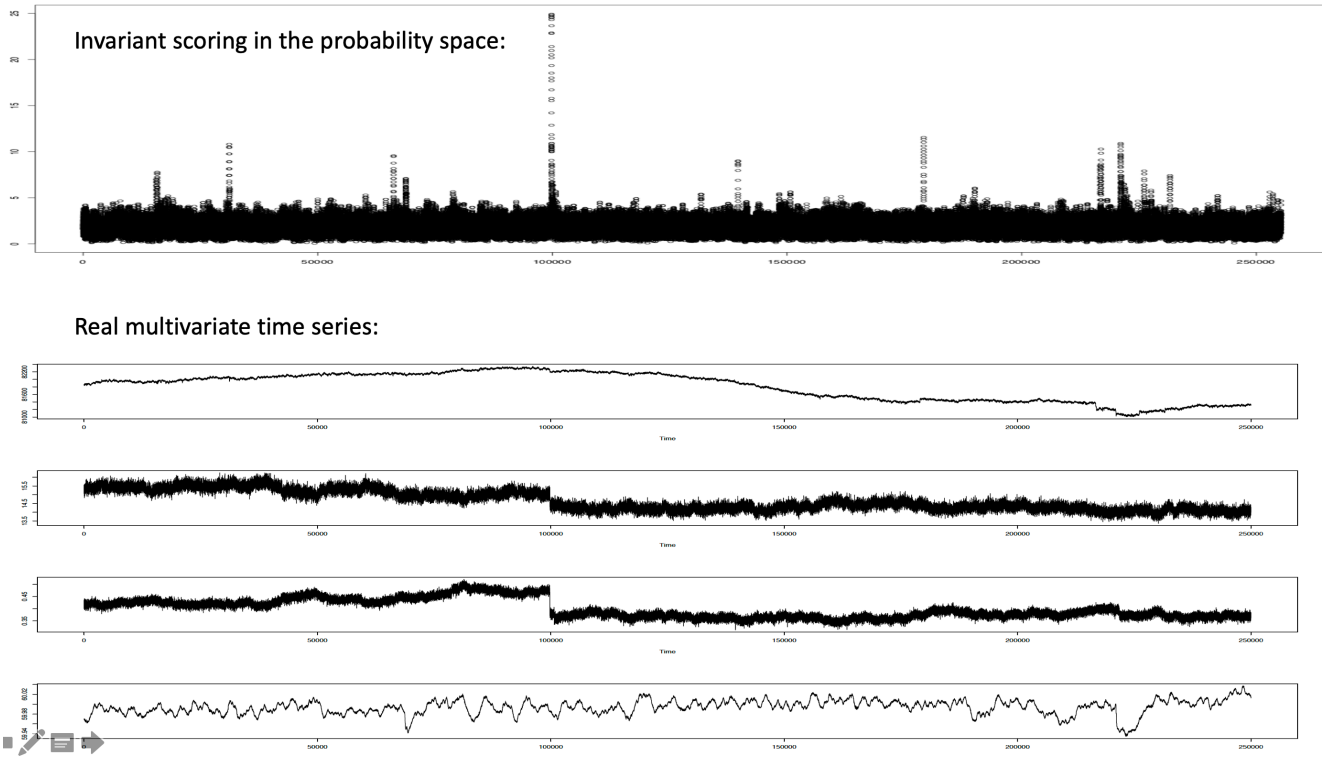
1. Los Alamos National Laboratory

In an effort to characterize tectonic tremor from seismic noise and probe the relationship between tremor and slow slip we use a method based on new developments in statistical learning theory. Current techniques for detecting tremor consist in looking at correlations of signals measured at different locations: in the presence of tremor, the correlation pattern should change. However, this method implicitly assumes that the noise at different location is weakly correlated; also, only tremors with high amplitude that affect signals at all seismic stations can be detected. Mathematically, the tremor detection problem can be viewed as the denoising problem in signal processing. The foundation of our method consists in exploiting recent advances in exact and sample-optimal learning of graphical models, that allows one to reconstruct structured multivariate distributions beyond Gaussian. Once the noise distribution is known, we will show how to construct a family of local likelihood estimators for extracting the tremor signal from single- or multi-stations measurements. In order to incorporate the potential time-dependence of the noise, we learn the noise model on the fly, using most recent measurements. This model allows the real-time likelihood scoring of the incoming signal in probability space, thus predicting the appearance of the tremor signal. An advantage of our method compared to black-box approaches like neural networks consists in the explicit instantiation of the multivariate noise distribution and the data-optimality guarantees.

Keywords: tectonic tremor, seismic noise, signal denoising, graphical models, multivariate time series



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Testing foreshock hypothesis against the ETAS model: why is it so difficult?

*Jiancang Zhuang[1]

1. Institute of Statistical Mathematics

Starting from the Epidemic-Type Aftershock Sequence (ETAS) model, which is widely used in seismology for describing clustering features of the earthquake process, we can derive the probability of the foreshock phenomenon and the distribution of largest aftershock magnitude related to the Bath law, both of which are close to the values in real seismicity. Theoretically, if the earthquake clustering is a coin, the foreshock phenomenon is on the head and the Bath law in the tail. It is hard to believe htat there is a mechanism that produces the foreshock phenomenon without changing other parts of this coin. Studying how the tectonic environment changes influence the earthquake clustering behavior is more meaningful than seeking foreshocks only.

For simulation studies, I found that, in previous researches where the foreshock phenomenon is concluded as a significant earthquake precursor, “weak-clustering” or biased estimated ETAS models have been used. Especially, ETAS parameters *c* and *D* parameters are difficult to estimated correctly when short-term missing events exist. Another pitfall is the magnitude threshold.

Therefore, to completely reject the hypothesis that the ETAS model does not produce the foreshock phenomenon, one must show that no ETAS simulations can produce the corresponding characters. Only showing that some particular ETAS model cannot produce foreshock characteristics in real catalog, especially only in the quantities of these characteristics, is not enough for rejecting this conjunction. Unless we can distinguish foreshocks before the entire earthquake sequence finishes completely, the foreshock is an impractical concept.

Keywords: foreshock, ETAS model, Earthquake precursor

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Analyses of the temporal change in size distribution of the earthquakes without using “moving window”

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1. Meteorological Research Institute

Since the usual methods for estimating temporal change in Gutenberg-Richter(GR)'s *b* value uses a “moving window” comprises a fixed number of events, the results necessarily show averaged characteristics of seismicity in a fixed spatiotemporal range with fixed estimation error mainly dependent on the width of the window. These methods are useful especially in the case where the spatiotemporal scale of targeted phenomena is clear and the seismicity rate is almost constant and suitable for the scale. However, since the seismicity rate can be too low or too high depending on its history, spatial- or temporal-scale sometimes comes to too large or too small unintentionally. Therefore, some methods for estimating temporal change in b value without using “moving window” can be the alternative tool especially in terms of the seismicity monitoring which targets any unusual change.

In the presentation, 2 different methods to estimate temporal change in b value without using “moving window”, estimating the Fourier amplitudes and the cumulative magnitudes respectively, are shown. Both methods are based on the idea that the change in b value can be estimated as change in average magnitude since the most likelihood estimation of b value corresponds to the inverse of average magnitude as long as GR relation holds. Since the Fourier amplitude of magnitude data contains information of periodic change of average magnitude and also that of seismic rate, the former information can be obtained by subtracting the latter, that is, the Fourier amplitude of averaged timeseries data having constant amplitude of the average of all original magnitude data and the same timestamp as the original magnitude data. The cumulative magnitudes can be used to monitoring the change in average magnitude more directly because the trend of the cumulative magnitudes plotted against event number is average magnitude itself. With some simulated data generated randomly assuming poison process and GR relation with periodic change of b value, the 2 methods show expected performance.

These methods have been applied to shallow inland earthquakes in the JMA unified earthquake catalogue. Although the Fourier amplitude of all magnitude of shallow inland earthquakes except for those around hypocenter of earthquakes whose magnitude is larger than 5 shows daily, weekly and annual change of seismic rate and average magnitude probably caused by the change of noise level of seismometers, no clear frequency components in the average amplitude has been observed in the case where the lower limit of magnitude is 0.8 or larger. Instead, a weak low-frequency broadband component of changes in average magnitude has been observed. On the other hand, the trend of cumulative magnitudes around hypocenters of earthquakes whose magnitude is larger than 4 shows a tendency to decrease after the centered earthquakes occurred. These results suggest that the earthquakes themselves affect the characteristic of the surrounding seismicity.

Keywords: b value, monitoring, seismicity

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[E] Oral | S (Solid Earth Sciences)：S-SS Seismology

[S-SS07] Earthquake prediction and forecast+pre-earthquake geoscientific changes(TBD)

convener:Masayuki Obayashi(Japan Agency for Marine-Earth Science and Technology), Toshitaka Baba(Graduate School of Science and Technology, Tokushima University), Chi-Yu King(Retired)

This session provides the opportunity for contributions that fall within the scientific spectrum of earthquake prediction and forecasting. We welcome theoretical, observational or numerical papers that are either on long- or short-term predictions, and either based on deterministic or probabilistic approaches. (TBD)

[SSS07-01] Hydrological earthquake precursors caused by slow-slip events

★Invited Papers

*Chi-Yu King[1], Chi-Yu King[1] (1.Retired)

[SSS07-02] Crustal deformations precursory to the Tohoku M9 earthquake and tsunami

*Fumihide Takeda[1,2] (1.Takeda Eng Consultant Co., 2.Earthquake Prediction Inst.)

[SSS07-03] **Nowcasting Earthquakes in Sulawesi Island, Indonesia**

*Sumanta Pasari[1], Andrean VH Simanjuntak[2] (1.Birla Institute of Technology and Science Pilani, 2.Indonesian Agency for Meteorology, Climatology and Geophysics)

[SSS07-04] Dilation of a sheared granular model experiment of earthquake to serve as a possible precursor

*Victor Simon Levy dit Vehel[1], Florine Dubourg, Loic Vanel[1], Knut Jørgen Måløy[2], Osvanny Ramos[1] (1.Institut Lumiere Matiere Lyon 1, 2.University of Oslo)

[SSS07-05] **A Mechanochemical Model of Stress-induced Charges for Generating the Electromagnetic Precursors of Earthquakes**

*Jeen-Hwa Wang[1] (1.Academia Sinica)

[SSS07-06] Likelihood model of crustal earthquakes in southwest Japan using GNSS strain rate data

*Takuya NISHIMURA[1] (1.Disaster Prevention Research Institute, Kyoto University)

Hydrological earthquake precursors caused by slow-slip events

*Chi-Yu King[1], Chi-Yu King[1]

1. Retired

Large earthquakes are often preceded or followed by slow-slip events, which when better understood, may help better understand the mechanism of the earthquakes and the possibiliity of their prediction. This paper presents some hydrological changes recorded at some sensitive sites in or near active fault zones before the occurrence of several moderate-to-large earthquaes in Taiwan and Japan. They include a large stream-flow change and a small water-level change recorded before the 1999 magniitude 7.6 Chi-Chi earthquake in central Taiwan, and a large water-level change recorded in a sensitive well at Tono, central Japan, before a magnitude 5.8 local earthquake. Several smaller water-level changes had also been recorded in this well before some large distant earthquakes of magnitude 6.1-8.1 at epicentral distances of 220-1260 km. All these changes can be attributed to the occurrence of some corresponding pre-earthquake slow-slip events.

Keywords: hydrological earthquake precursor, slow-slip event, sensitive sites

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Crustal deformations precursory to the Tohoku M9 earthquake and tsunami

*Fumihide Takeda[1,2]

1. Takeda Eng Consultant Co., 2. Earthquake Prediction Inst.

The Geospatial Information Authority of Japan (GSI) has more than 1240 Global Positioning System (GPS) stations laid throughout Japan. The northern part of Honshu is Tohoku that is at the eastern edge of a continental tectonic plate overriding the subducting Pacific Plate. A large fault surface between the plates held them together. The fault had a length of 500 km and a width of 200 km. The GPS stations in Tohoku and the Pacific Ocean observed three distinctive phases of the crustal deformations evolving into the March 11 2011 Tohoku M9 earthquake (EQ) and tsunami to follow. Their cross-sectional deformations are in Fig. 1.

The tectonic plate-driving forces as shown with arrows in Fig.1 had constantly compressed the Tohoku area. The compression kept pushing the west and east coasts of Tohoku upward and downward, respectively. This crustal deformation is a normal distortion for which the fault surface couples the two plates together as in Fig. 1a. A GPS station in the subducting western Pacific Plate (in the Pacific Ocean) was moving west at the speed of 3.8 cm per year that is about 0.1 mm/day averaged over 10 years.

A bulge of 1 –3 mm began forming from the normal distortion around December 8, 2009, which is about 16 months prior to the March 2011 M9 EQ. The formation is schematically drawn in Fig. 1b. As the bulge grew, the east coast of Tohoku began to pull the subducting plate further down by their fault coupling, which started around July 11, 2010. Its pulling action by the eastern edge of the overriding plate is shown by the dotted arrow over the fault in Fig. 1b. The pulling action accelerated the motion of the subducting plate. On December 22, 2010, the westward speed of the subducting motion reached its highest of 0.65 mm/day three times faster than that on July 11, 2010. On the same day as the highest westward speed is observed, the M7.9 event raptured at the epicenter in the Pacific about 668 km away from the GPS station to the east. The event had a normal faulting, which suggests the westward anomalous acceleration triggered the event. After the highest westward speed, the reaction against the pulling began decelerating the motion.

The reaction completely stopped the subducting motion on February 21, 2011, which kept stopping for four more days. The reaction then began pushing back the subducting motion to the east on February 26, 2011. The eastward speed reached 0.06 mm/day by only three days prior to the March 11 2011 M9 event. The reaction grew to the megathrust on the fault surface between the two tectonic plates, which generated the M9 EQ and tsunami as schematically drawn in Fig. 1c.

The three phases of the deformations in Fig. 1 are quantified by analyzing GPS displacement time series with a mathematical tool named Physical Wavelets (P-Ws). The tool has the time reversal property of the position and derivatives satisfied to define the position, velocity, and acceleration for the non-differentiable displacement time series data [1, 2]. Thus, the phase space analyses of displacements with P-Ws are a key to quantifying the bulge coupling of the two tectonic plates. The analyses have the resolutions of 0.1 mm and 0.0001 mm/day 5 orders of magnitude greater than the daily vertical displacement noise of about ±20 mm. The analyses assure that the short-term deterministic predictions within about two to three months prior to the ruptures of such impending megathrust events as suggested

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in Fig. 1 are available [1].

Fig. 1. Three phases of the crustal deformations. (a) Normal slow distortion. (b) Precursory bulge formation and its pulling action to accelerate the subducting Pacific Plate motion. (c) The reaction against the pulling grows to the megathrust to generate the M9 EQ and tsunami to follow.

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https://patents.google.com/patent/JP5798545B2/en
[2] F. Takeda, submitted to PRL (2020),
https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2017-454/

Keywords: Deterministic prediction of megathrust earthquake & tsunami, Crustal deformations evolving into megathrust events, GPS time series data analyses with physical wavelets, GPS time series data analyses with phase space paths

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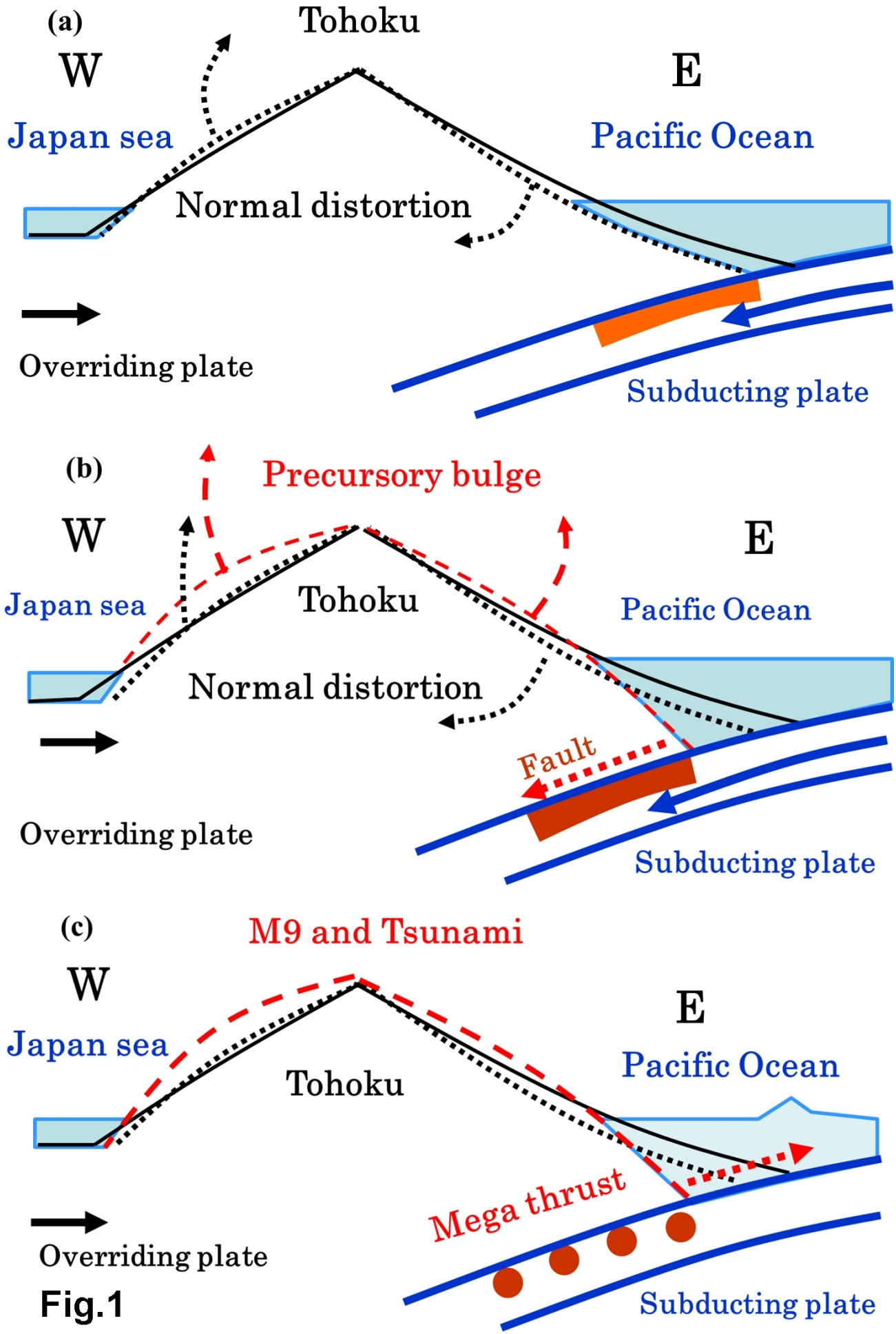

Fig.1

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Nowcasting Earthquakes in Sulawesi Island, Indonesia

*Sumanta Pasari[1], Andrean VH Simanjuntak[2]

1. Birla Institute of Technology and Science Pilani, 2. Indonesian Agency for Meteorology, Climatology and Geophysics

Large devastating events such as earthquakes often display frequency-magnitude statistics that exhibit power-law distribution. In this study, our objective is to implement a new technique of nowcasting (Rundle et al. 2016) to evaluate the present state of earthquake hazards in the seismic prone Sulawesi province, Indonesia. The nowcasting technique considers statistical behavior of small event counts, known as natural times, to infer the seismic progression of large earthquake cycles in a defined region. To develop natural time statistics in Sulawesi island, we employ eight probability distributions: Brownian passage time (inverse Gaussian), exponential, exponentiated exponential, gamma, inverse Weibull, lognormal, Pareto and Weibull. Statistical inference of natural times reveals that (i) exponentiated exponential distribution has the best representation to the observed data, (ii) estimated nowcast scores (%) corresponding to M>=6.5 events in the 300 km circular city regions around Palu, Makassar, Manado, Kendari, Bitung, Gorontalo, Palopo, Bau-bau, Luwuk, Toli-toli, Pare-pare, Poso, Bone, Kolaka, Buton, Watampone, Polewali, Donggala, Taliabu, Mamuju, and Morowali reach about 71, 60, 22, 34, 22, 43, 35, 54, 48, 66, 84, 43, 56, 36, 53, 67, 72, 71, 48, 67 and 39, respectively, and (iii) the results are broadly consistent to the changes of magnitude thresholds and area of local regions. Therefore, the present nowcasting analysis, as an alternative to the traditional earthquake hazard assessment techniques, offers a simple yet versatile metric to the scientists, engineers and policymakers to examine the present state of earthquake hazards in the thickly populated Sulawesi island.

Keywords: Natural times, Nowcast scores, Sulawesi island, Probability models

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Dilation of a sheared granular model experiment of earthquake to serve as a possible precursor

*Victor Simon Levy dit Vehel[1], Florine Dubourg, Loic Vanel[1], Knut Jørgen Måløy[2], Osvanny Ramos[1]

1. Institut Lumiere Matiere Lyon 1, 2. University of Oslo

Earthquake forecast has long been an objective for geoscience, resisting scientific efforts for more than a century. This difficulty stems in part from the very large spectrum of time and energy scales, a feature required of physics-earthquake analogies [1]. There are indications that any progress in prediction will come not from any single observable, but more likely in the form of a probabilistic combination (either analytical or based on recent machine-learning progress [2]) of many signals and measurements. The search for precursory signals had lead to a wide variety of candidates, such as slow-slip events [3] or low-frenquency changes. New precursors can be searched either in real-world data, or through model experiment –we focus on the later approach.
We present a granular shear experiment in a cylindrical couette geometry [1] which creates artificial quakes in the form of acoustic burst or mechanical energy release. This system has been shown to exhibit quantitative agreement to several key statistical features of earthquakes (Gutenberg-Richter law, Omori law, inter-event time distribution [4]). Additionally, the dilation of the granular medium is monitored during an experimental. This dilation increases on average prior to large events [5]. Furthermore, we show the link between average dilation increase and upcoming events hold for several magnitudes.

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Keywords: Earthquake, Shearing, Precursors, Dilation

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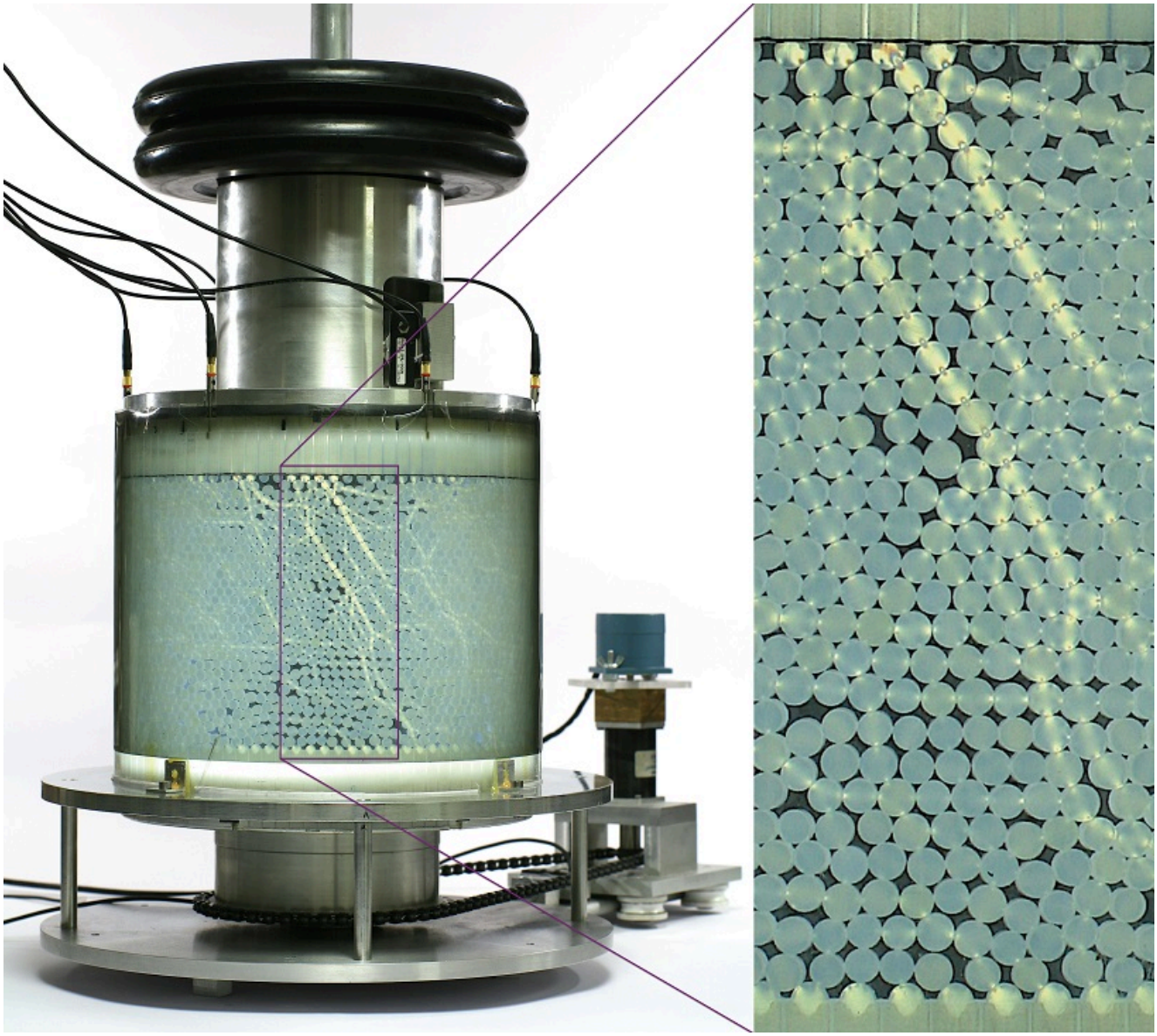

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A Mechanochemical Model of Stress-induced Charges for Generating the Electromagnetic Precursors of Earthquakes

*Jeen-Hwa Wang[1]

1. Academia Sinica

Abstract The generation of electric currents on the ground surface or in the shallow depths of upper crust inside and near the fault zone, where an impending earthquake will happen, is a necessary condition to produce the electromagnetic precursors of earthquakes. Such currents could be generated due to the presence of stress-induced charges. From laboratory experiments, Freund (cf. 2013) assumed that the stress-induced charges are caused by peroxy defect in the fault-zone rocks. He also proposed a peroxy defect theory to interpret the observations. To further interpret such a theory for the generation of stress-induced charges, a model based on mechanochemistry (Gilman, 1996) is considered in this study. Stress-induced generation of charges can be regarded as a kind of phase transition, which can be studied by using the Gibbs free energy (Gibbs, 1873): G(p,T)=U+pV-TS in which U, p, V, T, and S are, respectively, the internal energy, pressure, volume, temperature, and entropy. According to the Landau theory (Landau, 1937), the G for a structural transition can be described by a single-order-parameter function (see Sornette, 2000): $G=bQ^4/2-aQ^2+fQ+dQ\varepsilon+h\varepsilon^2/2$, in which Q is a scalar one-order parameter; a and b are two phenomenological coefficients for the phase transition; the f controls the breaking of symmetry between two phases; the d quantifies the strength of the coupling between Q and strain; and $h\varepsilon^2/2$ is the elastic energy density of the material with elastic modulus h. Analytical and numerical solutions based on this function will be performed for studying the intrinsic properties of the model and the possibility of stress-introduced electric current. Preliminary results reveal that the G function shows a symmetric double-well configuration as f=0, d=0, and $\varepsilon=0$; the parameter f and d break the symmetry of the function; and $h\varepsilon^2/2$ will shift the configuration upward. An increase of ε will make the phase state related to a solution change from the stable state, the metastable state, finally to the unstable state. This can explain stress-induced charge generation on a rock under external loading.

Keywords: Earthquake E&M Precursor, peroxy defect, stress-induced charges, mechanochemistry, phase transition, free energy.

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Keywords: Earthquake E&M Precursor, peroxy defect, stress-induced charges, mechanochemistry, phase transition, free energy

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Likelihood model of crustal earthquakes in southwest Japan using GNSS strain rate data

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1. Disaster Prevention Research Institute, Kyoto University

In Japan, the Headquarters for Earthquake Research Promotion has developed a nationwide probabilistic earthquake model called "National Seismic Hazard Maps for Japan" since the destructive 1995 Kobe earthquake. This model covers both subduction and crustal earthquakes based on a history of past large earthquakes from seismological, historical, and geological data. The model for crustal earthquakes relies on geological and geomorphological data of active faults and never use geodetic data, whereas contemporary deformation of the Japanese Islands is observed by one of the best GNSS network in the world. Here, we attempt to develop a preliminary likelihood model of shallow crustal earthquakes using GNSS velocity data.

We follow a procedure of Shen et al.(2007) to calculate the likelihood model. The GNSS velocities at continuous GNSS stations from April 2005 to December 2009 are used for the model in southwest Japan. Elastic deformation due to interplate coupling along the Nankai trough is removed using the block model of Nishimura et al. (2018). Strain rate field is calculated at a grid point of 0.2 deg x 0.2 deg by a method of Shen et al.(1996). The strain rates are converted to geodetic moment rates by a formula in Savage and Simpson (1997). Distance Decay Constant, thickness of a seismogenic layer, rigidity, and b value of the Gutenberg-Richter law are assumed to be 25 km, 12 km, 30 GPa, and 0.9, respectively. They are uniform in the modeled region. It is well-known that geodetic strain rates are much larger than seismological ones because geodetic strain includes both elastic and inelastic strain. Elastic strain rates presumably equal to seismological ones on long-term average. We compared seismic moment rates released by shallow historical earthquakes since 1586 and geodetic moment rates. Their ratio is 0.24 and 0.14 in the Chubu, Kinki and Chugoku region and whole southwest Japan. This difference indicates a regionality of the ratio between elastic and inelastic strain. Applying 0.14 for calculating elastic rates and the stationary Poisson process of the earthquake occurrence, probability of M>6 earthquakes for 30 years ranges from 4.3 % to 0.2 % in southwest Japan (Figure 1). We verify this likelihood model by using shallow (Depth<20 km) M>5 earthquakes occurred in 2010-2019. Total number of earthquakes was 36, which is roughly concordant to a predicted number of the model (2.73 per year). Cumulative histograms of geodetic strain rates integrated over area and earthquake count are very similar. About 58 % of the earthquakes occurred with 25 % of the area with highest strain rate. The verification suggests our preliminary likelihood model has the predictive power reasonably.

Keywords: earthquake probability, long-term forecast, Geodetic data, GNSS

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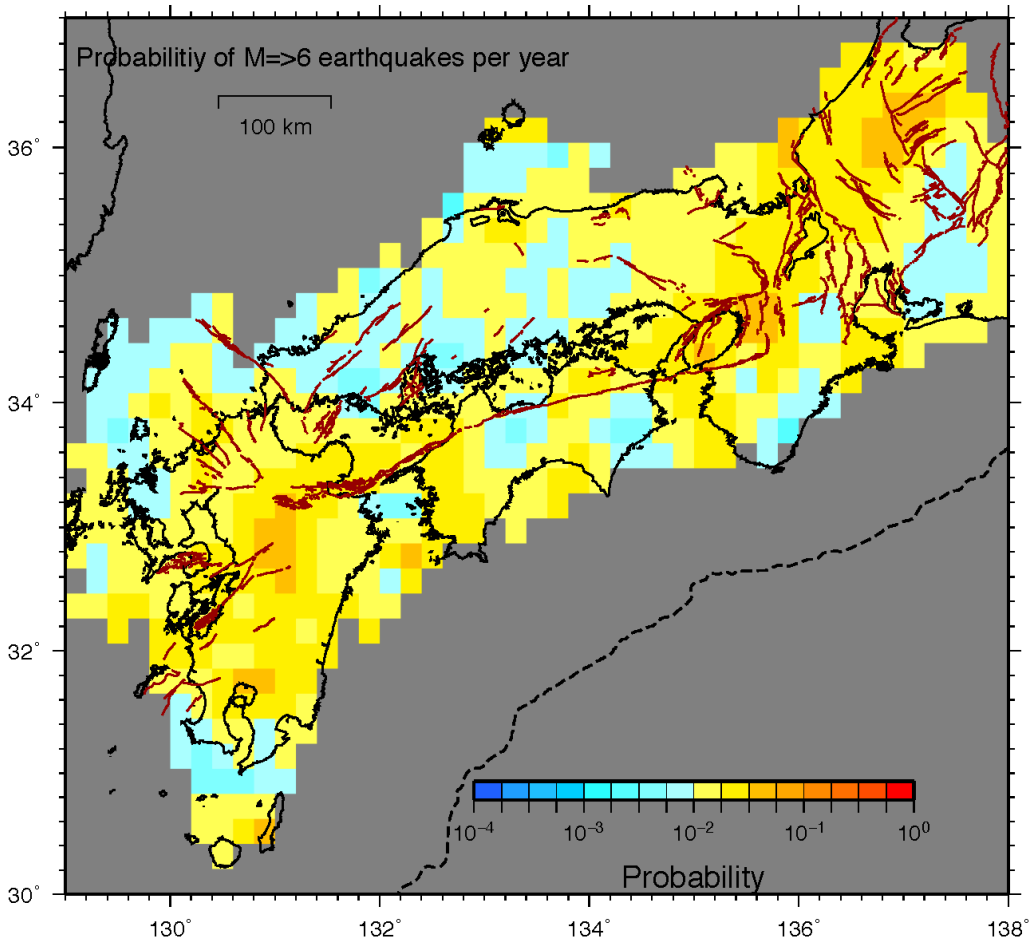

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[E] Oral | S (Solid Earth Sciences)：S-SS Seismology

[S-SS08] Statistical seismology and underlying physical processes

convener:Yasuhiro Yoshida(Meteorological College, Japan Meteorological Agency)

This session aims to improve our understanding on seismicity and underlying physical processes. Any contribution on behavior of earthquakes as a cluster, such as regional seismicity and aftershocks, is welcomed. We also welcome contribution on temporal and spatial interactions that control seismicity, and tectonic processes, and geological and thermal structures that regulate seismicity.

[SSS08-01] Stress state of the Earth's crust in the Korean Peninsula with reference to Japanese islands: Implication of weak faults

*Yasuto Kuwahara[1], Jin-Hyuck Choi[1], Youngbeom Cheon[1], Kazutoshi Imanishi[2] (1.Korea Institute of Geoscience and Mineral Resources, 2.Geological Survey of Japan, AIST)

[SSS08-02] **Effect of seasonal snow load on earthquake occurrence in the Pamir Mountains**

*Muhammad Usman[1,2], Kosuke Heki[2], Sigurjon Jonsson[1] (1.Department of Physical Sci. and Engineering, King Abdullah Univ. of Sci. and Tech., Thowal, Saudi Arabia, 2.Department of Natural History Sci., Hokkaido Univ. Sapporo, Japan)

[SSS08-03] The diversity of similar earthquakes in subduction zone

*Ayako Tsuchiyama[1], Junichi Nakajima[1] (1.Earth and Planetary Sciences, Tokyo Institute of Technology)

[SSS08-04] **Spatio-temporal clustering of successive earthquakes in Japan: analyses of F-net catalogue**

*Thystere Matondo Bantidi[1], Takeshi Nishimura[1] (1.Tohoku Univesity)

[SSS08-05] Foreshock Cascade to Failure in the M 6.4 July 4, 2019 Ridgecrest, California Earthquake

*William L Ellsworth[1], Andrew J Barbour[2], David R Shelly[2] (1.Stanford University, 2.U. S. Geological Survey)

[SSS08-06] Changes in stress state associated with the 2019 Ridgecrest, California, earthquakes

*Kazuyoshi Nanjo[1] (1.University of Shizuoka)

Stress state of the Earth’s crust in the Korean Peninsula with reference to Japanese islands: Implication of weak faults

*Yasuto Kuwahara[1], Jin-Hyuck Choi[1], Youngbeom Cheon[1], Kazutoshi Imanishi[2]

1. Korea Institute of Geoscience and Mineral Resources, 2. Geological Survey of Japan, AIST

The stress state in the Korean Peninsula is re-evaluated by analyzing earthquake focal mechanisms with a stress inversion method. Several previous studies of the stress state in the Korean Peninsula give consistent results: the stress state in Korea is characterized in average by a strike-slip faulting stress regime with the ENE-WSW maximum and the NNW-SSE minimum compressions. Further, Soh et al. (2018) suggests a nonuniform spatial distribution of stress magnitudes of the order of 100 MPa, which increase from west to east in the peninsula, by assuming a high Coulomb friction value of 0.85 and hydrostatic pore pressures. This suggestion is based on the “strong fault” hypothesis. In contrast to this, several results of stress states in Japanese islands indicate the weak fault, where the differential stress level is a few tens MPa, providing the apparent friction is around 0.1 at depths. Thus, this difference between the results in Korea and in Japan urges us to re-analyze the data, mainly because the assumptions or constraint models for the estimations of the absolute stress values still seem to be debatable. We then evaluate the focal mechanism data in the Korean Peninsula, and suggest possible estimations of the absolute values. We point out that the earthquake faulting types in the Korean peninsula are strongly controlled by azimuths of preexisting fault-strikes, being consistent with a spatially uniform distribution of the strike-slip stress regime with nearly equal tensional and compressional stresses relative to the vertical stress. We could explain that these reverse and normal faulting events in the Korean peninsula are caused by local stress heterogeneity around strike-slip faults under the strike-slip stress state with a low differential stress expected from the weak fault hypothesis.

Keywords: Earthquake, Korean Peninsula, Japanese islands, crustal stress, weak fault

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Effect of seasonal snow load on earthquake occurrence in the Pamir Mountains

*Muhammad Usman[1,2], Kosuke Heki[2], Sigurjon Jonsson[1]

1. Department of Physical Sci. and Engineering, King Abdullah Univ. of Sci. and Tech., Thowal, Saudi Arabia, 2. Department of Natural History Sci., Hokkaido Univ. Sapporo, Japan

The Pamir mountain region is among the seismologically most active areas in the world and has, in the past several decades, had many strong earthquakes, primarily of reverse and strike-slip mechanisms. By using earthquake catalogue data from the International Seismological Center (ISC) and the United States Geological Survey (USGS), we find significant seasonal tendency in earthquake occurrence for events of $M^3$5.5 and shallower than 50 km, with a clear peak in earthquake frequency in July and August. The study area is covered by snow and glaciers, whose mass exhibits large seasonal variability. This is reflected in the GRACE satellite MASCON data that indicate the surface seasonal load increases from mid-September to mid-April and then decreases during the rest of the year. The seasonal load variation corresponds to ~25 cm of Equivalent Water Table (EWT) change. In accordance to this, Global Precipitation Measurement (GPM) satellite data indicate that the average thickness of seasonal snow cover is around 80 cm. In addition, GPS data in the region also show seasonal oscillations with an amplitude of ~3 cm in the vertical component, where the timing of vertical low points coincide with the peak seasonal load. This temporal variability of the seasonal snow load directly alters fault-normal stresses in the region by a few kPa. The seasonal peak in earthquake frequency occurs before the peak unloading and coincides better with the time of the maximum unloading rate. Together the results suggest that the seasonal snow load significantly modulates the tectonic stress build-up and the rate of earthquake occurrence in this region.

Keywords: Seasonal Load, Satellite Data, Earthquakes

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The diversity of similar earthquakes in subduction zone

*Ayako Tsuchiyama[1], Junichi Nakajima[1]

1. Earth and Planetary Sciences, Tokyo Institute of Technology

Generation mechanism of deep earthquakes in subduction slabs is still enigmatic. Through cross-correlation analysis of earthquakes in central Japan, we identify five pairs and one cluster of deep earthquakes showing strong waveform similarities (coherence > 0.9) for a 40-s time window at more than three stations. For those clusters, we relocate hypocenters by hypoDD, determine the focal mechanisms solutions, and carry out spectral analysis to estimate physical parameters of seismic ruptures (i.e., stress drop, radiated energy and efficiency). The obtained results show that some similar deep earthquakes in each cluster occurred at a slightly different spot on a single fault and have almost the same stress drop. The scaled energy and radiation efficiency of the groups precisely estimated from high-quality similar waveforms show that seismic parameters are significantly different between faults. A wide range of source parameters that have been reported for deep-focus earthquakes may not represent the differences in generation mechanisms of earthquakes but reflect the diversity of inherent fault frictional properties.

Keywords: subduction zone, intraslab earthquakes, deep earthquakes

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Spatio-temporal clustering of successive earthquakes in Japan: analyses of F-net catalogue

*Thystere Matondo Bantidi[1], Takeshi Nishimura[1]

1. Tohoku Univesity

This study analyzes small earthquakes closely occurring in space and time in Japan in order to clarify their characteristics. We group the earthquakes that occur in a given space-time window from a target earthquake into a cluster (i.e., a group of the earthquakes successively occurring), and count the number of the clusters. To examine whether or not these successive earthquakes occur randomly, we compare the results with simulations in which earthquakes are set to randomly occur in time (but same in locations). We analyze shallow earthquakes with depths of <=70 km from Full Range Seismograph Network of Japan (F-net) for the period from 1998 to 2018 with magnitudes (*3.0*<=Mw<*5.5*). To significantly reduce the possibility to include so called aftershocks of a very large earthquake among successive earthquakes, we divide our catalogue in two sub-catalogues: pre-Tohoku oki earthquake (from 1998 to 2010) and post-Tohoku oki earthquake (from 2012 to 2018) catalogues. The results show that, within 365 days, successive earthquakes occurring close to the target fault account for about 2% of the total number of earthquakes around Japan for both cases. However, successive earthquakes occurred before Tohoku earthquake shows homogeneous spatial distribution of clusters around Japan while those occurring after Tohoku earthquake are mainly concentrated along the Pacific coast and Kyushu island. We then compare the results to those that were previously determined from the global CMT catalogue for the period from 1976 to 2016 (Bantidi and Nishimura, AGU 2019) and JMA catalogue for the period from 1998 to 2017 (Bantidi and Nishimura, SSJ 2019). The results show an eminent homogeneity of spatial clustering behaviors around Japan for both global and regional catalogues; and the spatio-temporal distribution of cumulative number of clusters exhibit similar features in logarithmic scale. Earthquakes in the magnitude range *5.0*<=Mw<*5.5*, are found to be triggered at the distance between 40 - 160 km and 50 –180 km in F-net catalogue for pre- and post-Tohoku sub-catalogues respectively, those are between 50 - 130 km in JMA catalogue and 55 –168 km in the CMT catalogue within 365 days. Furthermore, the triggering distance are roughly proportional to the cube root of the seismic moment. These consistencies in magnitude –triggering distance dependence suggest that static stress change is likely involved in the generation process of successive earthquakes.

Keywords: Spatio –temporal clustering, successive occurrence, triggering distance, earthquake generation process

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Foreshock Cascade to Failure in the M 6.4 July 4, 2019 Ridgecrest, California Earthquake

*William L Ellsworth[1], Andrew J Barbour[2], David R Shelly[2]

1. Stanford University, 2. U. S. Geological Survey

Our current understanding of how earthquakes nucleate leaves open critical questions about the physical processes that occur before dynamic rupture including whether or not foreshocks have other than weak statistical value as a precursor. Two end-member hypotheses that describe the underlying mechanisms are the preslip and cascade model, which take opposing views on the role of aseismic deformation in the nucleation process. Here we examine the foreshocks to the M 6.4 July 4, 2019 Ridgecrest, California earthquake. We used template matching to identify the events, cross correlation and first-motion timing with hypoDD to determine hypocentroids for all event and the initial hypocenters for the M > 2 foreshocks and the initiation point of the mainshock.

The foreshock sequence initiated 2.5 hours before the M 6.4 July 4 mainshock on a northwest-southeast striking fault. The initial events cluster at base of the sequence at 12 km depth. Thirty minutes before the mainshock, the largest foreshock, M 4.0 nucleated on the edge of area ruptured by the first foreshocks and ruptured unilaterally upward and to the northwest (see figure). We estimate a rupture dimension of 250 m, based on spectral ratio measurements. This event was followed by its own aftershock sequence, all located on the periphery of the M 4.0 event, including the M 6.4 which nucleated on the edge of the M_W4.0 rupture (see figure). The foreshocks form a cascade to failure, following the same pattern of closely packed ruptures observed in precision seismological analyses of the M 7.6 1999 Izmit, Turkey (Ellsworth and Bulut, 2018) and M 7.1 1999 Hector Mine, California (Yoon et al., 2019) earthquakes. The absence of repeating earthquakes in all three of the foreshock sequences argues against significant aseismic slip in the initiation process as a silent driver of the foreshock process.

Constraining aseismic slip is notoriously difficult. The M 6.0 2004 Parkfield, California earthquake is one of the few for which aseismic slip can be constrained. Johnston et al. (2006) used borehole straingrams to constrain any possible preslip to no more than M_W 2.2 in a region no larger than 30 m in radius. Note that this is a constraint, as there was no evidence from either strainmeters or seismometers of any signal before the dynamic rupture initiated. For the M 6.4 July 4 Ridgecrest earthquake we detected nothing before rupture initiation on either seismometers or a borehole tensor strainmeter located 18 km from the epicenter. We can, however, place a limit on undetectable aseismic slip during the half hour between the M 4.0 and mainshock. A strain with an amplitude greater than 0.2 nanostrain would have been observed, corresponding to an upper limit of aseismic slip equivalent to M 3.5. Consequently, if aseismic slip occurred it played at most a minor role in foreshock sequence and we can rule out slip acceleration as the time to failure approached.

The Ridgecrest, Izmit and Hector Mine earthquakes all began abruptly without direct evidence of a nucleation process over more than 6 orders of magnitude below the mainshock. In each case the mainshock nucleated on the edge of the foreshock rupture area, in agreement with the cascade model. The observations also agree with the predictions of rate-and-state theory if the laboratory measured meter-scale dimension of the nucleation zone applies to faults in nature.

Figure. Cross sectional view of the foreshocks projected onto the NW-SE striking plane defined by the

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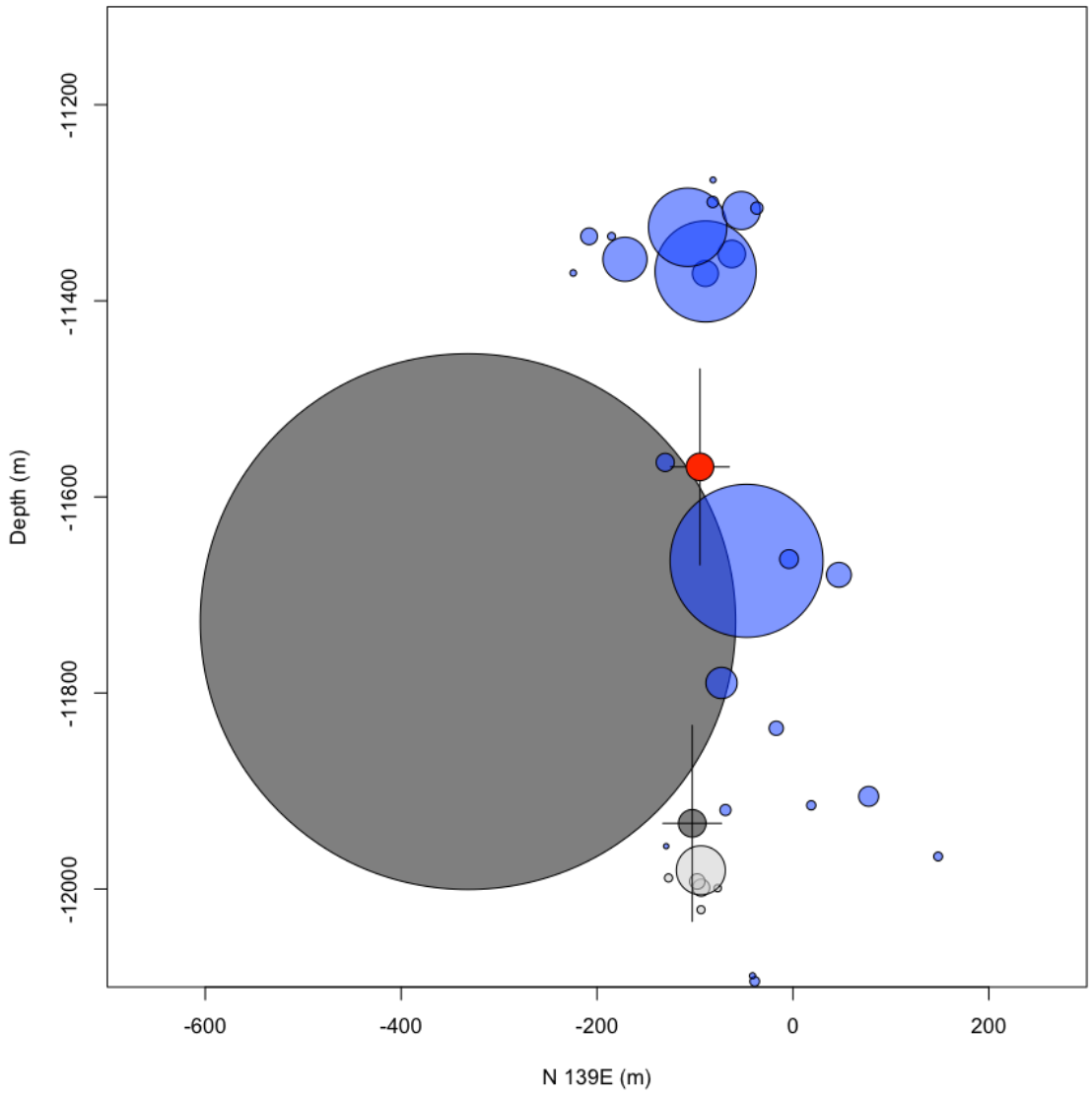
epicenters. Earthquakes shown by equivalent rupture areas for constant stress drop crack. Initial foreshocks in light gray. Dark gray dot with 95% uncertainty bounds marks the hypocenter of the M 4.0 foreshock and large gray circle rupture area centered on hypocentroid. Its aftershocks in blue. Red dot with 95% uncertainty bounds marks the initiation point of the M 6.4 mainshock.



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Changes in stress state associated with the 2019 Ridgecrest, California, earthquakes

*Kazuyoshi Nanjo[1]

1. University of Shizuoka

The 2019 Ridgecrest earthquakes, which occurred near the town of Ridgecrest, California, included a magnitude (M) 7.1 earthquake that struck on 5 July 2019 (UTC) as well as active foreshocks and aftershocks. A M6.4 earthquake preceded the M7.1 quake 34 hours later. The broad context of the Ridgecrest earthquakes is that they occurred under the current tectonic stress that created the Eastern California Shear Zone (ECSZ).

Crustal deformation due to the occurrence of large earthquakes causes stress perturbation in nearby regions. From the viewpoint of physics of earthquakes, the probability of a subsequent large earthquake depends on the stress conditions set up by the previous events and long-term tectonic state. Given the tectonic stress of the ECSZ, an investigation into the spatiotemporal state of stress along and near the faults coseismically ruptured by the M7.1 and M6.4 quakes can play a crucial role in understanding the distribution of post-seismic hazards after these quakes. A Coulomb stress model can be used, but such approaches have so far not been successful in forecasting upcoming large earthquakes any better than statistical models. This is partly due to the fact that the locations of potential faults, essential inputs to the calculation of change in Coulomb stress, are unknown.

Here, we used an alternative statistics-based approach to infer the changes in stress state, based on the b-value of the Gutenberg-Richter law. The b-value is sensitive to differential stress, and its inverse dependence on differential stress has been confirmed many times in both laboratory and field studies. We found that the rupture initiation from an area of low-b-values, indicative of high stress, was common to both M6.4 and M7.1 quakes. The post-M7.1-quake sequence revealedthat another low-b-value zone, which avoided its ruptured area, fell into the remaining unruptured area. This shows that if a high-likelihood future rupture were to occur, this might influence the nearby Garlock fault that hosted large earthquakes for several thousand years.

Keywords: Seismic modelling, Crustal deformation, Stress distribution, b values

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[E] Oral | S (Solid Earth Sciences)：S-SS Seismology

[S-SS09] INDUCED AND TRIGGERED SEISMICITY: CASE STUDIES, MONITORING AND MODELING TECHNIQUES

convener:Luca Urpi, Yusuke Mukuhira(Institute of Fluid Science, Tohoku University), Bogdan Enescu(Department of Geophysics, Kyoto University), Francesco Grigoli(ETH Zurich Swiss Federal Institute of Technology Zurich)

[SSS09-01] Value at Induced Risk: Managing injection-induced seismic risks based on low-probability, high-impact events

★Invited Papers

*William L Ellsworth[1], Cornelius Langenbruch[2], Jeong-Ung Woo[3], David J Wald[4] (1.Stanford University, 2.Risk Management Solutions, 3.Seoul National University, 4.U. S. Geological Survey)

[SSS09-02] Large-scale response of injection-induced seismicity modulated by geomechanics

*Matthew Weingarten[1] (1.San Diego State University)

[SSS09-03] Fast-linearized methods for hypocentre location, magnitude estimation and site amplification effects of seismic events induced in conventional and unconventional gas fields

*Germán Rodríguez-Pradilla[1,2] (1.Department of Geoscience, University of Calgary, 2.School of Earth Sciences, University of Bristol)

[SSS09-04] Seismicity induced by the Hutubi Underground Gas Storage Facility

*Hongfeng Yang[1], Pengcheng Zhou[1], Guoyan Jiang[1], Baoshan Wang[2], Jiancang Zhuang[3] (1.The Chinese University of Hong Kong, 2.University of Science and Technology of China, 3.Institute of Statistical Mathematics)

[SSS09-05] Detection and location of seismic events in continuous data of sparse monitoring network of an abandoned flooded mine

*Dalija Namjesnik[1,2], Jannes Kinscher[1], Yann Gunzburger[2], Pascal Dominique[3], Pascal Bernard[4], Isabelle Contrucci[1], Natalia Poiata[4,5], Emmanuelle Klein[1] (1.Ineris, Institut national de l'environnement industriel et des risques, France , 2.University of Lorraine, France, 3.BRGM, Bureau de recherches géologiques et minières, France, 4.IPGP, Institut de Physique du Globe de Paris, France, 5.National Institute for Earth Physics, Romania)

Value at Induced Risk: Managing injection-induced seismic risks based on low-probability, high-impact events

*William L Ellsworth[1], Cornelius Langenbruch[2], Jeong-Ung Woo[3], David J Wald[4]

1. Stanford University, 2. Risk Management Solutions, 3. Seoul National University, 4. U. S. Geological Survey

The increasing number of damaging earthquakes induced by underground injection of fluids and the public concern they cause demonstrates the need for critical thinking about and clear communication of induced seismic risk. We present a new methodology for seismic risk assessment, communication and management for underground injection of fluids (Langenbruch, et al., Geophysical Research Letters, 2020). Our method is based on low-probability, high impact events that have been largely ignored in past approaches. It summarizes induced seismic risk in a single time-dependent number, the Value at Induced Risk (VaIR) which quantifies the amount of economic losses that will not be exceeded at a given confidence level. VaIR informs the operator, regulators and non-expert stakeholders at risk in a comprehensible and standardized way. Using the Pohang, South Korea, geothermal project and the damaging (US$75M) local magnitude M 5.35 earthquake it triggered in 2017 as an example, our method reveals that the EGS project exposed the city of Pohang to a 2% chance of economic losses of US$140M or more. The high risk could have been identified during the sequence of reservoir stimulation, lasting almost two years. Other fluid injection projects have been terminated due to seismic safety concerns. A geothermal reservoir stimulation project below the city of Basel, Switzerland, in 2006 was permanently terminated after a M 3.2 event occurred. Using the same analysis procedure, we found that up to the time of that earthquake the Basel project was characterized by a probability of about 0.3% to exceed M 5. The same probability level was exceeded after the first stimulation cycle at Pohang. It is remarkable, because the largest earthquake induced during the first stimulation in Pohang was only M 1.5, a magnitude which by itself would not terminate the project, as it was below the red traffic-light magnitude for the project. VaIR opens new ways to assess and communicate risk to all stakeholders for informed risk management decision making that can only be improved by further development of physical and statistical models of induced and triggered earthquakes. Together, they can provide more reliable assessment of magnitude probabilities and reduced uncertainties for inclusion in predictive risk assessments.

Keywords: Induced seismicity, Earthquake hazard, Earthquake risk

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Large-scale response of injection-induced seismicity modulated by geomechanics

*Matthew Weingarten[1]

1. San Diego State University

The central and eastern United States have seen an unprecedented rise in the number of earthquakes in the past decade. The vast majority of these earthquakes have been tied to injection operations for the disposal of wastewater or for hydraulic fracturing. Wastewater injection in the states of Oklahoma and Kansas, specifically, has been tied to thousands of induced earthquakes across the two states. In both states, crystalline basement faults respond to stress changes from injection based upon the hydrogeologic and geomechanical parameters governing the region. Here, I will show that variations in the seismic response at the regional-scale may be explained by regional geomechanical properties. Stochastic models of geomechanical properties show that the regional stress state can modulate the availability of critically stressed fractures and faults. These fractures and faults are the primary pathways for fluid flow in the otherwise low-permeability crystalline basement. Regions of Oklahoma and Kansas which have exhibited shorter lag times between the onset of injection and seismicity are also regions which are predicted to have a greater density of critically stressed faults and fractures.

Keywords: Induced Seismicity, Geomechanics, Hydrogeology

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Fast-linearized methods for hypocentre location, magnitude estimation and site amplification effects of seismic events induced in conventional and unconventional gas fields

*Germán Rodríguez-Pradilla[1,2]

1. Department of Geoscience, University of Calgary, 2. School of Earth Sciences, University of Bristol

Microseismic monitoring is an essential tool required to better understanding the induced-seismicity processes observed in multiple oil and gas, and geothermal projects during fluid-injection or extraction operations. The data obtained from a seismic monitoring program, as the location and magnitude of the observed induced events, can be integrated with the near-surface conditions (represented by the average shear-wave velocity of the shallowest 30 meters - Vs30) to assess the ground motions generated by these events at surface, and its impact to local infrastructure. However, its reliability strongly depends on the implemented methods for hypocentre location, where most of the conventional methods rely on a pre-defined velocity model. For magnitude estimation, most of the conventional methods rely on the availability of broadband sensors, even though most microseismic monitoring programs are acquired with short-period geophones as those used in seismic reflection exploration surveys. As an alternative, an epicenter location method based on the linearized normal moveout (NMO) equation is proposed to locate events without the need of a velocity model, together with a magnitude estimation method based on the duration of the coda wave which can me measured in seismic data acquired with short-period sensors. These methods are applied to locate and estimate the magnitude of some induced seismic events reported during a multi-stage hydraulic fracturing stimulation in the Duvernay shale formation in western Canada, and in the Groningen gas field in the Netherlands. Both case studies were monitored with a dense shallow-borehole array that also allows a reliable measurement of seismic velocities of the near surface in the location of each shallow-borehole station, where the Vs30 can be calculated and integrated with a subsequent ground motion analysis of the same events.

Keywords: Hydraulic-Fracturing Induced Seismicity, Site Amplification Effects, Coda-Duration Magnitude

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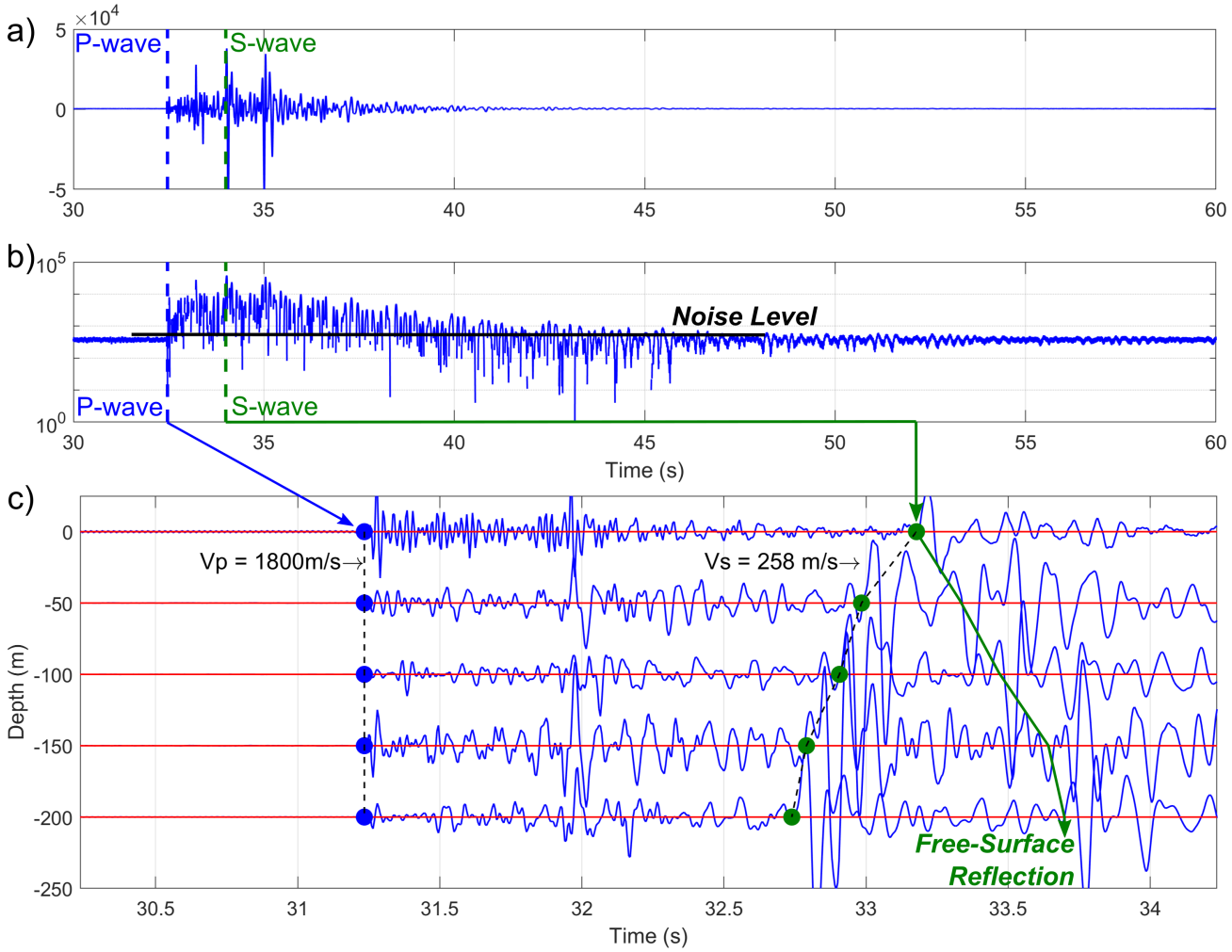

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Seismicity induced by the Hutubi Underground Gas Storage Facility

*Hongfeng Yang[1], Pengcheng Zhou[1], Guoyan Jiang[1], Baoshan Wang[2], Jiancang Zhuang[3]

1. The Chinese University of Hong Kong, 2. University of Science and Technology of China, 3. Institute of Statistical Mathematics

The Hutubi underground gas storage (UGS) facility in Xinjiang, China, with a maximum gas storage capacity of 10.7 billion m^3, provides an excellent opportunity to study seismicity induced by the annually cyclic injection and extraction of natural gas. To distinguish induced earthquakes, we first investigated the background seismicity probability using the ETAS model. Our statistical results suggest a potential link between gas injection and two groups of seismicity. We then relocated earthquakes with a dedicated mobile seismic network and a refined local velocity model. After relocation, these two groups of earthquakes moved much closer to the faults bounding the UGS and were situated at depth ~4 km, slightly deeper than the reservoir formation. Focal mechanism solutions of two largest earthquakes (Mw 2.8 and 3.0) in August 2013 show a reverse fault.Based on our high-resolution earthquake locations, we propose that these earthquakes are not hydrologically connected with the reservoir and thus are induced by poroelastic stress perturbations, which were quantified in our newly developed geomechanical model incorporating fully-coupled poroelasticity. The results shed light on seismic hazard assessments associated with large UGS that are actively developed globally.

Keywords: Underground gas storage, Cyclic injection and extraction, Induced earthquake by poroelastic stress, Geomechnical model

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Detection and location of seismic events in continuous data of sparse monitoring network of an abandoned flooded mine

*Dalija Namjesnik[1,2], Jannes Kinscher[1], Yann Gunzburger[2], Pascal Dominique[3], Pascal Bernard[4], Isabelle Contrucci[1], Natalia Poiata[4,5], Emmanuelle Klein[1]

1. Ineris, Institut national de l'environnement industriel et des risques, France , 2. University of Lorraine, France, 3. BRGM, Bureau de recherches géologiques et minières, France, 4. IPGP, Institut de Physique du Globe de Paris, France, 5. National Institute for Earth Physics, Romania

In the case of abandoned and flooded coal mine in southeastern France, induced seismicity seems to be controlled by interaction of complex hydrogeological settings, mining works and pre-existing seismotectonic conditions. Swarming seismic activity that occurs periodically in the area is sometimes felt by population and is monitored by local seismic monitoring network composed of three to five stations depending on observed period. To accurately assess local mine-related seismic hazard, precise knowledge of triggering mechanism for observed seismicity and characterization of the fault(s) is crucial.

Precise detection and location of seismic events are the first steps in understanding of observed seismicity. Due to large amount of available continuous data, manual analysis, nowadays, is no longer feasible. We will present an application of the automatic full-waveform-based detection and location method BackTrackBB (Poiata et al., 2016) to continuous data of our monitoring network with limited station coverage. The method was originally designed for application to dense seismic networks, but, as we show, successfully locates microseismic events using data recorded by three or five stations only. However, array coherence based criteria for detection of events implemented within BackTrackBB in this case results in similar coherency values for microseismic events and some noise sources. Thus, it is often impossible to distinguish between the two.

Therefore, in order to apply BackTrackBB to our noisy environment it was necessary to develop a pre-processing step allowing to reduce the large dataset to more manageable volume, minimizing the computation time and removing the coherent noise. Our final detection and location methodology consists of two parts. First part comprises two combined noise removal criteria: the modified STA/LTA trigger technique and the amplitude ratio-based location technique. Reduced dataset resulting from the first part represents a preliminary catalogue of events that is further reprocessed with BackTrackBB, which relocates events with higher precision.

Preliminary results of this new methodology application to the dataset from flooded coal mine has revealed spatio-temporal clustering of epicentral locations, indicating faulting or reactivation of preexisting faults. Swarming activity in some periods seems to be connected to ground water recharge due to rainfalls. To understand better the seismicity triggering mechanism in this complex settings, in order to asses possibility of triggering of the larger tectonic events, we currently examine spatio-temporal characteristics and source parameters of detected seismicity clouds as well as the connection with meteorologicall conditions in more detail.

The proposed detection and location approach will be further tested for implementation into operational monitoring of recently expanded monitoring network of Gardanne area. It can also be easily applied to other environments with limited monitoring capacities and is computationally efficient allowing to process large volumes of seismic data.

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Reference: N. Poiata, C. Satriano, J.-P. Vilotte, P. Bernard, and K. Obara, ‘Multiband array detection and location of seismic sources recorded by dense seismic networks’, *Geophys. J. Int.*, vol. 205, no. 3, pp. 1548–1573, Jun. 2016.

Keywords: detection and location, low magnitude, induced seismicity

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[E] Oral | S (Solid Earth Sciences)：S-SS Seismology

[S-SS09] INDUCED AND TRIGGERED SEISMICITY: CASE STUDIES, MONITORING AND MODELING TECHNIQUES

convener:Luca Urpi, Yusuke Mukuhira(Institute of Fluid Science, Tohoku University), Bogdan Enescu(Department of Geophysics, Kyoto University), Francesco Grigoli(ETH Zurich Swiss Federal Institute of Technology Zurich)

Induced and triggered seismicity occurs in conjunction with human activities such as reservoir impoundments, mining operations, conventional and non-conventional hydrocarbon production, geothermal energy exploitation, wastewater disposal, CO2 sequestration and gas storage operations as well as volcanic and hydrogeological processes. The stability of faults is affected by external solicitations such as pore-pressure diffusion, relaxation effects as well as perturbations related to mass, pressure, temperature and/or volume changes, dike intrusions and earthquake-earthquake interactions. A better understanding of the physical processes governing induced and triggered seismicity is important for the assess the risk of current and future industrial activities.

The study of induced and triggered seismicity is inherently an interdisciplinary problem, which requires the combination of seismological, hydrogeological, geodetic data and a wide range of modeling approaches. This session welcome contributions covering the analysis and modeling of induced and triggered seismicity at different spatial scales and environments.

Relevant topics to be presented include but are not limited to induced seismicity characterization, spatio-temporal variations of physical parameters (including stress, pressure and temperature changes), spatio-temporal patterns of seismicity, modeling strategies and case-studies.

The goal of the session is to cover both theoretical, numerical and experimental aspects of these topics.

[SSS09-06] Monitoring anthropogenic seismicity in Italy

★Invited Papers

*Thomas Braun[1], Stefania Danesi[1], Daniela Famiani[1], Andrea Morelli[1] (1.Istituto Nazionale di Geofisica e Vulcanologia (INGV))

[SSS09-07] Examination of the finite fault model for the M_W 5.5 2017 Pohang earthquake with multi-segmented fault system

*Jeong-Ung Woo[1], Junkee Rhie[1], Eunbyeol Cho[1] (1.Seoul National University)

[SSS09-08] Revisiting triggering intensity of earthquakes in southern California using resent seismic catalogs from 2008 to 2017

*Masatoshi Miyazawa[1], Emily E Brodsky[2], Huiyun Guo[2] (1.Disaster Prevention Research Institute, Kyoto University, 2.Department of Earth & Planetary Sciences, University of California Santa Cruz)

[SSS09-09] Effective medium approach for analysis of natural fracture activation trends during hydraulic fracturing

*Nikita Dubinya[1,2], Maria Trimonova[3], Victor Nachev[1,3] (1.Moscow Institute of Physics and Technology, 2.Schmidt Institute of Physics of the Earth of the Russian Academy of Sciences, 3.Sadovsky Institute of Geospheres Dynamics of the Russian Academy of Sciences)

Monitoring anthropogenic seismicity in Italy

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Public concern about anthropogenic seismicity in Italy first arose in the aftermath of the deadly M6 earthquakes that hit the Emilia-Romagna region (northern Italy) in May 2012. As these events occurred in a (tectonically active) region of oil and gas production and storage, the question whether stress perturbations due to underground industrial activities could have induced or triggered the shocks was raised. Following expert recommendations, in 2014, the Italian Oil & Gas Safety Authority published guidelines, describing regulations regarding hydrocarbon extraction, waste-water injection and gas storage that could also be adapted to other technologies, such as dams, geothermal systems, CO_2 storage, and mining. These guidelines describe the framework for the different actors involved in monitoring activities, their relationship and responsibilities, the procedure to be followed in case of variations of monitored parameters, the need for in-depth scientific analyses, the definition of different alert levels, their meaning and the parameters to be used to activate such alerts. Four alert levels are defined, the transition among them follows a decision to be taken jointly by relevant authorities and industrial operator on the basis of evaluation of several monitored parameters (micro-seismicity, ground deformation, pore pressure) carried for each area on by a scientific-technical agency. Only in the case of liquid reinjection, the alert levels are automatically activated on the basis of exceedance of thresholds for earthquake magnitude and ground shaking –in what is generally known as a Traffic Light System (TLS). The National Institute of Geophysics and Volcanology (INGV) has been charged by the Italian oil and gas safety authority to apply the monitoring guidelines in three test cases (two oil extraction and one gas storage plants).

The presentation will report about examples of hypothesized and documented anthropogenic seismicity in Italy. Special emphasis will be put on the Val d’ Agri (VA), which had been characterized as one of the areas with the highest seismic hazard in Italy. However, the VA hosts also the largest on-shore gas-/oilfield in Europe. INGV is responsible for monitoring the local seismicity (hypocenter, magnitude, PGV, PGA), and potential variations of ground deformation and pore pressure. In 2006 a small episode of induced seismicity (M_{max}=1.9) was reported after starting wastewater reinjection in a 3 km deep inoperative borehole. Beyond the extraction of hydrocarbons and the reinjection of production water, local seismicity may be also influenced by seasonal water level variations of the nearby located Pertusillo reservoir. Particular difficulties in applying the TLS have been encountered concerning uncertainties of the hypocenter location, whose accurate depth estimation is needed to decide the “exact” location with respect to the boundaries of the monitoring domain. Magnitude - a critical parameter used to define a possible step-up in activation levels of the TLS - has inherent uncertainty and can be evaluated using different scales.

A second focus concerns the geothermal energy production in Italy. After the forthcoming privatization of the National energy market and the entrance of multiple operators, the main effort of INGV will be the realization of an integrated monitoring project, able to assess the demands of seismic monitoring in adjacent concession areas. Prescriptions for new production permits to determine the initial blank-level monitoring stage, aimed at assessing background seismicity, may lose significance in case of nearby active production. Different exploitation technologies (vapor-/liquid-dominated plants, EGS), depending on the geothermal characteristics of the single concessions may not uniquely contribute to the seismic hazard.

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Discrimination of the local seismicity in terms of high-precision hypocenters, as well as in terms of its natural or anthropogenic origin, will be a great challenge.

Keywords: anthropogenic seismicity, Italy

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Examination of the finite fault model for the M_W 5.5 2017 Pohang earthquake with multi-segmented fault system

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1. Seoul National University

The 15 November 2017 *M*w 5.5 Pohang earthquake produced strong ground motions in a city of Pohang, South Korea with damaged buildings and injured people. This earthquake was recorded as the largest earthquake in seismicity near enhanced geothermal systems. With its focal depth of 4 km, the earthquake generated a measurable static deformation, which gives an opportunity to quantify its source mechanism. In this study, we estimated the rupture process of the Pohang earthquake from regional seismograms by using multiple-time-window linear inversion and segmented fault geometry inferred from its aftershock distribution. The initiated rupture propagated southwest downward by 2 km and generated maximum peak slip up to ~30 cm. The rupture then propagated to the opposite direction, and slip patches located NE direction are sequentially reactivated over the potential barriers between two adjacent fault segments. Two largest aftershocks of M_W 4.3 and M_W 4.6 are located on the edge of the slip distribution, which represents the existence of local asperities. Rupture duration of 4 s and fault dimension of 40 km^2 suggest relatively low stress drops, which may be caused by the retardation of rupture propagation by patches with strong asperities with a high stress state. The complicated rupture process of the Pohang earthquake illustrates how the rupture evolves in a complex fault system with possible fluid interaction and reconciles the importance of seismic barriers that can control following aftershocks as well as the slip history.

Keywords: Pohang earthquake, Finite fault inversion, complex fault geometry

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Revisiting triggering intensity of earthquakes in southern California using resent seismic catalogs from 2008 to 2017

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We revisit the systematic increase of local seismicity rate as a function of the amplitude of the transient strain change, using more recent seismic catalogs and data in southern California from 2008 to 2017. The previous studies showed the relationship using data from the Advanced National Seismic System (ANSS) earthquake catalog from 1984 to 2009. For the seismicity in the last decade, a more high-quality seismicity catalog for southern California has been available. We also apply the waveform-based approach to reproduce the triggering ground velocity from the teleseismic events, while a ground motion was previously estimated by using Ms attenuation relationship with the ANSS catalog. These make possible a more precise spatiotemporal estimate of the areas susceptible to remote triggering. The relationship is successfully reproduced using new datasets that are independent of previous studies. In addition, the new method allows us to check a greater range of hypotheses about triggering including the frequency. Furthermore, we examine the temporal changes of the triggering intensity around the 2019 Ridgecrest earthquake area before its occurrence.

Keywords: remote triggering, triggering intensity, southern California

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Effective medium approach for analysis of natural fracture activation trends during hydraulic fracturing

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The paper presents an approach for estimating positions and spatial orientations of natural fractures, which become active during the operation of hydraulic fracturing a formation, which is characterized by the existence of natural fractures. Alongside with methodology of the approach, we present a simplified numerical model of hydraulic fracture in a naturally fractured rock mass.

Although hydraulic fracturing is one of the most useful methods of enhancing oil recovery, there are still some problems with predicting its efficiency using numerical or theoretical models. In the current study, we focus on the problem of hydraulic fractures in naturally fractured rock masses. Despite the fact that there are many developed methods of modeling the interaction between hydraulic fracture itself and natural fractures surrounding it, there is a problem with input data regarding natural fractures. To use the full potential of such models, one has to know the positions and geometrical properties of each natural fracture, which may seem to be impossible in some cases. To solve this problem, we try to implement an effective medium approach to study the interaction between hydraulic fracture and the rock mass characterized by effective properties of natural fractures instead of using discrete fracture networks.

To construct such an effective model, we implement a special approach. First of all, we consider natural fractures in the rock mass as realizations of inelastic strain accumulated during the whole stress state history. Usage of non-associated plastic flow law with friction hardening to describe the mechanical behavior of a naturally fractured rock makes it possible to determine spatial orientations and positions of natural fractures emerging and developing in the rock mass during the history of its stress state. At the same time, the current stress state of the rock mass determines which fractures will be activated during external impact, e.g., hydraulic fracturing of the considered rock. To be precise, natural fractures' mechanical behavior is mostly governed by normal and shear stresses acting on their planes and friction. In the current study we used a recently developed analytical solution for predicting spatial orientations of all natural fractures which are critically stressed in an arbitrary stress state.

A numerical study of hydraulic fracture propagation in a naturally fractured rock mass was performed using the extended finite-element method. Natural fractures were related to accumulated inelastic strain instead of being introduced as discrete fractures. Non-associated plastic flow law was developed based on laboratory experiments carried out for rock samples from a particular oil field characterized by the existence of natural fractures. Although such an approach makes it impossible to precisely predict geometry of hydraulic fracture, it allows estimating some general trends in positions and spatial orientations of natural fractures, which get activated due to stresses induced by hydraulic fracture propagation or fluid filtration. Stereonets with spatial orientations of critically stressed fractures were constructed for different stages of hydraulic fracture propagation and different domains of rock mass surrounding it. It was shown that there is a well-established relationship between the obtained trends in natural fractures activation and the approaches developed for microseismic monitoring. The proposed approach may be used for the optimization of hydraulic fracturing, e.g., for enhancing hydraulic connectivity of natural fractures in the vicinity of the main hydraulic fracture.

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It should be noted that the aforementioned analytical solution for critically stressed fractures' spatial orientations is not limited to hydraulic fracturing. One is capable of implementing it to different problems of hydrocarbon reservoirs development, including prediction of induced seismicity caused by changes in fields of effective stresses.

Keywords: Hydraulic fracturing, Induced seismicity, Reservoir geomechanics

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[E] Oral | S (Solid Earth Sciences)：S-EM Earth's Electromagnetism

[S-EM18] Paleomagnetism and rock magnetism applied to solving geological and geophysical problems

convener:Martin Chadima(Institute of Geology of the Czech Academy of Sciences), Balazs Bradak(University of Burgos, Spain), Daniel Pastor-Galan(Center for North East Asian Studies, Tohoku University), Myriam Annie Claire Kars(Center for Advanced Marine Core Research)

Paleomagnetic studies have provided much key information about the geomagnetic field and plate motions, and rock magnetic methods have considerable potential for detecting and monitoring signals from past and recent environments. Integrated paleomagnetic and magnetic fabric studies, together with structural geology and petrology, are effective tools for increasing our knowledge about sedimentological, tectonic or volcanic processes on various scales. Determining how the geomagnetic field changes (i.e., reversals and paleointensity variations) helps to understand the evolution of Earth's interior, plate kinematics, dynamics of the core and mantle, long-term climate change, and true polar wander. We welcome presentations of innovative studies that make use of paleo-, rock, and environmental magnetic data in relation to geological, geomagnetic, and environmental processes, especially contributions that combine rock magnetic methods or novel approaches to data evaluation. We also solicit contributions from both experimental and theoretical aspects of paleomagnetic reconstructions, acquisition of petrofabrics, characteristic remanences, remagnetizations, polarity reversal records, paleointensity, and environmental magnetic methods.

[SEM18-01] Implications of new Paleocene paleomagnetic data from SW Japan for the mode of early opening of the Japan Sea

★Invited Papers

*Hiroyuki Hoshi[1] (1.Department of Earth Sciences, Aichi University of Education)

[SEM18-02] **Paleomagnetic and paleointensity results from a Pliocene lava flow sequence including a transitional field record**

*Manuel Calvo-Rathert[1,2], Elisa Maria Sanchez Moreno[1], Maria Felicidad Bogalo[1], Avto Gogichaishvili[3], George Vashakidze[4], Emilio Herrero-Bervera[2], Juan Julio Morales[3] (1.Departamento de Fisica, EPS, Universidad de Burgos, 09006 Burgos, Spain, 2.Hawaii Institute of Geophysics and Planetology, University of Hawaii at Manoa, Honolulu, Hawaii, United States, 3.Servicio Arqueomagnetico Nacional – Instituto de Geofisica, Universidad Nacional Autonoma de Mexico, Morelia, Mexico , 4.Alexandre Janelidze Institute of Geology – Ivane Javakhishvili Tbilisi State University, 0171 Tbilisi, Georgia)

[SEM18-03] Paleomagnetic study of Holocene lava flow age at Nakadake volcano in Aso caldera, Kyushu Japan: Contribution to establish the Eruption history

*Chisato Anai[1], Nobutatsu Mochizuki[2], Yasuo Miyabuchi[3], Mitsuru Utsugi[1], Hidetoshi Shibuya[2], Takahiro Ohkura[1] (1.Aso Volcanological Laboratory, Institute for Geothermal Sciences, Graduate School of Science, Kyoto University, 2.Earth and Environmental Science, Division of Natural Science, Faculty of Advanced Science and Technology, Kumamoto University, 3.Center for Water Cycle, Marine Environment and Disaster Management, Kumamoto University)

[SEM18-04] **Magnetic mineral change during thermal demagnetization monitored by principle component analysis of FORC: Sediments from Boso Peninsula recording geomagnetic reversals**

*Hirokuni Oda[1], Hiroomi Nakazato[2], Futoshi Nanayama[1] (1.Institute of Geology and Geoinformation, Geological Survey of Japan, AIST, 2.National Agriculture and Food Research Organization)

[SEM18-05] **Eocene global cooling event registered in the red clay sequence near Tibet**

*Vadim A Kravchinsky[1,2], Rui Zhang[2], Lioudmila P Koukhar[1] (1.Geophysics, Department of Physics, University of Alberta, Edmonton, Alberta T6G 2E1, Canada, 2.Institute of Cenozoic Geology and Environment, State Key Laboratory of Continental Dynamics, Department of Geology, Northwest University, Xi'an 710069, China)

[SEM18-06] Analyze the early 19th century's geomagnetic declination in Japanese archipelago from Tadataka Inoh's 67 volumes magnetic survey azimuth ledger Santou-Houi-Ki national treasure of Japan (The 14th report)

*Motohiro Tsujimoto[1], Akitoshi Omotani[2] (1.none, 2.San-in.System Consultant Co.Ltd)

Implications of new Paleocene paleomagnetic data from SW Japan for the mode of early opening of the Japan Sea

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Geological and paleomagnetic data suggest that the Japan Sea backarc basin has a two-phase opening history. The first phase may have been relatively slow opening that began in the Eocene or early Oligocene, and the second phase was relatively fast opening occurring in the early Miocene. Paleomagnetic data reported from the Japan arc over the past 40 years show that the second phase was accompanied by differential arc rotation, namely, clockwise rotation of the southwestern lithospheric sliver of the arc (SW Japan) and counterclockwise rotation of the northeastern sliver (NE Japan). However, it is uncertain whether the first phase was also accompanied by differential arc rotation. Here, new paleomagnetic data are presented to address this issue. In this study, Paleocene (~60 Ma) andesite dikes were sampled at 17 sites in the Toki-Mizunami area in SW Japan. These dikes vertically or subvertically intrude a late Cretaceous (~70 Ma) granite batholith and comprise an ENE-striking dike swarm. Stepwise demagnetization experiments were performed on all samples for obtaining characteristic remanent magnetization (ChRM) components. As a result, site-mean directions of ChRM components were determined for 14 sites. Thermal demagnetization of natural remanent magnetization (NRM) and isothermal remanent magnetization (IRM) shows that magnetite is the main magnetic carrier. Comparison of the site-mean directions with the anisotropy of magnetic susceptibility (AMS) suggests that the influence of the preferred orientation of magnetic particles upon the site-mean directions is absent or negligible. Although the site-mean directions display a small dispersion, the presence of dual polarities suggests that the dike emplacement extended over a set of normal and reverse polarity chrons. The overall mean direction of the 14 site-means is therefore interpreted to be a time-averaged paleomagnetic direction at ~60 Ma. It is deflected ~57° clockwise of an expected paleomagnetic direction calculated from a late Cretaceous paleomagnetic pole for the North China Block in the Asian continent, and the amount of clockwise deflection is larger than that (~44°) reported for early Miocene sediments in the Toki-Mizunami area. Therefore, small (~10–15°) clockwise rotation occurred in the study area between the Paleocene and the early Miocene. It is likely that this small rotation is associated with the early opening of the Japan Sea.

Keywords: Japan Sea, paleomagnetism, rock magnetism, SW Japan, tectonic rotation

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Paleomagnetic and paleointensity results from a Pliocene lava flow sequence including a transitional field record

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Knowledge about the direction and intensity variations of the Earth's magnetic field (EMF) is necessary to develop models that describe its characteristics and origin. Paleomagnetic and paleointensity data are the only means to retrieve information about the variations experienced by the field over time before direct magnetic records. Volcanic rocks can provide an instantaneous and reliable record of the EMF. However, lava flow sequences with a number of flows high enough will be needed to obtain better information about its variations.

We present paleomagnetic, paleointensity and rock-magnetic results of a study performed in the Pliocene lava flow sequence of Khaveti, which is located in the Lesser Caucasus, in the Republic of Georgia. The sequence consists of 28 flows. Paleomagnetic results show that the lower 14 flows of the sequence record a transitional direction, while the upper 14 flows show reverse polarity directions. Besides a relatively weak viscous component, in most flows only a single main paleomagnetic component can be distinguished. Thermomagnetic curves measured on samples of each of the studied flows display in most cases a reversible behaviour, showing a single ferromagnetic phase, which corresponds to magnetite.

Paleomagnetic characteristics and results of the rock-magnetic experiments indicate that most of the flows are suitable for paleointensity determinations. We present the results of paleointensity determinations carried out with a multi-method approach in three different laboratories. Paleointensity determinations were performed at the University of Hawaii (USA) with the Thellier-Coe method, at the University of Burgos (Spain) with the IZZI method, and at Universidad Nacional Autónoma (Mexico) with the multispecimen method.

Keywords: Paleointensity, Paleomagnetism, Caucasus, Polarity transition, Pliocene lava flows

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Paleomagnetic study of Holocene lava flow age at Nakadake volcano in Aso caldera, Kyushu Japan: Contribution to establish the Eruption history

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Nakadake volcano, which is the only active central cone inside the Aso caldera (Kyushu), is one of the most active volcanoes in Japan. It became active from ca. 22-21 ka, and has formed an old edifice (22-21 ka), a young edifice (around 5 ka) and a still younger pyroclastic cone (until present). The lava flows from the young edifice spread on the flank of the cone several times around 5 ka. These lava flows have been used to reconstruct the eruptive history of Nakadake volcano at those ages, but the chemical composition and lithology of these lavas cannot be used to distinguish each other because of their similarity, so that it is actually very difficult to establish the stratigraphy of those volcanic activities. A paleomagnetic study should contribute for the case because a paleo secular variation (PSV) record is high resolution age detector. Lava units may be distinguished by PSV, if they are separated more than about 50 years. Thus, we try a paleomagnetic study of these lava flows to unravel the correlation of those lava flows. This study is expected to contribute not only to the volcanology and volcanic geology but also to the disaster prevention and disaster risk reduction.

The samples collected form 14 lava flows and 6 agglutinates layers (welded scoria-fall deposits) were used for paleomagnetic and rock-magnetic measurements. These samples, from visual inspection, seemed to be influenced chemical alteration of their surface by sulfides of volcanic gas. To check the effect of the chemical alternation on the lavas and agglutinates, thermomagnetic analyses were made on chip samples from the top (surface of rock) and bottom (inside of rock) of the collected paleomagnetic cores. The thermomagnetic analyses indicate that the core top and bottom are approximately the same, in spite of different color, and the carrier of magnetization of each core is either titanium rich (x is about 0.6) or poor (x is about 0.1 to 0.2) titanomagnetites. The natural remanent magnetization of each sample shows a simple, single vector component in alternating field demagnetization experiments, which well defines the primary component. Site mean directions can be categorized into three different direction groups. These data suggest that the eruption producing lava flows and/or agglutinates occurred at three different ages. Furthermore, the paleomagnetic directions of two groups are not consistent with the directions of the eruptive ages of Nakadake young edifice assigned from the present stratigraphy. Comparing these directions with the paleomagnetic secular variation curve which drew from basaltic volcanoes in Aso central cones, these direction ages assigned to the age around 5 ka, 4.5ka, 3.5 ka, respectively.

Keywords: paleomagnetic secular variation curve, Aso Nakadake

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Magnetic mineral change during thermal demagnetization monitored by principle component analysis of FORC: Sediments from Boso Peninsula recording geomagnetic reversals

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We report paleomagnetic records of Matuyama-Brunhes geomagnetic polarity reversal associated key tephra layers from sediments of an outcrop in Boso Peninsula. The outcrop is ~4m height along a roadside in Terasaki, Chiba Prefecture, Japan. The sediment mainly consists of massive silt of Early-Middle Pleistocene Kokumoto Formation, Kazusa Group underlaid by thick sand. A 2mm-thick vitric tephra layer could be identified in the middle of the outcrop about 2 m above the boundary between silt and sand. Chemical compositions of the vitric tephra could be correlated to TNTT (Byk-E) tephra taken along Yoro River section, which is associated with Matuyama-Brunhes polarity transition in the previous studies. Drill cores were taken at intervals of 1~10 cm from the massive silt spanning the vitric tephra layer and 2-3 paleomagnetic samples were cut from each drill core. Neither progressive alternating field demagnetization nor thermal demagnetization was not successful in revealing primary remanent magnetization. In general, progressive thermal demagnetization up to 175˚C in vacuum followed by alternating field demagnetization was successful. In order to understand magnetic mineral change during thermal demagnetization, progressive heating experiments while monitoring FORC distributions were conducted. Principle component analysis of FORC revealed considerable change of FORC components by heating starting from 200˚C to 400˚C. The change is indicative of decomposition of higher coercivity mineral, which is considered as greigite. In the presentation, we will discuss magnetic mineral changes more in detail.

Keywords: geomagnetic reversal, Boso Peninsula, FORC PCA, magnetite, greigite, thermal decomposition

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Eocene global cooling event registered in the red clay sequence near Tibet

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We report a long cooling event registered in magnetic susceptibility (MS) data from a continuous eolian sequence near Tibet. The section was accurately dated using magnetistratigraphy and cyclostratigraphy. The MS and frequency dependence of the MS data mimic the general global climate cooling trend in the Eocene. Therefore, the global cooling was suggested to be the leading factor of aridification in the region overwriting the previously proposed dominant role of the Tibetan Plateau uplift (Li et al., 2018). Our high resolution MS record exhibits Asian monsoon intensification variations linked to eccentricity cycles. We show that global cooling reached its maximum at ~ 45 Ma ending up with a sharp warming event. Our analysis shows that this cooling event is also pronounced in the global oxygen isotope record and it is associated with alterations of geomagnetic reversal rate and plate tectonic motion speed. The tectonic changes appear to lag behind the changes in climate and geomagnetic reversal rate and could be driven by the climate change feedback mechanism proposed in Chen et al. (2015) that is linked to multimillion cyclical reorganization of the Earth’ s interior.

Li, J.X., Yue, L.P., Roberts, A.P., Hirt, A.M., Pan, F., Guo, L., Xu, Y., Xi, R.G., Guo, L., Qiang, X.K., Gai, C.C., 2018. Global cooling and enhanced Eocene Asian mid-latitude interior aridity. Nature communications 9(1), 1–8.

Chen, J., Kravchinsky, V.A., Liu, X., 2015. The 13 million year Cenozoic pulse of the Earth: Earth and Planetary Science Letters 431, 256–263.

Keywords: cyclostratigraphy, Eocene climate, eccentricity cycles, magnetic susceptibility, magnetostratigraphy, red clay

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Analyze the early 19th century's geomagnetic declination in Japanese archipelago from Tadataka Inoh's 67 volumes magnetic survey azimuth ledger Santou-Houi-Ki national treasure of Japan (The 14th report)

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1. none, 2. San-in.System Consultant Co.Ltd

The Santou-Houi-Ki is a national treasure of Japan recorded by Japanese Samurai cartographic surveor Tadataka Inoh in 1800 to 1816,consist of 67 volumes survey redger to produce the first survey map of Japan ,called "Costal Area Map of Japan,or Inoh Map(1:36000,1:216000,1:432000). In the Santou-Houi-Ki estimate 200,000 magnetic compass srvey azimuth data by acculacy of 0 degeree 05 minute unit were recrded, with the name or short description of magnetic compass survey execution reference point and target points. inoh's team carried out survey didnot apply the correction of magnetic declination. Because before the start of his survey ,Inoh tried to observe magnetic declination in Edo(Tokyo)was nearly zero. Inoh conducted the Survey on the assumption that the influence of magnetic declination to hissurvey map of Japan is at least. The surveyed region extends from North eastern coast of Hokkaido Island to Yakushima Island in western Japan. The geomagnetic declination at each province are different in long Japanese archipelago. We start the analysis,check the outline position of the survey execution reference point and target points from magnetic survey azimuth,or name of places recoded in Santou -Houi-Ki,Inoh Map,or from the description places in Inoh'sSurvey Diary,modern survey maps,today's digital maps,GPs,or local source books or maps etc. Itis able to calicurate backward the prcise position of of survey excution reference point,where the value of geomagnetic declination,subtracting the magnetic survey azimuth from the true azimuth to any target points is similar or approximate. Check the source books or msps of local history,adjust the precise detail position. Wemust execute interdisciplinary and simultaneous analysis of precise position of the survey execution reference point,target points(latitude and longitude less than 0.2 second level),real azimuth,geomagnetic declination from national treasure Santou-Houi-Ki.
We have already shown a proposal to modify the isogonic line of declination around Japanese archipelago in 1830,in Gauss and Weber's Atlas des Erd magnetismus.
Since there is almost no observation data of geomagnetic declination on land in Japan during more than 200 years long isolation period of Japan,analysis of Santou-Houi-Ki is very important.
Comparing the isogonic line of NOAA's 400 year's declination Viewer based on Andrew Jackson etal GUFM1 to
,NOAA's Isogonic line around Japanese archipelago in 1800-1810 is always slower more than 5 years at increase of declination west than the Isogonic line by analysis of Santou-houi-Ki. We are preparing to inject the geomagnetic declination data analyzed from Tadataka Inoh's Santou-Houi-Ki to Andrew Jackson GUFM1 and NOAA's 400 years declination viewer.

Keywords: Tadataka inoh's Santou-Houi-Ki, geomagnetic declination, iogonic line, NOAA's 400 year's declination viewer, Andrew Jackson etal GUFM1

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[E] Oral | S (Solid Earth Sciences)：S-EM Earth's Electromagnetism

[S-EM19] Earth and planetary magnetism: Observations, modeling, and implications on dynamics and evolution

convener:Hirokuni Oda(Institute of Geology and Geoinformation, Geological Survey of Japan, AIST), Futoshi Takahashi(Faculty of Sciences, Kyushu University), Courtney Jean Sprain(University of Florida), Yoichi Usui(Japan Agency for Marine-Earth Science and Technology)

Paleomagnetism and paleointensity are essential tools that are useful in investigating the history of Earth's lithosphere, deep interior, and environment. Likewise, geomagnetic observations, modeling, and dynamo simulations are also important tools that help elucidate the dynamics of the Earth's magnetic field and the core. Beyond Earth, studies on extracting ancient magnetic fields recorded by extraterrestrial materials are increasing, which are improving our understanding of the evolution of other planetary bodies in addition to the solar system. Here, we invite contributions in the broad spectrum of paleomagnetic research with special emphasis on the "Study of the Earth's Deep Interior" (SEDI) that illustrate modern advances and highlight further work to better understand the dynamics and evolution of Earth and other planetary bodies. Topics of interest include (but are not limited to): geomagnetic jerks, secular variation, excursions and reversals, magnetic field modeling and dynamo simulations, geometry of the geomagnetic field, paleointensity and evolution of the core and core-mantle boundary, polarity reversal frequency through time, magnetic shielding and solar radiation effects, evolution of magnetotactic bacteria and magnetic field, in addition to planetary magnetic fields and evolution of solar system.

[SEM19-01] Interpretation techniques for crustal magnetic fields in the presence of solar fields, instrument or mission challenges

★Invited Papers

*Michael E Purucker[1], Dhananjay Ravat[2], Benoit Langlais[5], Alexander Michels[3], Jack Connerney[4], Suzanne McEnroe[3] (1.NASA/GSFC, Greenbelt, MD, USA, 2.Univ.Kentucky, Lexington, KY, USA, 3.NTNU, Trondheim, Norway, 4.ADNET/NASA, Greenbelt, MD USA, 5.CNRS, U.Nantes, Nantes, France)

[SEM19-02] Constraints on the Source of the Martian Magnetic Anomalies Inferred From Relaxation Time of Remanent Magnetization

★Invited Papers

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[SEM19-04] Anelastic torsional oscillations in Jupiter's metallic hydrogen region

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[SEM19-05] Quantitative evaluation of the convection structure in the core with reference to a compositionally-driven lunar dynamo

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[SEM19-06] Effects of thermal boundary conditions on geodynamo with various Rayleigh numbers and inner core radii

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Interpretation techniques for crustal magnetic fields in the presence of solar fields, instrument or mission challenges

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There are many excellent descriptions (cf. Blakely, Cambridge, 1995) of interpretation techniques for crustal magnetic fields. But all magnetic field data sets have been gathered in the presence of other magnetic fields that complicate the interpretation of the crustal/lithospheric field component. Magnetic fields in the heliosphere contribute directly (via the solar wind) or indirectly (via currents on the magnetopause) to the magnetic fields measured by the satellites. Instrument and mission considerations are also of importance in properly interpreting magnetic field data sets, or in combining data sets collected during multiple missions. Because space missions (MAVEN, MGS) often collect data at multiple altitudes, we also have insight into the 3-D configuration of magnetic boundaries. One of the easiest interpretational techniques to implement is to plot scatterplots of along-track magnetic field gradients, either of the radial or scalar fields, along with comparable plots of altitude above the surface. In this invited review, we will discuss novel and established interpretations from magnetic field missions to the Moon, Mars, Mercury, and the Earth.

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Constraints on the Source of the Martian Magnetic Anomalies Inferred From Relaxation Time of Remanent Magnetization

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The strong magnetic anomalies observed over Mars originate from remanence of deep crust, which should be preserved during 4 billion years. We estimate the relaxation time of remanence carried by various types of magnetite, considering temperature and pressure dependences of magnetic parameters. The estimation shows that acicular-shaped single-domain magnetite is needed to retain the thick magnetized layer during 4 billion years in a low-Urey ratio scenario, whereas acicular-shaped single-domain, equidimensional single-domain, and pseudo-single-domain magnetites can be the source of anomalies in a high-Urey ratio scenario. In each case, fine-grained (<10 μm) and preferably high-aspect-ratio magnetite in deep crust is needed to explain the observed anomalies.

Keywords: Martian magnetic anomaly, magnetite, relaxation time of remanent magnetization

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Anelastic torsional oscillations in Jupiter's metallic hydrogen region

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We consider torsional Alfvén waves which may be excited in Jupiter's metallic hydrogen region. These axisymmetric zonal flow fluctuations have previously been examined for incompressible fluids in the context of Earth's liquid iron core. Theoretical models of the deep-seated Jovian dynamo, implementing radial changes of density and electrical conductivity in the equilibrium model, have reproduced its strong, dipolar magnetic field. Analysing such models, we find anelastic torsional waves travelling perpendicular to the rotation axis in the metallic region on timescales of at least several years. Being excited by the more vigorous convection in the outer part of the dynamo region, they can propagate both inwards and outwards. When being reflected at a magnetic tangent cylinder at the transition to the molecular region, they can form standing waves. Identifying such reflections in observational data could determine the depth at which the metallic region effectively begins. Also, this may distinguish Jovian torsional waves from those in Earth's core, where observational evidence has suggested waves mainly travelling outwards from the rotation axis. These waves can transport angular momentum and possibly give rise to variations in Jupiter's rotation period of magnitude no greater than tens of milliseconds. In addition these internal disturbances could give rise to a 10% change over time in the zonal flows at a depth of 3000 km below the surface.

Keywords: Gas planets, Secular variation, Waves

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Quantitative evaluation of the convection structure in the core with reference to a compositionally-driven lunar dynamo

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Now there is no global intrinsic magnetic field generated by a dynamo action on the Moon unlike the Earth, while lunar paleomagnetic records suggest that the Moon once had a magnetic field of several tens of μT in the period of 4.2 to 3.56 Ga [e.g., Garrick-Bethell et al., 2009]. Since this strength is the same as that of a surface field on the Earth in the order of magnitude, it is estimated that the magnetic field of the ancient Moon was maintained by a dynamo action. Various mechanisms of the lunar dynamo have been proposed so far. Some thermal history calculations of the lunar core show that the compositionally convection-driven dynamo due to inner core crystallization could continue from the early stage of the evolution to the present [e.g., Laneuville et al., 2014]. In order to investigate long-term variations of the lunar dynamo in detail, we perform numerical dynamo simulations using a MHD code [Takahashi, 2012] with a compositional buoyancy as a driving force of convection and a dynamo action. The duration of the lunar dynamo could be substantially longer than the magnetic diffusion time of the lunar core, which is a typical time-scale of the dynamo simulations. Therefore, we run the simulations for discrete time periods corresponding to different ages with three controlling parameters chosen to match thermal history of the lunar core computed by a thermochemical evolution model based on Sheinberg et al. (2015): (1) The ratio of the inner to the outer core radii χ similar to Heimpel et al. (2005), (2) the Ekman number E, and (3) the Rayleigh number Ra. Note that the Prandtl number Pr and the Magnetic Prandtl number Pm are fixed at 1 and 5, respectively, for all of our runs. We only consider compositional convection and define Ra as a function of a total mass flow of the light element from the inner core boundary. We change E and Ra at a given χ ranging from 0.1 to 0.7 based on a seismological observation of the Moon [Weber et al., 2011]. Parameter survey is carried out keeping E to be of O (10^{-4}).

We find that a larger Ra is needed to maintain convection and the dynamo as χ increases. The magnetic Reynolds number Rm, which is evaluated using the dynamic flow length scale L_u instead of the shell thickness, also increases with increasing χ. We find that the dynamo is maintained even if the Rm is less than 10 when χ <=0.5, unlike the cases of thick shell. Since Rm indicates the ratio of magnetic field generation to magnetic field diffusion, the results suggest that dynamo action is more efficient in a thin shell than in a thick shell. Furthermore, we find that the generated magnetic field is dipole-dominant in most cases, and the dipolarity f_{dip}, indicating the ratio of the dipole magnetic field at the core-mantle boundary, exceeds 0.7. An exception is obtained when χ is 0.5 and Ra is about six times the critical value. In this situation, the magnetic field is nondipolar and f_{dip} is less than 0.1. Also, in this anomalous case, the Elsasser number Λ is much smaller than unity. We find that both L_u and the ratio of the toroidal component to the poloidal component in the kinetic energy, KEP/KET, are relatively small in the case of the weak and nondipolar dynamo, compared with the other runs. Therefore, it is inferred that the morphology and strength of the magnetic field could change depending on the flow structure, which could be evaluated by the parameters such as L_u and KEP/KET.

Keywords: lunar dynamo, compositional convection, core crystallization, lunar thermochemical history, inner core growth, evolution of the magnetic field of the Moon

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Effects of thermal boundary conditions on geodynamo with various Rayleigh numbers and inner core radii

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The Earth has been sustaining its intrinsic magnetic field for at least 3.5 billion years as revealed by paleomagnetic studies [e.g., Biggin et al., 2015]. The geomagnetic field is generated and maintained by dynamo action due to convection of liquid iron alloy in the outer core. Studies of the thermochemical evolution of the Earth's core suggest that the solid inner core has been growing up for approximately one billion years [e.g., O'Rourke and Stevenson, 2016]. Consequently, heat flow in the core has also been changing through the Earth's history [e.g., Driscoll and Bercovici, 2014]. Hence it is important to investigate dynamo condition on heat flux with various inner core size to understand environment of the past Earth. There are some numerical dynamo simulations focusing on the various inner core size. Heimpel et al. (2005) evaluated dynamo onset conditions with various inner core size for fixed temperature boundary. Hori et al. (2010) found that magnetic field is more dipolar on the fixed heat flux boundary condition rather than on the fixed temperature boundary condition for two cases of different inner core size. A thermal evolution model suggests that geomagnetic field has been dipolar for recent 0.6 billion years [Driscoll, 2016]. Lhuillier et al. (2019) point out that magnetic field is less dipolar when the ratio of the inner to outer core radii, r_i/r_o, ranges between 0.2 and 0.22. However, it is still unclear how different inner core size influences the mechanism of generating dipolar or non-dipolar field.

In the present study, we investigate the effects of the thermal boundary conditions on numerical dynamos with various inner core size using a numerical dynamo code Calypso [Matsui et al., 2014]. We fix the Ekman, Prandtl, and magnetic Prandtl numbers to be $E = 10^{-3}$, $Pr = 1$, and $Pm = 5$, respectively, and change the Rayleigh number (Ra) and the ratio of inner to outer core radii to be $r_i/r_o = 0.15$, 0.25, and 0.35. We set two boundary conditions; (FT case) fixed temperature at the inner core boundary (ICB) and at the core-mantle boundary (CMB), and (FF case) fixed heat flux at the ICB and at the CMB. We calculate dipolarity (f_{dip}) to evaluate the ratio of the axial dipole component to total components and the Elsasser number (Λ)to investigate how strong the Lorentz force is against the Coriolis force.

The results of numerical simulations carried out in the present study are summarized in Table 1 and Figure 1. The range of Ra/Ra_{crit} (Ra_{crit} is the critical Rayleigh number) for $\Lambda >> 1$ are listed in Table 1, which indicates that the range for FF case is narrower than that for FT cases. Figure 1 shows the dipolarity as a function of Ra/Ra_{crit}. The Ra dependence of f_{dip} for $r_i/r_o = 0.25$ is similar to that for $r_i/r_o = 0.35$ in FT case, whereas f_{dip} has different behavior between $r_i/r_o = 0.25$ and 0.35 in FF cases.

In $r_i/r_o = 0.35$, f_{dip} in FF case decreases more rapidly with increasing Ra than that in FT cases. In large Ra cases, an axial component of magnetic energy is dominant in FT while the axisymmetric magnetic energy is small in the FF cases.

In $r_i/r_o = 0.25$, f_{dip} is larger than 0.55 in all Ra range where Λ is much larger than 1 in FT, but is larger only in $Ra/Ra_{crit} = 1.9$ in FF. In large Ra cases, difference of f_{dip} between FT and FF cases is smaller in $r_i/r_o = 0.25$ than in $r_i/r_o = 0.35$. Different from $r_i/r_o = 0.35$, the axisymmetric magnetic energy is dominant in all FT and FF cases.

In $r_i/r_o = 0.15$, dipolar dominancy is weak while the Lorentz force is not small in large Ra in FT cases. In these cases, although convection is intense, magnetic field is concentrated in one of anti-cyclonic columns. This kind of dynamos only exist in $r_i/r_o = 0.15$. In FF cases, magnetic field is not sustained in

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large *Ra*. Dipolar field is sustained in small *Ra* range for $\Lambda >> 1$.
The common dependency on the inner core size in FT and FF is that dipolar dynamos are difficult to occur with the smaller inner core. FF cases are more difficult to sustain dipolar dynamos than FT cases. For considering the Earth's heat history, we need further simulations with larger heat flow on CMB than on ICB to take into account of the cooling process of the outer core.

Keywords: geodynamo, the Rayleigh number, inner core size, past Earth, dipolarity, the Elsasser number

Table 1 The Ra/Ra_{crit} range where Λ is much larger than 1.

$r_{\mathrm{i}}/r_{\mathrm{o}}$	FT	FF
0.15	$10.1 - 15.6$	$8.1 - 8.9$
0.25	$2.2 - 3.1, 4.6 - 5.0$	1.9
0.35	$2.0 - 6.1$	$2.7 - 3.8$

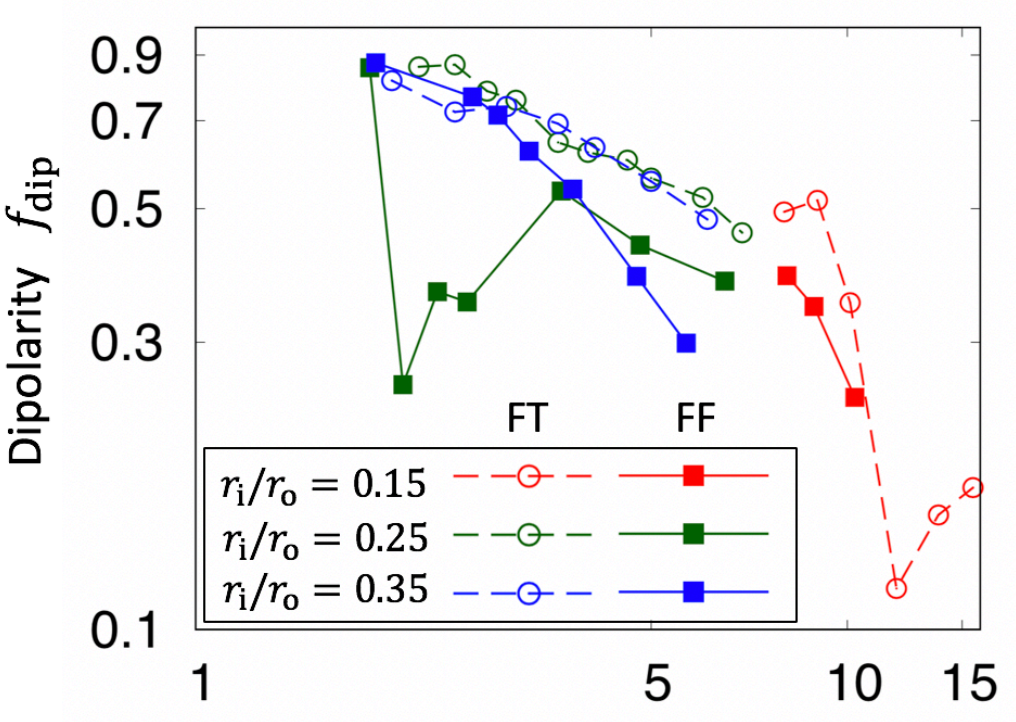

Figure 1 Dipolarity as a function of Ra/Ra_{crit}.

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[E] Oral | S (Solid Earth Sciences)：S-EM Earth's Electromagnetism

[S-EM19] Earth and planetary magnetism: Observations, modeling, and implications on dynamics and evolution

convener:Hirokuni Oda(Institute of Geology and Geoinformation, Geological Survey of Japan, AIST), Futoshi Takahashi(Faculty of Sciences, Kyushu University), Courtney Jean Sprain(University of Florida), Yoichi Usui(Japan Agency for Marine-Earth Science and Technology)

Paleomagnetism and paleointensity are essential tools that are useful in investigating the history of Earth's lithosphere, deep interior, and environment. Likewise, geomagnetic observations, modeling, and dynamo simulations are also important tools that help elucidate the dynamics of the Earth's magnetic field and the core. Beyond Earth, studies on extracting ancient magnetic fields recorded by extraterrestrial materials are increasing, which are improving our understanding of the evolution of other planetary bodies in addition to the solar system. Here, we invite contributions in the broad spectrum of paleomagnetic research with special emphasis on the "Study of the Earth's Deep Interior" (SEDI) that illustrate modern advances and highlight further work to better understand the dynamics and evolution of Earth and other planetary bodies. Topics of interest include (but are not limited to): geomagnetic jerks, secular variation, excursions and reversals, magnetic field modeling and dynamo simulations, geometry of the geomagnetic field, paleointensity and evolution of the core and core-mantle boundary, polarity reversal frequency through time, magnetic shielding and solar radiation effects, evolution of magnetotactic bacteria and magnetic field, in addition to planetary magnetic fields and evolution of solar system.

[SEM19-07] **Origin, Diversity and Evolution of Magnetotctic Bacteria: Implication for Earth's Magnetic Field**

★Invited Papers

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[SEM19-08] Hints of 3.4 billion-year-old magnetofossils: Possible early coevolution of life and the geodynamo

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[SEM19-09] Shallow water MHD waves trapped near the poles in a stably stratified outermost Earth's core

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[SEM19-10] Contribution to IGRF-13 from Japan: A secular variation model using a numerical dynamo model and 4DEnVar data assimilation

*Takuto Minami[1], Shin ya Nakano[2], Futoshi Takahashi[3], Masaki Matsushima[4], Ryosuke Nakashima[3], Hisayoshi Shimizu[5], Hinami Taniguchi[3], Hiroaki TOH[6] (1. Kobe University, 2.The Institute of Statistical Mathematics, 3.Kyushu University, 4.Tokyo Institute of Technology, 5.The University of Tokyo, 6.Kyoto University)

[SEM19-11] **Estimating rates of change in the geomagnetic field**

★Invited Papers

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Origin, Diversity and Evolution of Magnetotctic Bacteria: Implication for Earth’ s Magnetic Field

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The well-known prokaryotes capable of sensing the geomagnetic field are magnetotactic bacteria (MTB), a group of motile, diverse microorganisms that biomineralize intracellular, membrane-bounded magnetic single-domain crystals of either Fe_3O_4 or Fe_3S_4 called magnetosomes, usually organized into chain(s). The magnetosome chain(s) causes the cell to behave like a compass needle where the cell aligns and swims parallel to the geomagnetic field lines. So far, MTB have been found in almost all types of aquatic environments. It has been noted that the large-scale biogeographic distribution of MTB and their magnetotacitc velocity may be related to the strength of geomagnetic field. A fluorescence-coupled electron microscopy method has been developed for efficient characterization of uncultured MTB at the single-cell level. For geological perspective, the single-domain fossil magnetosomes (also referred to as magnetofossils) are nice records of ancient field. The origin of MTB could provide constraints on geomagnetic field in early time. Recently, we have shown that the gene cluster responsible for magnetosome formation and arrangement originated before or near the Archean divergence between the bacterial phyla of Nitrospirae and Proteobacteria, which occurred well before the Great Oxygenation Event (GOE). Magnetotaxis likely evolved due to environmental pressures conferring an evolutionary advantage to navigation via the geomagnetic field. Earth’ s dynamo must therefore have been sufficiently strong to sustain microbial magnetotaxis in the Archean, suggesting that magnetotaxis coevolved with the geodynamo over geological time.

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Keywords: geomagnetic field, magnetotactic bacteria, diversity and evolution

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Hints of ~3.4 billion-year-old magnetofossils: Possible early coevolution of life and the geodynamo

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Evidence for a relatively strong Paleoarchean to Hadean geomagnetic field from single crystal paleointensity studies (Tarduno et al., Science, 2010, 2015; Tarduno et al., PNAS, 2020) is important for our understanding of the evolution of life because of the role magnetic shielding plays in planetary habitability. The presence of the geomagnetic field also implies that magnetotaxis could have been employed by bacteria billions of years older than the oldest reported putative magnetofossils. Here we investigate this possibility. We use rock magnetism, electron microscopy, and ferromagnetic resonance to test for the presence of bacterial magnetite particles in micro-paleo-redox environments of the ~3.40 Ga Buck Reef Chert of the Barberton Greenstone Belt, South Africa. Magnetic hysteresis properties of bulk samples show a variety of rock magnetic behaviors, including multidomain, pseudo-single domain, single domain, and wasp-waisted curves; the latter indicate grain and/or compositional mixtures. Electron microscopy of magnetic separates and in-situ particles from the Buck Reef Chert show cubo-octahedral to quasi-rectangular and hexagonally shaped grains that fall within a stable single domain range typical of biogenic magnetite. Ferromagnetic resonance spectra from bulk samples appear asymmetrical and skew towards low fields, suggesting a magnetic anisotropy that is similar to the spectra seen from some strains of modern magnetotactic bacteria. Thus, while there is clearly a mixture of magnetic particles within the Buck Reef Chert, as expected for typical sediments, our data suggest one component could be ancient relic magnetosomes. Thus, these observations lend support for an early coevolution of magnetotactic bacteria and the geodynamo.

Keywords: magnetotactic bacteria

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Shallow water MHD waves trapped near the poles in a stably stratified outermost Earth's core

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Magnetohydrodynamic (MHD) shallow water linear waves are investigated over a rotating sphere with an imposed equatorially antisymmetric toroidal magnetic field: $B_{0\Phi}=B_0 \sin\theta\cos\theta$, where B_0 is a constant, θ is the colatitude and Φ is the azimuth. This system can imitatively represent the dynamics of a liquid metal within a stably stratified layer at the top of the Earth's core, which was detected through seismological surveys (e.g. Helffrich & Kaneshima, 2010[1]) and also has been deduced from geophysical and geochemical knowledge (e.g. Buffett & Seagle, 2010[2]; Pozzo et al., 2012[3]; Gubbins & Davies, 2013[4]; Brodholt & Badro, 2017[5]). Because slowly propagating waves in the liquid core can result in geomagnetic secular variations, comparison between exhaustive studies of MHD waves in a rotating stratified fluid and observations of geomagnetic fluctuations should provide constraints on the obscure stratified layer in the outermost core (e.g. Braginsky, 1993[6]; Buffett, 2014[7]).

The adopted configuration of the background field complicates solving the eigenvalue problem of linear waves due to the emergence of an Alfvén continuum and critical latitudes unless dissipation effects are taken into account. These result from non-dissipative Alfvén resonance, which occurs only when $B_{0\Phi}/\sin\theta$ depends on θ, that is, regular singular points appear in the differential equation of linear problems. The solutions of the continuum are required to express the transient evolution of an arbitrary initial disturbance (e.g. Case, 1960[8]; Goedbloed & Poedts, 2004[9]). We can confirm numerically and analytically that introducing magnetic diffusion eliminates these Alfvén continuous modes and their singular structures around critical latitudes (Nakashima, Ph.D. thesis, 2020[10]).

For the Earth's core-like parameter ($B_0 \simeq 0.5$—5mT and magnetic diffusivity $\eta \simeq 1 \mathrm{m}^2/\mathrm{s}$), westward polar trapped modes are obtained as eigenmodes, which have a period of around from several to 1000 years. We may be able to observe these modes as geomagnetic secular variations in high latitude regions, if the strength of stratification in the stratified layer is close to the estimate of Buffett (2014)[7]. The analyses of recent geomagnetic models and paleomagnetic data in terms of such waves could confirm the robustness of previous estimates of the properties of the layer.

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http://dyna.geo.kyushu-u.ac.jp/HomePage/nakashima/pdf/doctoral_thesis.pdf

Keywords: a stably stratified layer at the top of the Earth's outer core, geomagnetic secular variations, MHD shallow water, polar trapped waves

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Contribution to IGRF-13 from Japan: A secular variation model using a numerical dynamo model and 4DEnVar data assimilation

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The thirteenth generation of International Geomagnetic Reference Field (IGRF-13) was released by International Association of Geomagnetism and Aeronomy (IAGA) in December, 2019. Prior to the release, we submitted a secular variation (SV) candidate model for IGRF-13 using a data assimilation scheme and a magnetohydrodynamic (MHD) dynamo simulation code (Minami et al. submitted to EPS special issue for IGRF-13). Our candidate SV model was evaluated by IAGA Division V Working Group V-MOD and contributed to the final IGRF-13SV model with the optimized weight. This became the first contribution to the IGRF community from research groups in Japan. This was enabled by bilateral corroboration between Japan and France; in our data assimilation scheme, we used the French main field model (Ropp et al. 2020), which was developed from magnetic observatory hourly means, and CHAMP and Swarm-A satellite data. We adopted an iterative assimilation algorithm based on four-dimensional ensemble-based variational method (4DEnVar) (Nakano 2020), which linearizes outputs of our MHD dynamo simulation (Takahashi 2012; 2014) with respect to the deviation from a dynamo state vector at an initial condition. The data vector for the assimilation consists of the poloidal scalar potential of the geomagnetic field at the Earth’ s core surface, and flow velocity field slightly below the core surface, which was calculated by presuming magnetic diffusion in the boundary layer and tangentially magnetostrophic flow below it (Matsushima 2020). Dimensionless time of numerical geodynamo was adjusted to the actual time by comparison of secular variation time scales. For estimation of our IGRF-13SV candidate model, we first generated an ensemble of dynamo simulation results from a free dynamo run. We then assimilated the ensemble to the data with a 10-year assimilation window from 2009.50 to 2019.50 through iterations, and finally forecasted future SV by linear combination of the future extension parts of the ensemble members. We generated our final SV candidate model by linear fitting for the best linear combination of the ensemble MHD dynamo simulation members from 2019.50 to 2025.00. We derived errors of our SV candidate model by one standard deviation of SV histograms based on all the ensemble members. In the presentation, we plan to report our IGRF project through the bilateral corroboration with France, and describe our SV candidate model.

Keywords: IGRF, secular variation, dynamo, data assimilation

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Estimating rates of change in the geomagnetic field

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Direct observations of the geomagnetic field over the past few hundred years allow estimates of secular variation and of core-surface flow velocities under specific assumptions. The relatively modest maximum rates of change of the order of 150 nT/year in intensity and 0.1º/year in direction and flow velocities of up to 40 km/year found for a recent high-latitude jet, probably do not represent peak values that could arise during the most extreme geomagnetic events. However, such extreme variations in the direction and strength of Earth's magnetic field are likely to contain important information about the operation of the geodynamo. Paleomagnetic studies have reported rapid directional changes reaching 1º/year although the observations are controversial and their relation to physical processes in Earth's core are as yet unknown. GGF100k, a global field model based on paleomagnetic data and spanning 0-100 ka exhibits peak rates of change in the range of 2.5-3.0º/year, associated with an approximately log-normal overall distribution of rates, and has a higher probability of fast rates occurring at low absolute latitudes. Archeomagnetic records of the Levantine geomagnetic spike suggest local intensity changes up to 10 times faster than in the modern field. However, given the limited temporal resolution available in the paleomagnetic records, both directional and intensity results only provide lower bounds on peak rates of change.

For a better understanding of the processes underlying these rapid changes we turn to a suite of numerical dynamo simulations which can provide a complete record of field changes and fluid flow. We find excellent agreement between amplitudes and latitude ranges of extreme directional changes in the geodynamo simulations and GGF100k. Remarkably, maximum rates of simulated directional change reach 10º/year even in times of stable polarity, almost 100 times faster than current changes. Detailed analysis of the dynamo simulations and a simple analogue model indicate that extreme directional changes are associated with movement of reversed flux across the core surface. Our results demonstrate that such rapid variations are compatible with the physics of the dynamo process and suggest that future searches for rapid directional changes should focus on low latitudes. In contrast, the most rapid intensity changes are more prevalent at mid to high latitudes, and may reflect rapid motions of strong normal flux. In the event that anticyclonic gyre-like flow similar to that inferred for the modern field is present, poleward motion of normal (reverse) flux could act to strengthen (weaken) the usually dominant dipole.

Keywords: paleomagnetism, geomagnetic secular variation, extreme geomagnetic variations

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[E] Oral | S (Solid Earth Sciences)：S-EM Earth's Electromagnetism

[S-EM20] Electric and Electromagnetic survey technologies and the scientific achievements: Recent advances

convener:Kiyoshi Baba(Earthquake Research Institute, The University of Tokyo), Tada-nori Goto(Graduate School of Life Science, University of Hyogo), Toshihiro Uchida(National Institute of Advanced Industrial Science and Technology), Toru Mogi(Faculty of Science, Tokyo Institute of Technology)

Detailed subsurface images by electric and electromagnetic (EM) surveys are indispensable to investigate the electrical features of the interior of the Earth both for academic and commercial purposes. The technologies, techniques, and methods for surveys, data analysis, and interpretation involve many common aspects that should be solved by scientists and engineers in cooperation since the studies cover a broad range of targets in various spatial-time scales and places on land and seafloor, e.g., natural resource explorations, environment and hazard evaluations, and the crustal and mantle tectonics and dynamics. And the knowledge should be shared in the international community for further development of this field. The session invites papers on recent advances in the electric and EM survey technologies and techniques including instrumentations, the data analysis methods including modeling, inversion, and imaging techniques, and the scientific achievements including novel way of interpretations, from the world.

Introduction

[SEM20-01] **Case studies on ERT monitoring in Taiwan**
★Invited Papers

*Chien-Chih Chen[1,2] (1.Department of Earth Sciences, National Central University, Taoyuan, Taiwan, 2.Earthquake-Disaster and Risk Evaluation and Management Center, National Central University, Taoyuan, Taiwan)

[SEM20-02] **Carbonate Imaging with Magnetotellurics in a Shallow-Water Environment, South Yellow Sea, China**

*Shuangmin Duan[1], Yuguo Li[1], Jianxin Pei[1], Tiehu Zhao[2], Zhiqiang Wu[2], Bo Han[3], Xinsheng Yu[1], Lanjun Liu[1], Jialin Chen[1] (1.Ocean Univ. of China, 2.Qingdao Inst. of Marine Geology, 3.China Univ. of Geosciences (Wuhan))

[SEM20-03] Three-dimensional Electrical Resistivity Structure of Tokachidake Volcano Revealed by GREATEM Survey Data

*Sabry Abdallah[1], Toru Mogi[1], Yusuke Yamaya[2], Takashi Hashimoto[2], Makoto Murakami[2], Akira Jomori[3], Youichi Yuuki[4], Hideshi Kaieda[5], Hisatoshi Ito[5] (1.Earthquake and Volcano Research Center Graduate School of Environmental Studies, Nagoya University, 2.Institute of Seismology and Volcanology, Hokkaido Univ., 3.Neoscience co., 4.Oyo,Co., 5.CRIEPI)

[SEM20-04] **Anatomy of Active Volcanic Edifice at the Kusatsu-Shirane Volcano, Japan, by Magnetotellurics: Hydrothermal Implications for Volcanic Unrests**

Kuo Hsuan Tseng[1], *Yasuo Ogawa[1], Nurhasan Nurhasan[1], Sabri Bülent Tank[1], Yoshimori Honkura[1], Naoto Ujihara[1], Akihiko Terada[1], Yoshiya Usui[1], Wataru Kanda[1] (1.Volcanic Fluid Research Center, School of Science, Tokyo Institute of Technology)

[SEM20-05] Global electrical conductivity model of Miyake-jima: insights into its hydrothermal and magmatic system

*Marceau Gresse[1], Takao Koyama[1], Makoto Ueshima[1], Yuichi Morita[1], Yoichi Sasai[2], Jacques Zlotnicki[3], Tsuneo Ishido[4], Hideaki Hase[5], Wataru Kanda[6], Koki Aizawa[7], Derek Weller[1], Tawat Rung-Arunwan[8], Yasuo Matsunaga[6], Hideki Ueda[9], Maki Hata[1], Yusuke Yamaya[10] (1.Earthquake Research Institute, The University of Tokyo, Tokyo, Japan, 2.Earthquake Prediction Research Centre, Tokai University, Shizuoka,

Japan, 3.CNRS, OPGC-UMR6524, Aubière, France, 4.Geological Survey of Japan, AIST, Tsukuba Ibaraki, Japan, 5.Geothermal Energy Research & Development Co., Ltd., Tokyo, Japan, 6.Tokyo Institute of Technology School of Science, Tokyo, Japan, 7.Institute of Seismology and Volcanology, Faculty of Science, Kyushu University, Fukuoka, Japan, 8.Curl-E Geophysics Co., Ltd., Thailand, 9.National Research Institute for Earth Science and Disaster Resilience, Tsukuba, Japan, 10.Renewable Energy Research Center, National Institute of Advanced Industrial Science and Technology (AIST), Fukushima, Japan)

Case studies on ERT monitoring in Taiwan

*Chien-Chih Chen[1,2]

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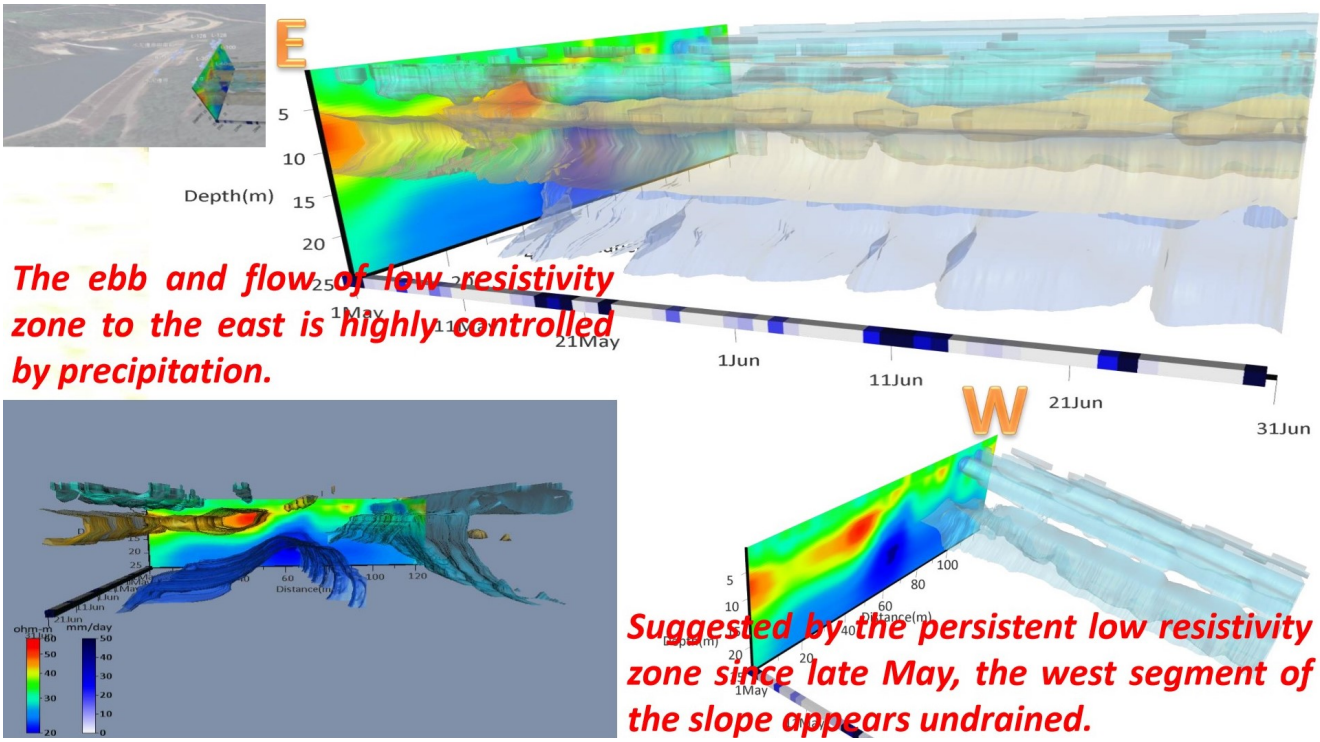
Electrical resistivity tomography (ERT) has been widely used for the investigation to various kinds of urban and mountain hydrogeological problems. Groundwater, together with its physical and chemical conditions, is sensitive to electrical resistivity of soil-rock mixtures. To address these hydrogeological problems *dynamic* factors such as variation in water content and preferential path are even more important than *static* distribution in space of groundwater. Developing real-time ERT monitoring technique thus becomes crucial in hydrogeology. Yet another attractive benefit from a series of consecutive ERT images is to reduce ambiguity in interpreting resistivity structures. While electrical resistive or conductive structures could have multiple explanations in a single ERT image, short-term resistivity/conductivity changes in a series of consecutive ERT monitoring images are very likely attributed to some specific dynamics relevant to, say, water content and pollutant concentration. Given in this presentation are some case studies on ERT monitoring about applications to landslides, water resources management and environmental pollution in Taiwan.

Keywords: Electrical resistivity tomography, Monitoring, Taiwan



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Carbonate Imaging with Magnetotellurics in a Shallow-Water Environment, South Yellow Sea, China

*Shuangmin Duan[1], Yuguo Li[1], Jianxin Pei[1], Tiehu Zhao[2], Zhiqiang Wu[2], Bo Han[3], Xinsheng Yu[1], Lanjun Liu[1], Jialin Chen[1]

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Complex structure distribution and wide-spread Meso-Paleozoic carbonate strata have limited the use of the seismic investigation in the South Yellow Sea, China. To figure out the carbonate strata distribution, we conducted magnetotelluric data acquisition in the Central Uplift of the South Yellow Sea Basin at a water depth of ~20 m. Novel receivers with a smaller size and a lower center of mass has been developed to reduce the instability caused by the shallow water motions. Magnetic fields associated with the ocean motions, mainly tides and gravity waves, have been identified and segmentation multi-station processing was applied to the data. We have conducted 1-D and 2-D inversions to derive the resistivity models. Significantly elevated resistivity zone has been obtained at depths between 3 and 8 km. Combining the seismic data, drilling well and local geology, we have concluded that the marine carbonate strata at the Central Uplift holds a thickness of over 7 km which starts from the Indo-Chinese unconformity surface at a depth of ~ 650 m and extends to the metamorphic basement at a depth of ~ 8 km.

Keywords: Marine magnetotelluric, Shallow water, Carbonate imaging, Ocean water motion



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Three-dimensional Electrical Resistivity Structure of Tokachidake Volcano Revealed by GREATEM Survey Data

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The Tokachidake Volcano is a group of quaternary volcanoes in central Hokkaido. Historical eruptions accompanied by pyroclastic materials occurred in 1926, and phreatic eruption occurred in 1962 and 1988. During the 1926 eruption, a collapse of the caldera cone resulting in mudflow which struck the area claiming 146 deaths and missing persons. After the 1988-89 eruption, vigorous fumarolic activities have continued in the central part of the volcano group and seismic activities and crustal deformations have been observed. To study the structure of Tokachidake Volcano and discuss the process of its phreatic eruption, which can help in future eruptions mitigation, airborne electromagnetic (AEM) surveys using the grounded electrical-source airborne transient electromagnetic (GREATEM) system were conducted over Tokachidake Volcano. We performed numerical forward modeling to generate a three-dimensional (3D) resistivity structure model that fits the GREATEM data where the stitched 1D resistivity model was used as the initial model. A 3D electromagnetic forward-modeling scheme based on a staggered-grid finite-difference method was modified and used to calculate the response of the 3D resistivity model along each survey line. We verified the model by examining the fit of magnetic-transient responses between the field data and 3D forward-model computed data. The 3D resistivity models show that a moderately resistive structure (50–200 Ωm) is characteristic of most of the volcano, and were able to delineate a very conductive structure zone within the volcanic edifice. This structure may be either hydrothermal or alteration zone caused by previous large sector collapse.

Keywords: Airborne EM, 3D resistivity modeling, GREATEM survey, Volcanic surveys

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Anatomy of Active Volcanic Edifice at the Kusatsu-Shirane Volcano, Japan, by Magnetotellurics: Hydrothermal Implications for Volcanic Unrests

Kuo Hsuan Tseng[1], *Yasuo Ogawa[1], Nurhasan Nurhasan[1], Sabri Bülent Tank[1], Yoshimori Honkura[1], Naoto Ujihara[1], Akihiko Terada[1], Yoshiya Usui[1], Wataru Kanda[1]

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We aimed to perform three-dimensional imaging of the underlying geothermal system to a depth of 2km using magnetotellurics (MT). We deployed 91 MT sites focusing around the peak area of 2km x 2km with typical spacings of 200m. The full tensor impedances and the magnetic transfer functions were inverted, using an unstructured tetrahedral finite element code to include the topographic effect. The final model showed (1) impermeable clay cap as the near surface conductor, (2) brine reservoir as a deep conductor at a depth of 1.5 km from the surface, and (3) a vertical conductor connecting the deep conductor to the clay cap associated with the seismicity, which implies a fluid/gas path. The past magnetization/demagnetization sources and the inflation source of the 2014 unrest are located just below the clay-cap, consistent with the clay capped geothermal model.

Keywords: Phreatic eruption, volcanic unrest, Magnetotelluric method, clay cap, brine

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Global electrical conductivity model of Miyake-jima: insights into its hydrothermal and magmatic system

*Marceau Gresse[1], Takao Koyama[1], Makoto Ueshima[1], Yuichi Morita[1], Yoichi Sasai[2], Jacques Zlotnicki[3], Tsuneo Ishido[4], Hideaki Hase[5], Wataru Kanda[6], Koki Aizawa[7], Derek Weller[1], Tawat Rung-Arunwan[8], Yasuo Matsunaga[6], Hideki Ueda[9], Maki Hata[1], Yusuke Yamaya[10]

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Measuring the electrical conductivity of rocks is an efficient tool used to investigate volcanoes at depth. Broadband Magnetotellurics is the only technique capable of retrieving electrical conductivity structures from shallow to great depth. Hence, it is a central method in the characterization of volcanic edifices at a global scale.

Here, we present the electrical conductivity model of the Miyake-jima volcano obtained from 13 broadband magnetotelluric stations deployed in 2012. We reveal a sharp contrast between the resistive vadose-zone and its underlying conductive hydrothermal system. By combining the electrical conductivity model with hypocenters distributions, surface temperature and CO_2 surveys, we highlight the shallow plumbing system of the volcano: deep magmatic fluids rise through a narrow path, interact with the hydrothermal system before being finally released in the main fumarolic area inside the caldera.

Keywords: Hydrothermal system, Magnetotellurics, Miyake-jima, Electrical conductivity, Volcano

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[E] Oral | S (Solid Earth Sciences)：S-EM Earth's Electromagnetism

[S-EM20] Electric and Electromagnetic survey technologies and the scientific achievements: Recent advances

convener:Kiyoshi Baba(Earthquake Research Institute, The University of Tokyo), Tada-nori Goto(Graduate School of Life Science, University of Hyogo), Toshihiro Uchida(National Institute of Advanced Industrial Science and Technology), Toru Mogi(Faculty of Science, Tokyo Institute of Technology)

[SEM20-06] **Advances in Marine Electromagnetic Instruments and Data Processing Techniques**
★Invited Papers

*Yuguo Li[1,2] (1.Ocean Univ. of China, 2.Key Lab of Submarine Geosciences and Prospecting Techniques of Ministry of Education)

[SEM20-07] Ocean bottom electromagnetometers of Earthquake Research institute

*Kiyoshi Baba[1] (1.Earthquake Research Institute, The University of Tokyo)

[SEM20-09] Effecitive combination of MT and GDS survey for three-dimensional imaging of geothermal resovoir

*Tada-nori Goto[1], Yuji Yamada[2] (1.Graduate School of Life Science, University of Hyogo, 2.Graduate School of Engineering, Kyoto University)

[SEM20-10] Estimation of electrical conducitivity in the mantle transition zone by using the Sq source model GAIA

*Takao Koyama[1], Shigeru Fujita[2], Ikuko Fujii[2], Kiyoshi Baba[1] (1.Earthquake Research Institute, The University of Tokyo, 2.Meteorological College)

Discussion

Advances in Marine Electromagnetic Instruments and Data Processing Techniques

*Yuguo Li[1,2]

1. Ocean Univ. of China, 2. Key Lab of Submarine Geosciences and Prospecting Techniques of Ministry of Education

In this presentation, we will report on advances in marine electromagnetic data acquisition system and data processing techniques at the EM laboratory of Ocean University of China (OUC). A new type of broadband Ocean-Bottom ElectroMagnetic (OBEM) receiver has been recently developed at OUC. The OBEM receiver collects three components of the electrical field and two horizontal components of the magnetic field. Our receiver is capable of resisting water pressure to depth of 6000 meters. We have seen more than 100 deployments with 100% recovery rate. We also have developed a new transmitter for the marine CSEM sounding. The transmitter can deliver up to 1500A currents into a neutrally buoyant antenna of 200m long. It was deep-towed at the end of a cable containing three optical fibers that is used to power the transmitter and for telemetry between the deep-towed transmitter and the shipboard control console. The transmitter has been successfully tested in the Yellow Sea and in the Southern China Sea. 3D modeling of electromagnetic fields is of vital importance for interpreting EM data collected in complex geologic settings. We developed two numerical algorithms for modeling 3D marine CSEM fields. One is the goal-oriented adaptive edge-based finite element (FE) algorithm, which can simulate marine CSEM responses in 3D arbitrarily anisotropic conductive media. The other is the high-order finite difference time domain algorithm for modelling marine CSEM responses in both the fictitious time domain and the diffusive frequency domain, which facilitates the full exploration of EM diffusive properties in the fictitious wave domain. Concepts, such as reflection, refraction, diffraction and transmission, can be adopted for interpreting marine CSEM data.

Keywords: Electromagnetic Instruments, Data Processing, 3D Moddeling



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Ocean bottom electromagnetometers of Earthquake Research institute

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Ocean bottom electromagnetometers (OBEMs) are utilized to measure electromagnetic field variation at seafloor for investigating electrical conductivity structure of the Earth’ s interior. Earthquake Research Institute has 21 OBEMs at the present and six of them are new type ones developed in 2012. The OBEMs are commercial products by Tierra Tecnica, Co, Ltd., which consist of a package of three-component fluxgate magnetic sensors and two-component tilt sensors, a unit of a magnetometer, a potentiometer, a tiltmeter, and a data logger, an acoustic transponder system, and batteries in pressure cases, two electric dipoles, float, weight, weight release system, a radio beacon, and a flashlight. The OBEMs are launched from a ship and descend to seafloor, and then start measurement by a timer. After the observation, they release the weight by an acoustic command sent from a ship and ascend to the sea surface to be recovered.

The new type OBEMs are characterized by compactness in size (width: 951 mm, depth: 895 mm, and height: 640 mm for the main frame and 4.6 m horizontal electric dipoles), low power consumption (~1.8 W in average), and low running and maintenance costs, compared to conventional type OBEMs. The OBEM can measure the data with continuous sampling of 8 or 1 Hz for more than 20 days, or intermittent sampling of 60 seconds for more than 8 months with 14 DD-size lithium batteries. The sampling rate can be changed during observation by a timer. The electric and magnetic field can be resolved with 1.2 nV in the range of ±10mV and 0.1pT in the range of ±65,000 nT, respectively.

The instrumental attitude during descending in the deployment, and descending/ascending speed were measured in a test cruise in 2013. A long-run (about one year) test was then conducted in 2013 - 2014 and the recovered data were compared with those collected by a conventional type OBEM that deployed in the same time in the same position. Although small drift in the magnetic field was observed, the magnetotelluric response estimated from the two OBEM data agrees well in the estimate errors. The new type OBEMs are now in practical use. Since 2016, total number of 9 new type OBEMs have been successfully deployed around Nishinoshima island volcano and recovered with useful data.

Keywords: ocean bottom electromagnetometers, marine magnetotellurics, electric and magnetic field

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Effecitive combination of MT and GDS survey for three-dimensional imaging of geothermal resovoir

*Tada-nori Goto[1], Yuji Yamada[2]

1. Graduate School of Life Science, University of Hyogo, 2. Graduate School of Engineering, Kyoto University

Magnetotelluric (MT) survey is mainly used for acquiring subsurface information, essential for exploration and development of geothermal resources. Since the geothermal alteration zone located above the geothermal reservoir shows a remarkably low resistivity, the subsurface resistivity structure obtained by MT survey is useful for discovery of the geothermal reservoir and evaluation of the subsurface temperature distribution. In recent years, with high-speed computers and sophisticated algorithms, the inversion of MT data for inferring three-dimensional (3-D) resistivity structures has been actively carried out. The 3-D inversion requires a number of MT stations. However, due to the steep topography, it is difficult to set MT stations densely in geothermal areas. This is because MT survey requires a flat area of several tens of meters square. Sparse MT stations result in low spatial resolution, and less effectiveness to geothermal explorations. Furthermore, MT data is strongly affected by near-surface local resistivity anomalies (so called static distortion), which may reduce the reliability of inversion results of MT data.

In this research, we focus on the Geomagnetic Depth Sounding (GDS) survey, carried out in a small space on the geothermal field. The GDS survey can obtain the subsurface resistivity information by measuring horizontal and vertical magnetic field. The GDS survey is also known as the robustness to the small-scale near-surface anomalies. Therefore, we perform the effectiveness of the densely-arrayed GDS survey together with a few MT stations, for overcoming the problem on the low spatial resolution and severe effects of near-surface heterogeneity on the MT data.

We discuss the 3-D inversion accuracy with varying the number of MT/GDS stations. A typical 3-D resistivity model in a geothermal area is assumed first, then the synthetic MT / GDS data is obtained by 3-D forward calculations. This synthetic data is used for the input dataset to a 3-D inversion code. Finally, the obtained inverted result can be compared with the 3-D model original assumed for evaluation of the optimal combination of MT/GDS stations.

In the case of no static distortion in MT data, we found that the subsurface resistivity structure could be properly obtained even with a small number of MT stations and a lot of GDS stations. We also validate the effectiveness of the MT / GDS combined analysis in the case of sever distortion in MT data as follows: i) with adding the static distortion numerically and randomly to the raw synthetic MT data, and ii) with a 3-D model having a number of near-surface resistivity anomalies on the shallow surface. As a result, it was clarified in the case (i) that the effect of the static distortion in MT data was corrected by the spatially dense GDS data. On the other hand, in the case (ii), the inversion results still include the false images due to the near-surface anomalies even if we added the dense GDS data. In the forward calculations, we found that horizontally elongated low resistivity zones near the surface can distort the GDS data, which was the major cause of less effectiveness of MT/GDS combination in the case (ii). We conclude that the combination of MT/GDS survey can effectively refine the spatial resolution and also reduce the static distortion, except for the near-surface low resistive body such as pipelines and power lines.

Keywords: Magnetotellurics, Geothermal field, Geomagnetic Depth Sounding

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Estimation of electrical conducitivity in the mantle transition zone by using the Sq source model GAIA

*Takao Koyama[1], Shigeru Fujita[2], Ikuko Fujii[2], Kiyoshi Baba[1]

1. Earthquake Research Institute, The University of Tokyo, 2. Meteorological College

We've tried to estimate the electrical conductivity of the mantle structure by using the Sq variation derived from the GAIA (Ground-to-topside model of Atmosphere and Ionosphere for Aeronomy). From the late 19th century, many paper have reported the vertical structure of the electrical conductivity in the Earth by using magnetic field data, and recently, some paper also reported the three-dimensional structure of the conductivity in the subsurface or the global Earth. MT methods suppose the plane-wave assumption and it can be adapted
in the period below about 10,000 sec. On the other hand, the Dst or ring current source in the magnetosphere is notable in the period over 100,000 sec, and geomagnetic P10 source assumption may be valid. Between 10,000 and 100,000 sec, however, it is well known that Sq field is dominant, and that has complex source distribution and we must consider the complexity of the spatial pattern of the source as well as the electrical conductivity in the Earth. In order to detect the details of the source field, we need a lot of observation on the Earth. We, however, have only a couple of hundreds geomagnetic stations at the most so far, and thus we can know geomagnetic components in a long spatial length, which is only up to spherical harmonic degree, say, 10-15 at the most. Very recently, some paper reported trial of the usability of the satellite data, but they are not well done to estimate the electrical conductivity so far. Therefore we try another approach. We use the well-modelled Sq field as the inducing field, GAIA, which is developed by upper atmosphere researchers in Japan. GAIA is based on fluid dynamics, photo-chemistry
and electromagnetics, combining atmospherere model, ionosphere model, and electro daynamics model which are developed separatedly.
First we executed spherical harmonic expansion of GAIA magnetic field
of GAIA for 3 day time series up to 20, which correspond to three sequent solar quiet days. And then, three-dimensional forward modeling in the spherical coordinate was executed in the frequency domain. Now, we
suppose the 1-D structure in the Earth under the ocean-land lateral contrast. As the results, the calculated geomagnetic data inversely converted to the time domain could be closer to the observed data, compared to the GAIA Sq field itself, that is, total of RMS data misfit at 71 stations decreases by 40%.
Next, we try to find the best fit 1-D model in the mantle. We suppose the basic 1-D model as the standard model by Baba (2017) in the northwest Pacific. We also try other models which are more conductive and less
conductive, and as the results, the original model by Baba (2017) is almost the best to explain the vertical magnetic field data of Sq, and slightly more conductive model may be the very best.

Keywords: Sq, GAIA, mantle transition zone

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[E] Oral | S (Solid Earth Sciences)：S-IT Science of the Earth's Interior & Techtonophysics

[S-IT23] Property and role of liquids inside terrestrial planets

convener:Tatsuya Sakamaki(Department of Earth Science, Tohoku University), Yoichi Nakajima(Kumamoto University, Priority Organization for Innovation and Excellence)

Liquids of silicates and metals inside of terrestrial planets play important role in the physical, chemical, and thermal evolutions of planets. This session aims at understanding the physical and chemical properties of liquids from shallower to deep parts of terrestrial planets, which are strongly related to the long history of those planets from the planetary accretion to the present-day dynamics. In addition, we call for presentations by researchers from various backgrounds of geochemical, experimental, theoretical/computational, and seismic/geodynamical ones, who investigate the physical and chemical properties of liquids and the behaviors and roles inside of terrestrial planets. Relevant topics include, but are not limited to, partial melting and melt extraction, liquid-solid partitioning, high pressure experiments on melts, and seismic detections of mantle melts and outer core anomaly.

[SIT23-01] A multifaceted experimental approach to studying silicate liquids under high pressure

★Invited Papers

Young Jay Ryu[1], *Yanbin Wang[1], Tony Yu[1], Vitali Prakapenka[1], Zhicheng Jing[6], Man Xu[5], Clemens Prescher[2], Eran Greenberg[1], Sergey Tkachev[1], Heather Watson[3], Yoshio Kono[4], Peter Eng[1], Joanne Stubbs[1] (1.Center for Advanced Radiation Sources, University of Chicago, Chicago, IL, USA, 2.DESY, FS-PS, Hamburg, Germany, 3.Union College, NY, USA, 4.Geodynamics Research Center, Ehime University, Matsuyama, Japan, 5.Case Western Reserve University, OH, USA, 6.Southern University of Science and technology, Guangdong, China)

[SIT23-05] X-ray diffraction measurements on aluminosilicate glasses at ultrahigh-pressure conditions

*Itaru Ohira[1,2], Yoshio Kono[1,2], Yu Shu[3], Yuki Shibazaki[4,5], Curtis Kenney-Benson[3], Rostislav Hrubiak[3], Atsunobu Masuno[6], Guoyin Shen[3] (1.Geodynamics Research Center, Ehime University, 2.Geophysical Laboratory, Carnegie Institution of Washington, 3.High Pressure Collaborative Access Team (HPCAT), X-ray Science Division, Argonne National Laboratory, 4.Frontier Research Institute for Interdisciplinary Sciences (FRIS), Tohoku University, 5.International Center for Young Scientists (ICYS), National Institute for Materials Science (NIMS), 6.Graduate School of Science and Technology, Hirosaki University)

[SIT23-06] Equation of State for Liquid Iron under Extreme Conditions

★Invited Papers

*Yasuhiro Kuwayama[1], Guillaume Morard[2], Yoichi Nakajima[3,4], Kei Hirose[1,5], Alfred Q. R. Baron[4], Saori I Kawaguchi[6], Taku Tsuchiya[7], Daisuke Ishikawa[6,4], Naohisa Hirao[6], Yasuo Ohishi[6] (1.The University of Tokyo, 2.Laboratoire ISTERRE, Université Grenoble Alpes, 3.Kumamoto University, 4.RIKEN MDR, 5.Tokyo Institute of Technology, 6.JASRI, 7.Ehime University)

A multifaceted experimental approach to studying silicate liquids under high pressure

Young Jay Ryu[1], *Yanbin Wang[1], Tony Yu[1], Vitali Prakapenka[1], Zhicheng Jing[6], Man Xu[5], Clemens Prescher[2], Eran Greenberg[1], Sergey Tkachev[1], Heather Watson[3], Yoshio Kono[4], Peter Eng[1], Joanne Stubbs[1]

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We have developed a range of experimental techniques at GSECARS beamlines of the Advanced Photon Source (APS) to study structures and physical properties of liquids and glasses under high pressure. A Paris-Edinburgh press (PEP) is used to study structures of silicate liquids using monochromatic x-ray diffraction. A multichannel collimator (MCC) is inplemented with the PEP to minimize background scattering of the pressure media used in the high-pressure cell. Structural data have been collected at pressure and temperature conditions up to 7 GPa and 2300 K, respectively, on $MgSiO_3$, $CaSiO_3$, and $MgCaSi_2O_6$ liquids. Acoustic velocity measurements are conducted in a Kawai apparatus. Relaxed acoustic velocities of $MgCaSi_2O_6$ liquid have been measured to 4 GPa and 2400 K, to constrain equation of state for this liquid. To complement these data on liquids from the large-volume press, diamond-anvil cell experiments are conducted on glasses (supercooled liquids) to 70 GPa, using both synchrotron x-ray diffraction and micro-Raman spectroscopy. While the x-ray diffraction technique provides information on time- and volume-average atomic arrangements of liquids and glasses, Raman spectroscopy senses local atomic interactions. With the two techniques combined, more information can be extracted to understand structural response to pressure. Brillouin scattering is then used to examine unrelaxed elastic response of glasses to pressure. Such responses are then correlated with Raman spectroscopy and x-ray diffraction observations to understand the impact of pressure on structural evolution and physical properties. We will present new data on $MgSiO_3$ liquid and glass to demonstrate the power of this multifaceted approach.

Keywords: liquid structure and properties, High pressure, Synchrotron radiation

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X-ray diffraction measurements on aluminosilicate glasses at ultrahigh-pressure conditions

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Knowledge about the pressure-induced structural changes in magmas, natural silicate melts, near the pressure conditions of the Earth's core-mantle boundary (CMB) region is important in understanding the buoyancy and motion of magmas at the CMB. However, such knowledge is still scarce due to challenges in the experiments on silicate melts at the extreme pressure and temperature conditions of the CMB. Investigation of structures of silicate glasses, considered analogues of silicate melts, is one of the ways to address this issue. Efforts have been made to understand the structures at >100 GPa in silicate glasses using the diamond anvil cell (DAC) by using Brillouin scattering (e.g., Murakami and Bass, 2010) and X-ray diffraction methods (e.g., Prescher *et al.*, 2017). However, there are still challenges to collect structural information of amorphous materials inside DAC because the sample volume of DAC is normally very small.

The opposed type double-stage large volume cell developed in Paris–Edinburgh (PE) press can provide a capability of ultrahigh-pressure generation using a large volume sample (~100 times larger than DAC sample) with a wide solid angle access for X-ray diffraction ($2\theta_{max} = 35^{\circ}$). This advanced capability makes an advantage in measuring structure factor $S(Q)$ of glass under ultrahigh-pressures. The maximum pressure generation by the double-stage cell depends on the culet sizes of the 2nd-stage diamond anvils (e.g., Kono *et al.*, 2020). Using the 0.5 mm culet anvil design, we succeeded in generating pressure of 131 GPa, comparable to the pressure of the CMB (Ohira *et al.*, 2019).

We have investigated ultrahigh-pressure structural changes in aluminosilicate glasses using the opposed type double-stage cell combined with a multi-angle energy-dispersive X-ray diffraction technique. A 60 mol% Al_2O_3–40 mol% SiO_2 glass shows that its T–O (T = Si, Al) length starts to deviate from the linear compression trend above ~110 GPa and becomes constant at 110–121 GPa, implying the increase of average Al–O CN from 6 to >6. On the other hand, a basaltic glass does not show a plateau of T–O length under compression, while there are marked changes in the short and long T–T peaks in the pair distribution function $g(r)$, which is assigned as the distances between corner-sharing TO_x polyhedra and between edge-sharing polyhedra, respectively. Our results show that the basaltic glass transforms gradually from the corner-sharing dominant structure to the edge-sharing dominant structure up to 120 GPa, similar to $MgSiO_3$ glass (Kono *et al.*, 2018). Our result implies that the processes of ultrahigh-pressure structural changes in the magmas at the CMB varies depending on their chemical compositions.

This work was performed at HPCAT (Sector 16), Advanced Photon Source (APS), Argonne National Laboratory (ANL). HPCAT operations are supported by DOE-NNSA's Office of Experimental Sciences. The APS is a U.S. Department of Energy (DOE) Office of Science User Facility operated for the DOE Office of Science by ANL under Contract No. DE-AC02-06CH11357. This research was supported the National

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Prescher *et al.* (2017) *Proc. Natl. Acad. Sci. U.S.A.* **114**, 10041–10046.

Keywords: Aluminosilicate glass, Ultrahigh-pressure, Double-stage cell, X-ray diffraction, Magma at the core-mantle boundary region

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Equation of State for Liquid Iron under Extreme Conditions

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The Earth's core is composed mainly of iron and almost molten. Likewise, Mercury and Mars are also expected to have a partially molten iron core. Since density (ρ) and longitudinal sound velocity (V_P) are the primary observables of the Earth's liquid outer core and possibly for other planets in future, laboratory measurements on these properties at relevant high-pressure conditions are of great importance to understand the core composition and dynamics of Earth and other terrestrial planets. Our knowledge for those properties of liquid iron under high-pressure and -temperature (*P*-*T*) conditions is, however, completely limited because of the experimental difficulties. In this study, we have determined the ρ and V_P of liquid iron up to 116 GPa and 45 GPa, respectively, via static compression in a laser-heated diamond-anvil cell (LH-DAC).

We determined the ρ of liquid iron up to 116 GPa and 4350 K based on in-situ x-ray diffraction measurements at BL10XU, SPring-8 [1]. A new analytical method was applied to derive ρ from the diffuse x-ray scattering signals from the liquid. We also obtained the V_P of liquid iron up to 45 GPa by inelastic x-ray scattering (IXS) measurements in the LH-DAC at BL43LXU, SPring-8 [2]. From our new data combined with previous shock-wave data, we obtained the $P-T-\rho-V_P-\gamma$ relation for the Earth's entire outer core conditions. Compared to the ρ, V_P, and adiabatic bulk modulus (K_S) of liquid iron calculated along the isentrope with T_{ICB} (the temperature at the inner core boundary) = 5400 K, the Earth's outer core have 7.5–7.6% lower ρ, 3.7–4.4% higher V_P but an almost identical K_S.

Seismology gives the density difference between the liquid and solid core at the ICB; $\Delta\rho_{ICB}$ = 0.55–0.82 g/cm^3 (e.g., [3]). Our results show that liquid iron is less dense than hexagonal-close-packed (hcp) iron [4] by = 0.32 g/cm^3 at 330 GPa and its melting point of 6230 K [5]. This is approximately half of the observed $\Delta\rho_{ICB}$, indicating that the remaining 0.23–0.50 g/cm^3 (corresponding to 1.9–4.1% of the outer core density at the ICB) should be attributed to a compositional difference between the outer and inner core.

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Keywords: liquid iron, equation of state, density, sound velocity, high pressure

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[E] Oral | S (Solid Earth Sciences)：S-IT Science of the Earth's Interior & Techtonophysics

[S-IT24] MAGMA AND FLUID TRANSPORT IN THE EARTH'S INTERIOR

convener:Bjorn Mysen(Geophysical Laboratory, Carnegie Inst. Washington), Eiji Ohtani(Department of Earth and Planetary Materials Science, Graduate School of Science, Tohoku University), Dapeng Zhao(Department of Geophysics, Tohoku University), Michihiko Nakamura(Division of Earth and Planetary Materials Science, Department of Earth Science, Graduate School of Science, Tohoku University)

The principal mass and energy transport agents in the Earth's interior are magma and fluids. The objective of the proposed session is to combine experimental data, observations, and theoretical modeling to describe the transport properties and processes.
Melting, crystallization, and devolatilization occur across temperature intervals within which the distribution of mass between melts, fluids, and crystals is established. Element partitioning between melts, crystals, and fluids is needed to describe these processes. Physical properties of melts and fluids are controlled by their chemical composition, temperature, and pressure. The mass transfer processes depend on the property information. Magma aggregation at depth and ascent toward the surface are direct functions of density contrasts and permeability and depends on temperature, pressure, chemical composition and concentration of volatile components.
The mass transfer processes are imaged globally and locally by geophysical observations such as seismic tomography and electrical conductivity profiles. Magma sources in the deep mantle and the crust are also imaged by these geophysical tools. The mass transfer to the surface can be observed as the volcanic eruption in which phase separation of magma and fluid, and crystallization during the magma ascent control the type of eruptions. These are processes imaged with geophysical methods with which a three-dimensional structure of magma and fluid plumbing systems can be described, and in the geological records of earlier phenomena.
The proposed session will focus on those phenomena including laboratory experiments, numerical modeling, and observations using geophysical, seismological and geochemical approaches. These include physical and chemical properties and process of magma and fluid, near surface processes of volcanic eruptions, and geophysical imaging of various scales from locally to globally. Contributions to any of these subjects are encouraged.

[SIT24-01] Searching for the deep roots of arc volcanoes: seismic imaging in the Washington Cascades (Invited)

★Invited Papers

*Geoffrey A Abers[1], Michael E Mann[1], Kayla J Crosbie[1], Roque Soto Castaneda[1], Carl Ulberg[2], Kenneth C Creager[2] (1.Cornell University, 2.University of Washington)

[SIT24-02] Combining InSAR and GNSS to model magma transport during the May 2016 eruption of Piton de la Fournaise Volcano (La Réunion Island

*Valerie Cayol[1], Delphine Smittarello[2], Virginie Pinel[2], Aline Peltier[3], Jean-Luc Froger[1] (1.CNRS, UCA, LMV, OPGC, IRD, Clermont-Ferrand, France, 2.ISTerre, IRD, CNRS, USMB, Le Bourget du Lac, France, 3.OVPF, IPGP, UP, CNRS, La Réunion, France.)

[SIT24-03] Salinity map of subduction-zones fluids recorded in fluid inclusions

★Invited Papers

*Tatsuhiko Kawamoto[1] (1.Department of Geoscience, Faculty of Science, Shizuoka University)

[SIT24-04] Developing a laboratory technique to probe volatile transport in the deep mantle

★Invited Papers

*Catherine McCammon[1], Serena Dominijanni[1], Leonid Dubrovinsky[1], Nobuyoshi Miyajima[1], Egor Gennadievich Koemets[1], Dan Frost[1] (1.Bayerisches Geoinstitut, University of Bayreuth)

[SIT24-05] Temperature dependence on nitrogen solubility in bridgmanite under lower mantle conditions: its role in formation of deep nitrogen reservoir through solidification of magma ocean.

*Ko Fukuyama[1], Hiroyuki Kagi[1], Toru Inoue[2,3], Sho Kakizawa[1], Toru Shinmei[3], Yuji Sano[4,5], Cécile Deligny[6], Evelyn Füri[6] (1.Geochemical Research Center, Graduate School of Science, The University of Tokyo, 2.Department of Earth and Planetary Systems Science, Graduate School of Science, 3.Geodynamics Research Center, Ehime University, 4.Division of Ocean and Earth Systems, Atmosphere and Ocean Research Institute, University of Tokyo, 5.Institute of Surface-Earth System Science, Tianjin University, 6.Centre de Recherches Pétrographiques et Géochimiques)

[SIT24-06] Effect of Spin transition of iron in physical properties of hydrous phase δ-(Al,Fe)OOH under the lower mantle conditions

*Eiji Ohtani[1], Wen-pin Hsieh[2], Takayuki Ishii[3], Itaru Ohira[4] (1.Department of Earth and Planetary Materials Science, Graduate School of Science, Tohoku University, 2.Institute of Earth Science, Academia Sinica, 3.Bayeriches Geoinstitute, University of Bayreuth, 4.Geodynamics Research Center, Ehime University)

Searching for the deep roots of arc volcanoes: seismic imaging in the Washington Cascades (Invited)

*Geoffrey A Abers[1], Michael E Mann[1], Kayla J Crosbie[1], Roque Soto Castaneda[1], Carl Ulberg[2], Kenneth C Creager[2]

1. Cornell University, 2. University of Washington

Many arc volcanoes erupt mantle-sourced basalts and high-temperature lower-crustal magmas, yet seismic images of this deep plumbing are almost non-existent. Are deep partial-melt bodies too small for seismology to see, or are typical seismic arrays too limited to detect them? We address these questions with a 2014-16, 70-station broadband array around Mount St. Helens (MSH), termed iMUSH (imaging Magma Under St. Helens). Receiver functions image 35-40 km of upper-plate crust and a subducting plate 65-68 km directly beneath MSH. This leaves very little mantle to melt, yet basalts are present. As elsewhere in the Cascades, the upper-plate Moho vanishes in the forearc (west of MSH), an observation usually interpreted as serpentinized mantle. Ambient-noise tomography shows slightly low wavespeeds consistent with partially hydrated mantle, requiring temperatures low enough for serpentines to be stable. However, the vanishing Moho is largely a consequence of upper-plate geology: very high wavespeeds are observed in the lower crust west of MSH, greatly reducing the Moho velocity contrast. This is likely due to the presence of an accreted oceanic plateau terrane (Siletzia), which is present everywhere in Cascadia the Moho has vanished. Overall, we see little evidence for melt except far east of MSH, and these observations show little sign of the deep magma plumbing system. Instead, they imply that the lower crust and uppermost mantle are too cold directly beneath the edifice to generate the observed melts. To reconcile these observations with the volcanism at MSH requires significant lateral melt transport within the crust. Melt may originate beneath mafic vent fields 25-40 km east of MSH, or somewhere south of iMUSH.

Keywords: volcanism, subduction, seismic imaging

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Combining InSAR and GNSS to model magma transport during the May 2016 eruption of Piton de la Fournaise Volcano (La Réunion Island

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Magma propagation is an unsteady and complex process controlled by the magma-crust interaction. For instance, at Piton de la Fournaise volcano (La Réunion, France), intrusions have different velocities depending on the distance of the eruptive fissures from the summit, some intrusions fail to result in eruptions, and eruptive fissures can be located at the summit, on the cone flanks or can be distal. To gain information into the dynamics of magma propagation at the volcano, we invert complementary ground deformation data which cover the 8 hours preceding the May 2016 eruption. Data are inverted using 3-D boundary element models combined with a Monte Carlo inversion method in order to search for the best magma intrusion geometry. We first retrieve the final geometry of the intrusion based on four interferograms, both in ascending and descending tracks, spanning the whole propagation phase. The imaged intrusion consists in a 2700 m long sill located at an elevation of 800 m, connected to the eruptive fissure by a 880 m sub-vertical dike. Using continuous GNSS data and a Sentinel-1 InSAR interferogram acquired during the propagation phase, we show the a-priori brought by InSAR is required to constrain the intrusion depth. Temporal inversions with a 5 min time step evidence that the horizontal part of the intrusion opens a few tens of minutes after the beginning of the crisis. The intrusion then stalls for 5 hours, with no volume increase, until the last part of the intrusion propagates vertically in a fracture narrower than the sill.The unsteady propagation and the final change of direction indicate the presence of structural barriers to propagation, while the lack of volume change and the narrow vertical fracture might be related to magmatic gas in the final part of the intrusion.

Keywords: Joint inversion, deformation data, Piton de la Fournaise volcano

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Salinity map of subduction-zones fluids recorded in fluid inclusions

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High-pressure experiments suggest that saline fluids can play a significant role in transfer of H_2O and elements from subducting oceanic plates to the mantle wedges (Keppler 1996 Nature, Kawamoto et al., 2014 EPS, Huang et al., 2019 Nature comm). In the natural rocks, we have observed fluid inclusions and reported saline fluids under various circumstances: mantle peridotites (Kawamoto et al., 2013 PNAS), jadeitites and jadeite-rich rocks (Fukuyama et al., 2017, JMPS, Kawamoto et al., 2018 Lithos), and high-pressure metamorphic rocks (Shinji et al., 2019 JMPS). Salinity of these fluid inclusions common ranges from 3-7 wt. % NaCl equivalent, which is similar to or a little greater than 3.5 wt. % NaCl equivalent of the present seawater. This may indicate seawater recycling via hydration and dehydration reactions of oceanic plates. In addition to these findings, we reported low-salinity saline fluids in listvenites (carbonates and quartz rocks) in Ethiopia (2 wt% NaCl equivalent, Kawamoto et al., Japanese Association of Mineralogical Sciences 2018 Fall meeting) and Oman (1 wt% NaCl equivalent, Kawamoto et al., JpGU 2019 meeting). Such fluid inclusions of the listvenites are characterized by their low-salinity of 1-2 wt% NaCl equivalent. This suggests us to interpret them as saline fluids diluted by on-going serpentinization in juvenile island arcs, where Cl is preferentially partitioned into serpentine minerals. This can result in the formation of low-salinity fluids as recorded in the fluid inclusions. Lower-salinity fluids dissolve less amounts of carbonate ions than higher-salinity fluids (Ellis, Am J Sci, 1963; Newton and Manning Am Mineral, 2002). Consequently carbonate minerals can precipitate from the low-salinity fluids, which forms carbonates-quartz rocks. If this is the case, subduction-zone fluids vary their salinity from deep to shallow locations and along with or without on-going serpentinization. In the Southwest Japan forearc, Arima-type springs show up to 5 wt% NaCl equivalent (Sano and Wakita, JGR 1985), while in Izu-Bonin-Mariana forearc, springs through serpentinite mud volcanoes are characterized by lower salinity than seawater (Mottl et al., GCA 2004). The latter low-salinity saline fluids can be observed in the fluid inclusions of carbonate minerals in the listvenites.

Keywords: saline fluids, CO2

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Developing a laboratory technique to probe volatile transport in the deep mantle

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Transport of volatiles as melts or fluids is influenced not only by pressure, temperature and chemical composition, but also by oxygen fugacity. Scenarios that investigate volatile transport at mantle conditions to depths of around 700 km can be explored through high pressure and high temperature experiments in large volume presses where oxygen fugacity is monitored, for example using metal alloys as sliding redox sensors. However, so far oxygen fugacity has only rarely been measured in diamond anvil cell experiments, which are the gateway to the extreme pressure and temperature conditions of Earth’ s deep interior. To address this deficiency, we are developing a new approach to measure and control oxygen fugacity in a diamond anvil cell. In preliminary experiments we reacted ferropericlase and iridium metal in a laser-heated diamond anvil cell to produce iron-iridium alloy and ferropericlase, and used the composition of the iron-iridium alloy to calculate oxygen fugacity. We traced the progress of redox reactions through Mössbauer, XANES and EELS and determined chemical compositions using EMPA, SEM and FIB-TEM. Results provide a quantitative picture of mass balance and transport of oxygen during the diamond anvil cell experiments. We will present the latest results including a comparison to a parallel experiment carried out using a multianvil press.

Keywords: volatiles, oxygen fugacity, diamond anvil cell

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Temperature dependence on nitrogen solubility in bridgmanite under lower mantle conditions: its role in formation of deep nitrogen reservoir through solidification of magma ocean.

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Nitrogen occupies about 80% of the Earth's atmosphere and is one of essential elements of life. Despite its importance, nitrogen behavior in the Earth's interior remains poorly understood. Nitrogen is depleted in the Earth compared to other volatiles, especially carbon: this is so-called “missing” nitrogen and has persisted as a mystery. Experimental researches suggested that "missing" nitrogen is caused by nitrogen stored in the deep mantle through magma ocean (e.g., Li et al., 2013; Yoshioka et al., 2018). Yoshioka et al. (2018) is the only study reporting the nitrogen solubility of bridgmanite which occupies about 80 vol% of the lower mantle in the pyrolite model, but their experimental conditions were limited at 24 GPa and 1600 ˚C.

In this research, we investigated temperature dependence on nitrogen solubility in bridgmanite. High-pressure and high-temperature experiments were conducted using multi-anvil apparatus installed at Geodynamics Research Center, Ehime University. The pressure condition was 28 GPa and temperature conditions ranged from 1400 ℃ to 1700 ℃. Fe-FeO buffer was used to control the redox state equal to the lower mantle. Nitrogen in recovered samples were analyzed using a secondary ionization mass spectrometer (HR-1280, Cameca) installed at CNRS-CRPG, France.

A series of experimental results revealed that nitrogen solubility in bridgmanite increased from 1.8 to 5.6 ppm with increasing temperature. The results implies that the lower mantle can store 3-4 PAN (PAN: mass of Present Atmospheric Nitrogen) only by bridgmanite at maximum. This trend between nitrogen solubility and temperature in bridgmanite is opposite of those in metallic iron reported by Yoshioka et al. (2018). In addition, this concentration is much higher than that of carbon in bridgmanite; i.e. below 30–200 ppb (Shcheka et al., 2006). Bridgmanite firstly crystallized in cooling magma ocean (Stixrude et al. 2009; Ozawa et al., 2018) and would capture nitrogen there. Our study suggests that bridgmanite played an important role in reserving nitrogen through the solidification of magma ocean. Metallic iron in the present lower mantle could reserve nitrogen, which can be supported by the discovery of iron nitride in super deep diamond originating from the lower mantle (Kaminsky and Wirth, 2017). This formation process of "hidden" nitrogen reservoir in the lower mantle may relatively deplete nitrogen in the Earth: only one planet where life has been confirmed in the solar system.

Keywords: Magma ocean, Bridgmanite, "Missing" nitrogen, Secondary ion mass spectrometry, High-pressure and high-temperature experiment, Atmosphere-Mantle coevolution

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Effect of Spin transition of iron in physical properties of hydrous phase δ-(Al,Fe)OOH under the lower mantle conditions

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Recent experimental evidence indicated that the Earth's transition zone contains significant amount of water at least locally. Subduction of the slabs into the lower mantle can transport water further into the lower mantle. One of the most important carrier of water into the lower mantle is hydrous phase δ. Our works on the stability of this phase revealed that it coexists with bridgmanite in the lower mantle [1, 2]. Therefore, existence of δ-phase could potentially make the significant effect on dynamics of the lower mantle.

Our experimental works of time domain synchrotron Mossbauer spectroscopy revealed that δ-(Fe,Al)OOH undergoes a HS–LS transition at the pressure range of 32–45 GPa. Our compression experiments of the phase showed that the volume collapse due to a transition from high-spin to low-spin states in the Fe^{3+} ions occurs at pressures of 32–40 GPa [3]. These observations revealed that there is reduction in the bulk sound velocity associated with the spin-transition at the top of the lower mantle.

In order to clarify the effect of the spin transition on physical properties of δ-(Fe,Al)OOH, we have measured the thermal conductivity of this phase at room temperature and high pressure exceeding 100 GPa. The measurement was conducted by using TDTR (Time Domain Thermoreflectance method) combined with a diamond anvil cell [4]. The thermal conductivity varies drastically by twofold to threefold across the spin transition of iron, resulting in the thermal conductivity of δ-(Al,Fe)OOH-rich crustal material larger than that of the surrounding pyrolitic mantle, which may in turn enhance the heat transfer between the slab and its surroundings at the top of the lower mantle. Whereas, the low-spin Fe^{3+} bearing δ-phase has an exceptionally low thermal conductivity at the lowermost mantle. Such a drastic variation of thermal conductivity would induce temperature anomaly within the slab promoting local heterogeneous density and buoyancy distribution at the base of the lower mantle.

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Keywords: Spin transition of iron, Hydrous δ-(Al,Fe)OOH, Thermal conductivity, Lower mantle

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[E] Oral | S (Solid Earth Sciences)：S-IT Science of the Earth's Interior & Techtonophysics

[S-IT25] Structure and Dynamics of Earth and Planetary Mantles

convener:Takashi Yoshino(Institute for Planetary Materials, Okayama University), Takashi Nakagawa(Department of Earth Sciences, The University of Hong Kong), Dapeng Zhao(Department of Geophysics, Tohoku University)

Interdisciplinary approach can lead to a better understanding of the dynamics and evolution of the deep interiors of the Earth and planets. We welcome any submissions of recent results in observational, theoretical and experimental studies on seismology, geomagnetism, mineral physics, dynamics of deep interiors, and any other relevant fields from researchers in many countries. The integration of such results is also welcome. In particular, we encourage any contributions focusing on "plate and mantle dynamics in Earth and terrestrial planets". This session will be organized as the main session of the SEDI-J group in the Solid Earth Section of JpGU. We encourage all participants concerning the deep planetary interior to submit this session.

[SIT25-01] Application of the mixed length theory to assess the generation of melt in internally heated systems

*Kenny Vilella[1], Shunichi Kamata[1] (1.Hokkaido University)

[SIT25-02] **New insights into structural elements of the upper mantle below the contiguous United States from S-to-P converted seismic waves**

Rainer Kind[2], *Walter D Mooney[1], Xiaohui Yuan[2] (1.USGS Western Regional Offices Menlo Park, 2.Helmholtz Center Potsdam GFZ)

[SIT25-03] **The effect of water on seismic attenuation of upper mantle olivine and its implications for origin of the sharp lithosphere-asthenosphere boundary**

*Chao Liu[1], Takashi Yoshino[1] (1.Institute for Planetary Materials, Okayama University)

[SIT25-06] **Source stacking followed by cross-correlation: the first application to real long period data for full-waveform inversion at the global scale**

*Li-Wei Chen[1], Barbara Romanowicz[1,2,3] (1.University of California, Berkeley, 2.Institut de Physique du Globe de Paris, 3.Collège de France, Paris)

Application of the mixed length theory to assess the generation of melt in internally heated systems

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The thermo-chemical evolution of a planetary mantle is fundamental to understand the past and current state of the whole planet. This evolution is however complex because characterized by several complexities. One of the major issue to model mantle evolution is to account for their chemically heterogeneous nature. Indeed, melting of rocks and its associated volcanism induce chemical differentiation producing rocks with a large range of chemical compositions. A robust description of the chemical differentiation would require to track each element compounds and consider their partitioning between solid and liquid. This feature is not yet implemented in 3D numerical codes because it would require heavy computational resources.
Alternatively, we propose a new analytical framework allowing to estimate the amount and depths of melting in 1D parameterized convection. To do so, we develop an approach, partly based on an extended version of the mixed length theory, able to estimate the distribution of the hottest temperatures in natural systems. Due to the novelty of the approach, we apply our framework to a simplified convective system consisting of a purely internally heated fluid in a Cartesian geometry. The approach involves several free parameters that are calibrated by fitting 3D numerical simulations. We then successfully compared the amount of melting estimated from our 1D analytical approach to results of 3D numerical simulations. Building on this success, we develop an algorithm able to calculate the 1D thermal evolution of our convective system including the effect of melting on the heat budget. We then apply our algorithm to the long-term evolution of a generic planetary mantle and compare to the evolution calculated with 3D numerical simulations.

Keywords: Internal heating, Convection, Melting, Parameterized convection, Mixed Length Theory, Mantle dynamic

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New insights into structural elements of the upper mantle below the contiguous United States from S-to-P converted seismic waves

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The S-receiver function (SRF) technique is an effective tool to study seismic discontinuities in the upper mantle like the lithosphere-asthenosphere boundary (LAB). It uses deconvolution and aligns traces along the maximum of the deconvolved SV signal. Both of these steps lead to acausal signals, which may cause interference with real signals from below the Moho. We go back to the origin of the S-receiver function method and process S-to-P converted waves applying the original processing method by using S-onset times as reference and waveform summation without deconvolution. We apply this “causal” SRF (C-SRF) method to data of the USArray and obtain partially different results in comparison with previous studies using the traditional acausal SRF method. The new method does **not** confirm the existence of a mid-lithosphere discontinuity (MLD) beneath the cratonic US. The shallow LAB in the western US is, however, confirmed with the new method. The elimination of the MLD signal below the cratonic US reveals lower amplitude but highly significant phases that previously had been overwhelmed by the apparent MLD signals. Along the northern part of the data coverage area we see relics of Archean or younger north-west directed low-angle subduction below the entire Superior Craton. In the cratonic part of the US we see indications of the cratonic LAB near 200 km depth. In the Gulf Coast of the southern US we image relics of southeast directed shallow subduction, likely of mid-Paleozoic age.

Keywords: S-receiver function, lithosphere, LAB, MLD

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The effect of water on seismic attenuation of upper mantle olivine and its implications for origin of the sharp lithosphere-asthenosphere boundary

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Seismological observations have shown attenuation of seismic waves in the asthenosphere (Dziewonski and Anderson, 1981; Takeuchi et al., 2017) and a sharp drop of seismic velocity at the lithosphere-asthenosphere boundary (LAB) (Kawakatsu et al., 2009; Rychert et al., 2009). Such a sharp change in shear wave velocity was caused by the difference of their physical properties between the lithosphere and asthenosphere rather than the thermal gradient (Karato et al., 2015; Kawakatsu et al., 2009). The presence of partial melt, reduced grain size or increased water content have been previously proposed as the origin of the geophysically observed anomalies in the oceanic asthenosphere (e.g., Anderson and Sammis, 1970; Hirth and Kohlstedt, 1996; Faul and Jackson, 2005; Yoshino et al., 2006; Jackson et al., 2010; Karato, 2012). Although partial melting has been considered as the most popular model, from the petrological point of view, such a sharp velocity drop at the LAB (~60 km) in the old oceanic upper mantle (120 Myr) is difficult to be explained by partial melting (Hirschmann, 2010).

To figure out the effects of water and grain size on seismic attenuation, attenuation factor Q^{-1} and Young's modulus of polycrystalline forsterite with variable grain sizes and water contents were measured by cyclic loading with oscillation periods ranging from 0.5 to 1000 s. The in situ X-ray radiographic observation was obtained in a deformation DIA press with a short-period cyclic loading system at the bending magnet beamline BL04B1 at SPring-8, Japan (Yoshino et al., 2016).

The results show that Q^{-1} increases with decreasing grain size and increasing the water content of forsterite, whereas Young's modulus decreases with decreasing grain size and increasing the water content of forsterite. To distinguish the effects of water content and grain size on attenuation quantitatively, all the Q^{-1} data were globally fitted by the modified power-law function (Jackson et al., 2002; Karato and Jung, 1998): $Q^{-1}=Ad^{m}\tau^{\alpha}C^{r}\exp(-\alpha\Delta H/RT)$, where Q^{-1} is a quality factor for attenuation, d is a grain size (μm), τ is a period (s), C is a water content (ppm wt. H_2O), ΔH is an activation enthalpy, R is the gas constant and T is the temperature (K). A= 121(50) $s^{-\alpha}$ μm^{m} (ppm wt. $H_2O)^{r}$, m= 0.28(3), α= 0.221(7), ΔH = 407(22) kJ.mol^{-1} and r= 0.33(6). The exponents of grain size (um) and water content (ppm wt. H_2O) exponent 0.28(3) and 0.34(6), respectively. The effect of grain size on attenuation is consistent with the previous study (Jackson et al., 2002). The shear modulus was calculated from the Young modulus assuming constant bulk modulus by the relationship of them: $G=3KE/(9k-E)$ (where G is shear modulus, E is Young's modulus and K is bulk modulus). Although the unrelaxed velocity contributed from unrelaxed shear modulus is still controversial (Karato, 2012), seismic velocities were calculated based on the relationship between shear wave velocity and shear modulus: $V_s=(G/\rho)^{1/2}$ (where V_s is shear velocity, G is shear modulus, and ρ is the density). Assuming that only shear modulus contributes to shear wave velocity, the effect of water on velocity is as follows: the samples with a higher water content of 147 ppm wt. H_2O shows a 10% lower shear modulus than of that with the water content of 77 ppm wt. H_2O at the temperature of 1100°C and the period of 1 s; then it could results in a 10% velocity drop of the sample with relative lower water (From $Vs=(G/\rho)^{1/2}$, so $dV_s/V_s=dG/G$). Even if we consider the effect of grain size on attenuation, the water could potentially be one possible factor to produce the seismic anomalies

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observed at the LAB.

Keywords: cyclic loading, in situ X-ray observation, lithosphere-asthenosphere boundary (LAB), seismic attenuation, upper mantle

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Source stacking followed by cross-correlation: the first application to real long period data for full-waveform inversion at the global scale

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Source stacking was proposed (Capdeville et al., 2005) to reduce the cost of numerical wavefield simulations in global mantle tomography. However high-amplitude fundamental mode surface waves dominate the summed waveform, which impedes the contribution of the overtone energy in full-waveform inversion. By cross-correlating the summed waveforms between station pairs, the contribution of overtones and body waves can be boosted (Romanowicz et al., 2019). The quality of reconstructed Green’ s function is less important since we can apply the same processing to the 3D synthetics and observations, also we’ ve had good knowledge of the source location and its mechanism. This approach also allows us to perform synthetic tests in a numerically efficient way, such as, for example, to investigate spatial and depth resolution and trade-offs between various physical parameters in full-waveform tomography, or accounting for the non-linear character of the inversion, which is not feasible with conventional approaches. Here we present synthetic tests based on a realistic synthetic dataset derived from SEMUCB-WM1 (French and Romanowicz, 2015), which includes a 3D crustal model and mantle structure. We computed a 3-component long-period (> 60s) waveform dataset for globally distributed 273 events and 515 stations using the Spectral Element Method. The experiments enable us to evaluate the capability of resolving the shear wave velocity and its anisotropic structure in the upper mantle. We have also collected a large dataset of real data at the global scale, for a time interval that includes first and second orbit surface waves. Regarding the existence of missing data in the real situation which might demolish the resolving power, subsets of summed waveforms are computed for replacing the missing data; also, cluster analysis can help to group the data so as to minimize the number of missing waveforms in each group. We then compare the resulting long-wavelength global 3D radially anisotropic shear velocity model to other existing models constructed by using conventional approaches.

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[E] Oral | S (Solid Earth Sciences)：S-IT Science of the Earth's Interior & Techtonophysics

[S-IT25] Structure and Dynamics of Earth and Planetary Mantles

convener:Takashi Yoshino(Institute for Planetary Materials, Okayama University), Takashi Nakagawa(Department of Earth Sciences, The University of Hong Kong), Dapeng Zhao(Department of Geophysics, Tohoku University)

Interdisciplinary approach can lead to a better understanding of the dynamics and evolution of the deep interiors of the Earth and planets. We welcome any submissions of recent results in observational, theoretical and experimental studies on seismology, geomagnetism, mineral physics, dynamics of deep interiors, and any other relevant fields from researchers in many countries. The integration of such results is also welcome. In particular, we encourage any contributions focusing on "plate and mantle dynamics in Earth and terrestrial planets". This session will be organized as the main session of the SEDI-J group in the Solid Earth Section of JpGU. We encourage all participants concerning the deep planetary interior to submit this session.

[SIT25-07] Numerical experiments on stagnation and avalanche of subducting slabs: Important roles of trench migration and its temporal change

*Mana Tsuchida[1], Masanori Kameyama[1] (1.Geodynamics Research Center, Ehime University)

[SIT25-08] Topography on the mantle discontinuities beneath the Ontong Java Plateau

*Daisuke Suetsugu[1], Hajime Shiobara[2], Hiroko Sugioka[3], Aki Ito[1], Takehi Isse[2], Yasushi Ishihara[1], Satoru Tanaka[1], Masayuki Obayashi[1], Takashi Tonegawa[1], Junko Yoshimitsu[1], Takumi Kobayashi[3] (1.institute for Marine Geodynamics, Japan Agency for Marine-Earth Science and Technology, 2.Earthquake Research Institute, the University of Tokyo, 3.Department of Planetrology, Graduate School of Science Kobe University)

[SIT25-10] **Iron content induced pressure- and temperature-dependency change of thermal conductivity of ferropericlase: implications for mantle dynamics**

*Youyue Zhang[1], Takashi Yoshino[1], Masahiro Osako[2] (1.Institute for Planetary Materials, Okayama University, 2.National Museum of Nature and Science)

[SIT25-11] Shear localization and shear instability induced by the olivine-spinel transformation of fayalite at 8 GPa

*Yuichiro Mori[1], Tomoaki Kubo[1], Takuya Iwasato[2], Yuji Higo[3], Yoshinori Tange[3] (1.Kyushu University, 2.Shin-Nippon Nondestructive Inspection Co., Ltd, 3.JASRI)

[SIT25-12] Volatile cycle across the Earth-like planet – Impact to plate tectonics and climate

*Takashi Nakagawa[1] (1.Department of Earth Sciences, The University of Hong Kong)

Numerical experiments on stagnation and avalanche of subducting slabs: Important roles of trench migration and its temporal change

*Mana Tsuchida[1], Masanori Kameyama[1]

1. Geodynamics Research Center, Ehime University

We conducted numerical simulations of thermal convection of highly viscous fluids in a 2-D spherical annulus in order to study what mechanisms control the dynamic behaviors of subducting slabs such as the formation of ``stagnant slabs'' in the mantle transition zone (MTZ) and their avalanche into the lower mantle. Two series of experiments are carried out, by applying the different histories of migrating motion of ``trench'' where the slab of cold fluids descends from the top surface, together with systematically varying the velocities of subducting slabs and trench migration, the Clapeyron slope at around 660 km depth, and the viscosity jump between the upper and lower mantle. In the first series of experiments where the migration rate of trench is kept constant with time, our model successfully reproduces the diverse morphology of subducting slabs depending on the delicate combinations of control parameters, including five fundamental types named penetration (P), accumulation (A), flotation (F), long-term stagnation (LS) and short-term stagnation (SS). In addition to the above fundamental types, we found two distinctive types of slab behaviors (named pS and cS) where the slabs are stagnated at the base of MTZ after they experience the penetration or collapse into the lower mantle and yield the snapshot behaviors very close to those of SS at some time instances. In the second series of experiments where we imposed a step-like change in the trench retreat velocity with time, we found that a deceleration of trench retreat enhances the collapse of the horizontally-lying or stagnant slabs (SS, cS, pS and LS types in the first series of experiments) into the lower mantle whose style and course strongly depend on the slab shapes at the time instance of the sudden stop of the trench retreat. In these experiments, we obtained wider variations of slab behaviors than in the cases with continuous trench retreat, such as the avalanche of stagnant slabs from its hinge and the flattening of slabs below the 660 km discontinuity without any discontinuous changes in mantle properties at the depth. Our results suggest that the formation and avalanche of stagnant slabs are strongly related to the trench retreat, particularly through its temporal changes. In other words, the variations in the shapes of subducting slabs in nature are most likely to reflect the difference in the history of trench migration.

Keywords: numerical simulation, mantle convection, stagnant slab, trench retreat, subduction zone

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Topography on the mantle discontinuities beneath the Ontong Java Plateau

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We conducted geophysical observations on the Ontong Java Plateau (OJP) and its vicinity from late 2014 to early 2017 to determine the underlying crust and upper mantle structure beneath the OJP. Most of the OJP was emplaced in the present South Pacific region at 122 Ma by massive volcanism. The observation network named “the OJP array” is composed of seafloor and island stations. P-wave tomography with seismic data from the OJP array shows a paleo-Pacific slab stagnant in the mantle transition zone beneath the OJP and a mantle upwelling above the mantle transition zone to the Caroline hotspot chain. It is unclear whether the mantle upwelling is connected to the Pacific superplume (LLSVP) or not from the tomography. We perform a receiver function analysis with teleseismic body waves to determine topography of the mantle discontinuities at around 410 and 660 km, which can be used to estimate temperature anomalies in the mantle transition zone. The 410-km discontinuity is depressed beneath the Caroline hotspot chain as compared with that beneath the OJP, indicating higher temperatures around the 410-km discontinuity beneath the Caroline hotspot chain. It is depressed beneath OJP, which may be due to the paleo-Pacific slab in the mantle transition zone.

Keywords: Ontong Java Plateau, Mantle transition zone, BBOBS

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Iron content induced pressure- and temperature-dependency change of thermal conductivity of ferropericlase: implications for mantle dynamics

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The thermal conductivity of Earth's materials is an important factor to govern the heat transport in the Earth's interior, and consequently plays a critical role in thermal evolution and dynamics of the mantle and core. Ferropericlase, which is the second most abundant mineral in the Earth's lower mantle, is of great importance for the control of heat flux across core-mantle boundary. Recent studies have revealed that at the bottom of mantle some areas can be enriched in iron oxides, in particular iron-rich ferropericlase, which believed to be one of possible candidates to explain the origin of ultra-low velocity zones (ULVZs) [1]. The effect of iron content on thermal conductivity of ferropericlase thus becomes indispensable for understanding the origin of ULVZs and lateral heat flux heterogeneity at the core-mantle boundary (CMB). Although several laboratory measurement results of lattice thermal conductivity of ferropericlase are available, the inconsistent pressure dependence and lack of data regarding temperature dependence make it difficult to discuss such issue [2–5].

In this study, thermal conductivity and diffusivity of ferropericlase were determined simultaneously by combining multi-anvil high pressure experimental technique and pulse heating method. Thermal properties of ferropericlase with six different Fe contents (Fp_3, Fp_5, Fp_{10}, Fp_{20}, Fp_{30}, Fp_{50}) were measured under high pressure and high temperature in a Kawai type multi-anvil press. The experiment results show that even small addition of iron can strongly reduce the thermal conductivity of ferropericlase at room temperature. The effects of pressure and temperature on thermal conductivity of ferropericlase are also highly correlated with the iron concentration and decrease with increasing iron content. Such high sensitivity for iron content suggests that the global iron fraction, iron enrichment at some regions of lowermost mantle and iron partitioning between ferropericlase and other mantle phases could largely influence the heat transport and temperature distribution in the lower mantle. Iron-rich ferropericlase is expected to have much lower thermal conductivity than iron-poor one due to the small pressure dependence. It means that in iron enrichment regions heat loss will be suppressed and allow the persistence of small pockets of hot materials at the bottom of mantle up to now. Inversely, much faster heat transport is anticipated for relatively iron poor area.

Reference: [1] Wicks, JK. et al., Geophys Res Lett. 37: L15304 (2010). [2] Manthilake, GM. et al., Proc National Acad Sci. 108, 17901–17904 (2011). [3] Goncharov AF. et al., Phys Earth Planet Inter. 247, 11–16 (2015). [4] Ohta, K. et al., Earth Planet Sc. Lett. 465, 29–37 (2017). [5] Hsieh, W.-P. et al., Proc National Acad Sci. 115, 4099–4104 (2018).

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Keywords: Thermal conductivity, Ferropericlase, High pressure, Mantle

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Shear localization and shear instability induced by the olivine-spinel transformation of fayalite at 8 GPa

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Deep-focus earthquakes have been observed to occur within subducting oceanic plates at depths of 300 to 700 km. It has been proposed that phase transformations of mantle minerals induce strain localization and shear instability responsible for earthquakes. Previous studies showed that the olivine-spinel transformation of Mg_2GeO_4, which is an analog of Mg_2SiO_4, induce AE activities associated with thin shear bands composed of nanograins of spinel phase (e.g., Schubnel et al., 2013). However, the pressure conditions are still relatively low around 3-5 GPa. In the present study, we used the olivine-spinel transformation in silicate olivine Fe_2SiO_4 to observe shear instability at higher pressures.
Deformation experiments were conducted at 6-10 GPa, 400-800˚C using D-DIA apparatus, SPEED Mk. II at BL04B1, SPring-8. Pressure was generated by MA 6-6 type cell assembly. Monochromatic X-rays (60keV) were used to obtain radiography images and two-dimensional X-rays diffraction patterns every 5-10 minutes, from which transformation kinetics and creep behaviors were monitored. In addition, we used MA6-6 type AE measurement system to search for the condition of shear instability. The starting material is fayalite (Fe_2SiO_4) powder. We annealed it at 3 GPa and ~700-900˚C in the olivine stability field after cold compression prior to deformation in the spinel stability field. All deformation experiments were conducted with constant anvil displacement rate of 200-500 μm/h and constant temperature ramping rate of 0.07-0.11˚C/s).
At the smaller overpressure (dP) of ~2 GPa, we observed the initiation of the transformation at 750˚C. In the case of the larger dP of ~5 GPa, the transformation started at the lower temperature of 600˚C. Strain rates and final strains were $9.5x10^{-5}$ /s and 51%, and $1.6x10^{-4}$ /s and 44%, respectively. In the latter case, we detected AEs around the sample region associated with the olivine-spinel transformation. Both AE event rate and AE magnitude increased abruptly as reaction proceeded. SEM and EBSD observations revealed that fine-grained spinel nucleates along the olivine grain boundaries and preferentially grows perpendicular to the principal stress direction forming the interconnected spinel network in both runs. These transformation and deformation textures are relatively homogeneous in the run at smaller dP and higher T without AEs. In contrast, shear localization was observed in the run at larger dP and smaller T with AE activities. The spinel grain size seems to be smaller in the latter case, which may cause the different deformation behavior. These results suggest that shear localization and shear instability occur associated with the olivine-spinel transformation at the higher pressure condition of ~8 GPa, however further studies are needed to constrain the factors inducing shear instability.

Keywords: deep earthquakes, phase transformation, high pressure experiments, deformation experiments, in-situ X-ray observation

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Volatile cycle across the Earth-like planet –Impact to plate tectonics and climate

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I will present a reasonable scenario for the long-term evolution of the surface environment associated with the plate tectonics as a result of the dynamics of the deep planetary interior. The plate tectonics is believed to continue over a few billion years, driven by the mantle convection. Still, it is not quite clear when the plate tectonics is initiated, which is suggested from the various geological constraints (e.g., review article by Korenaga, 2013). The plate tectonics also controls the volatile cycle (water/carbon) across the deep interior (e.g., Nakagawa and Nakakuki, 2019). As a result, the plate tectonics also affects the long-term climate evolution because the volcanic outgassing process may change the chemical composition and optical property of the atmosphere-ocean system (e.g., Kadoya and Tajika, 2019). To find out the reasonable scenario of the evolution of the surface environment, I develop a coupled model of the thermal evolution of the rocky planet and energy balance climate evolution. With a developed model, I explore how the onset timing of the plate tectonics controls the volatile cycling across the deep interior and its impact on climate evolution.

The main findings are as follows: 1. The plate tectonics is likely to be initiated around 1.5 to 3 Ga to explain the reasonable scenario of the water cycling that may reveal the present-day volume of the surface seawater. The total amount of water in the planetary system would be around ten times as much as the present-day volume of the surface seawater, and the silicate mantle may have a few Ocean mass initially. However, the expected subduction flux may be an order of magnitude larger than that constrained by the water solubility experiments (Iwamori, 2007) and sea-level change associated with the tectonic plate (Karlson et al., 2019). 2. For the climate evolution, the stable climate so that may allow the planet to have the liquid water is found when the plate tectonics is successfully operated, but the snowball limit cycle solution is found when the plate tectonics is not operated (Stagnant lid planet). As a consequence, the volcanic activities (i.e., the volcanic outgassing) associated with the plate tectonics is essential to keep the planet warm so that the liquid water may be found, that is, the planetary surface is a habitable condition.

Keywords: Plate tectonics, Volatile Cycle, Climate, Habitability

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[E] Oral | S (Solid Earth Sciences)：S-IT Science of the Earth's Interior & Techtonophysics

[S-IT26] Interaction and Coevolution of the Core and Mantle in the Earth and Planets

convener:Kenji Ohta(Department of Earth and Planetary Sciences, Tokyo Institute of Technology), Tsuyoshi Iizuka(University of Tokyo), Kenji Kawai(Department of Earth and Planetary Science, School of Science, University of Tokyo), Taku Tsuchiya(Geodynamics Research Center, Ehime University)

Recent observational and experimental investigations have significantly advanced our understanding of the structure and constituent materials of the deep Earth. Yet, even fundamental properties intimately linked with formation and evolution of the planet, such as details of the chemical heterogeneity in the mantle and light elements dissolved in the core, remain unclear. Seismological observations have suggested a vigorous convection in the lower mantle, whereas geochemistry has suggested the presence of stable regions there that hold ancient isotope signatures. The amounts of radioactive isotopes that act as heat sources and drive dynamic behaviors of the deep Earth are also still largely unknown. We provide an opportunity to exchange the achievements and ideas, and encourage persons who try to elucidate these unsolved issues of the core-mantle evolution using various methods, including high-pressure and high-temperature experiments, high-precision geochemical and paleomagnetic analyses, high-resolution geophysical observations, geo-neutrino observations, and large-scale numerical simulations. Papers stimulating an interdisciplinary collaboration relating to establishment of the Japan-SEDI community are also welcomed.

[SIT26-01] Thermal and Chemical Interactions between the Core and Mantle

*Taku Tsuchiya[1], Haruhiko Dekura[1], Zhihua Xiong[1], Atsuroh Ohba[1] (1.Geodynamics Research Center, Ehime University)

[SIT26-02] Martian Core Heat Flux: Electrical Resistivity and Thermal Conductivity of Liquid Fe at Martian Core P-T Conditions

*Innocent Ezenwa[1], Takashi Yoshino[1] (1.Institute for Planetary Materials, Okayama University)

[SIT26-03] **Advances in a high pressure-temperature experiment for understanding thermal transport property of the Earth's core**

*Kenji Ohta[1], Sho Suehiro[1], Hayato Inoue[1], Akira Hasegawa[1] (1.Department of Earth and Planetary Sciences, Tokyo Institute of Technology)

[SIT26-04] Iron diffusion in ε-iron

*Daisuke Yamazaki[1], Naoya Sakamoto[2], Hisayoshi Yurimoto[2] (1.Institute for Planetary Materials, Okayama University, 2.Hokkaido University)

[SIT26-05] Determination of noble gas partition coefficients between metal and silicate melts under high-pressure and high-temperature conditions

*Hirochika Sumino[1], Tomotaka Tanaka[1], Hideharu Kuwahara[2], Satoshi Kishi[1], Kenji Mibe[4], Ryuichi Nomura[3], Hiroyuki Kagi[5] (1.Department of Basic Science, Graduate School of Arts and Sciences, University of Tokyo, 2.Geodynamics Research Center, Ehime University, 3.Graduate School of Human and Environmental Studies, Kyoto University, 4.Earthquake Research Institute, University of Tokyo, 5.Geochemical Research Center, Graduate School of Science, University of Tokyo)

Thermal and Chemical Interactions between the Core and Mantle

*Taku Tsuchiya[1], Haruhiko Dekura[1], Zhihua Xiong[1], Atsuroh Ohba[1]

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The core-mantle boundary (CMB), where the silicate mantle directly contacts the iron core, is the largest boundary in the Earth. The core and mantle interact with each other physically and chemically at the CMB, and those interactions might control the evolution of the Earth's interior. For example, elemental partitioning between iron and silicate during the core formation process and also at the present CMB might affect the chemical evolution of the outer core. Also, the cooling rate of the core and thus the geodynamo activity significantly depend on the heat flow from the core to mantle. However, related physical and chmecal properties such as partitioning coefficients and thermal conductivity at high-P,T remain largely unclear.

We have therefore started developong theoretical techniques to investigate those properties based on the ab initio density functional framework, (1) the direct anharmonic lattice dynamics (ALD) method + Boltzmann transport equation (BTE) for lattice theraml conductivity (Dekura and Tsuchiya, 2017,2019,in prep.) and (2) the one-step thermodynamic integration (TI) + ab initio molecular dynamics (AIMD) method for liquid free energy then metal-silicate partitioning coefficient (Taniuchi and Tsuchiya, 2018; Xiong et al., 2018; Xiong and Tsuchiya, under review).

Calculated thermal conductivities of the major lower mantle phases (ferropericlase, bridgmanite, and post-perovskite) suggest the CMB heat flow less than 10 TW, which is distinctly smaller compared to the conductive heat flow proposed for the outer core expected from its considerably larger thermal conductivity (de Koker et al., 2014; Pozzo et al., 2014; Ohta et al., 2016). On the other hand, calculated liquid iron-silicate melt partitioning properties suggest that noble gases and water (hydrogen) both remain lithophile at 135 GPa but the core could have stored enough amount of promordial helium. Geophyscal insights drawn from these new results will be discussed in the presentation.

Keywords: Ab initio density functional calculations, Thermal conductivity, Metal-silicate elemental partitioning

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Martian Core Heat Flux: Electrical Resistivity and Thermal Conductivity of Liquid Fe at Martian Core P-T Conditions

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The cores of the rocky planetary bodies are mainly Fe in composition, thus, the understanding of the transport properties of Fe at their core pressure and temperature conditions is important in understanding their core dynamics. Through the on-going InSight mission on Mars, an in-depth understanding of the Martian interior and dynamics can be made through acquired seismic and heat probe data. However, the heat probe (Heat Flow and Physical Properties Package : *HP*^{3}*)* can only penetrate up to a distance of 5m into Martian crust, hence, to better complement the heat flow data, electrical resistivity measurement of Fe up to Martian core and derived thermal conductivity values are highly needed. Although attempts has been made in investigating the electrical resistivity of Fe at high pressure conditions in multi-anvil, existing data varies over a wide margin. We investigated the electrical resistivity of solid and liquid Fe sample devoid of contamination up to Martian core pressure and derive thermal conductivity from our data using Wiedemann Franz' s law with the Sommerfeld value of Lorenz function. All the three phases of Fe at various pressure and temperature conditions were clearly identified. Our results suggests that the electrical resistivity of Fe at Martian core conditions is not as high as some recent studies have suggested. Since our recovered samples have no trace of impurity, our data sets provide the highly needed data for constraining the upper bound of the electrical resistivity, thermal conductivity and heat flux from Martian core. This will complement the on-going measurement by *HP*^{3} on Mars.

Keywords: Martian Core Heat Flux, Electrical Resistivity of Fe, Thermal Conductivity of Fe

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Advances in a high pressure-temperature experiment for understanding thermal transport property of the Earth's core

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Heat flow inside of the Earth controls the scale of dynamics and thermal evolution in each layer of the Earth such as core and mantle. Electrical resistivity and related thermal conductivity of iron-light element alloys at high pressure (*P*) and temperature (*T*) are key parameters to constrain the heat flux in the core. Static high *P-T* experiments using a laser-heated diamond anvil cell (LHDAC) are now capable of obtaining the thermal and electrical conductivities of iron at the Earth's core conditions, but the obtained values are inconclusive so far [1]. Disadvantages in the existing LHDAC technique may cause the discrepancy, and thus technical developments for the high *P-T* conductivity measurements of iron alloy are required.

We have recently developed an internally resistive heated DAC technique to be capable of measuring the electrical conductivity of a metal sample via the four-terminal method [2]. A new instrument to determine the thermal diffusivity of metal *in-situ* at high *P-T* has been made based on the combination of the thermoreflectance method and the LHDAC system [3]. Such technical progress provided us chances to determine the thermal transport properties of core materials at the *P-T* conditions relevant to the Earth's deep interior.

We report our new experimental results of the electrical resistivity measurements of liquid iron and Fe-Si alloys at high *P-T*conditions using the four-terminal method in an internally heated DAC. The *T* dependence of electrical resistivity of *hcp* Fe-Si alloys was suppressed as both Si concentration and *T* increased, which indicates the resistivity saturation phenomenon: the electrical resistivity of metal asymptotically approaches the "saturation resistivity". The obtained saturation resistivities for *hcp*Fe-Si alloys are comparable to those for *hcp* pure Fe at around 100 GPa. Resistivity increase in iron across melting was observed to 70 GPa. Besides, high-*T* thermal diffusivity of iron was obtained to Mbar pressure range utilizing the combination of the thermoreflectance method and LHDAC system. These new results shed light on the problem of the Earth's core conductivity and thermal evolution.

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Keywords: Core, Electrical resistivity, Thermal diffusivity

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Iron diffusion in ε-iron

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Seismic observations in the inner core suggest the variation in the seismic attenuation between the western side and eastern side of the inner core (Monnereau et al., 2010, Iritani et al., 2014, Pejic et al., 2017). Western side shows 2-3 times higher quality factor and smaller attenuation than western side. For the constraint on dynamics of the inner core, it is important to understand the reason why such variation is formed. The inner core is mainly composed of hcp Fe-Ni alloy with some amount of light element(s). Rheological properties of hcp iron (ε -iron) are therefore keys for understanding such seismological features because there is strong relationship between quality factor and viscosity. Taking account into the secular growth of the inner core in the light elements enriched outer core, the investigation of the effect of light element(s) on viscosity of ε -iron is necessary for understanding rheology of ε -iron of the inner core. In this study, we determine self-diffusion of iron in ε -iron at high pressure and temperature and investigate the effect of silicon, as one of candidate of light element, on the diffusivity by means of isotope diffusion method with high pressure experiments. We conducted high pressure experiments at pressures of 40-55 GPa and temperatures of 1300-1400 K in the Kawai-type multianvil apparatus installed at Okayama University. In the experiments, the natural isotopic iron and ^{54}Fe enriched iron was used as diffusion couple together with 3 wt.% silicon bearing iron. Diffusion profiles were obtained by using isotope imaging technique using SIMS1270 at Hokkaido University. Obtained diffusion profiles indicate that self-diffusion coefficient of iron in pure ε -iron is slightly higher than that in silicon bearing iron. This suggest that the observed large variation in quality factor is difficult to be explain by simple alloying by silicon.

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Determination of noble gas partition coefficients between metal and silicate melts under high-pressure and high-temperature conditions

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Noble gas isotopes have been a strong argument for the presence of primordial geochemical reservoir characterized by unradiogenic noble gas signatures (e.g., high $^{3}He/^{4}He$ and low $^{40}Ar/^{36}Ar$ ratios) in the deep earth. There has been much debate about the area holding the primordial noble gases deep in the Earth [1], including that the primordial noble gasses have been retained in the deepest region of the mantle since 4.4 Ga [2], or in the core since the core-mantle separation [3,4]. However, recent understanding of mantle dynamics has revealed difficulty with the isolation within the mantle. On the other hand, the validity of the core as the source of primordial noble gases strongly depends on the quantity of noble gases the core incorporates during its segregation in the magma ocean. Although a few experiments reported partition coefficient of noble gases between liquid iron-rich metal and silicate melt under high pressure and high temperature [4,5], there are still several uncertainties. For a better understanding of the primordial noble gas reservoir, we conducted new experiments to determine noble gas partition coefficients between molten metal and silicate.

In order to investigate noble gas partitioning behavior between the core and mantle, noble gases were dissolved into metal-silicate melts under high temperature and pressure conditions, and then the samples were quenched, recovered, and analyzed for noble gas concentrations. Sample synthesis was performed at the Geodynamics Research Center, Ehime University. Noble-gas doped silicate glass, which was prepared by using a hot isostatic pressing equipment at the Earthquake Research Institute of University of Tokyo, and iron were melted and equilibrated under high pressure and temperature (3-28 GPa, 1700 and 2400 ˚C) using a multianvil apparatus. The sample capsule was cut and the polished surface of the section was investigated with scanning electron microscope and Raman spectroscopy. The chemical compositions of silicate and metal phases were determined with electron microprobe. And then, the noble gases in the silicate phase were extracted by an ultraviolet laser ablation apparatus and analyzed using a noble gas mass spectrometer at the University of Tokyo.

We determined the partition coefficient D, where D = (noble gas in metal phase)/(noble gas in silicate phase), of Ne,Ar, Kr, and Xe at pressures between 3 and8 GPa. The D values ranged from orders of 10^{-6} to 10^{-3}, which is consistent with the previous work [5]. Although we confirmed that the silicates obtained with higher pressures than 10 GPa contain a sufficient amount of noble gas, we have not determined amount of the noble gas in the metals because they are too small to be selectively analyzed with the laser ablation system for noble gas extraction. Moreover, we have not determined He partition coefficient in the all pressure range as it was difficult to retain enough amount of He in high-pressure and temperature apparatus during the experiments. However, the D values are highest for Ar, and lower for in order of Ne, Kr, and Xe, suggesting the D value of 10^{-4} or less for He, which is lower than the previously reported values by two orders of magnitude [4]. Since this estimate is close to the lower limit with which the core holds enough primordial He to supply the present-day degassed mantle [3], further experiments are

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necessary to determine the partition coefficients at higher pressures, at least 30 GPa with which the elemental partition between iron and silicate melt would have occurred during core formation [6].

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Keywords: Noble gas, Partition coefficient, Core, Mantle

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[E] Oral | S (Solid Earth Sciences)：S-IT Science of the Earth's Interior & Techtonophysics

[S-IT26] Interaction and Coevolution of the Core and Mantle in the Earth and Planets

convener:Kenji Ohta(Department of Earth and Planetary Sciences, Tokyo Institute of Technology), Tsuyoshi Iizuka(University of Tokyo), Kenji Kawai(Department of Earth and Planetary Science, School of Science, University of Tokyo), Taku Tsuchiya(Geodynamics Research Center, Ehime University)

Recent observational and experimental investigations have significantly advanced our understanding of the structure and constituent materials of the deep Earth. Yet, even fundamental properties intimately linked with formation and evolution of the planet, such as details of the chemical heterogeneity in the mantle and light elements dissolved in the core, remain unclear. Seismological observations have suggested a vigorous convection in the lower mantle, whereas geochemistry has suggested the presence of stable regions there that hold ancient isotope signatures. The amounts of radioactive isotopes that act as heat sources and drive dynamic behaviors of the deep Earth are also still largely unknown. We provide an opportunity to exchange the achievements and ideas, and encourage persons who try to elucidate these unsolved issues of the core-mantle evolution using various methods, including high-pressure and high-temperature experiments, high-precision geochemical and paleomagnetic analyses, high-resolution geophysical observations, geo-neutrino observations, and large-scale numerical simulations. Papers stimulating an interdisciplinary collaboration relating to establishment of the Japan-SEDI community are also welcomed.

[SIT26-06] Tungsten isotopic compositions of Ethiopian and Aden Bay basalts and the Samoan ocean island: implications for core-mantle interaction in their source

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[SIT26-07] Ultrasonic velocity measurement of deep Earth hydrous phase (Al-bearing phase D) under high pressure and high temperature

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[SIT26-08] Mantle flows in the lowermost mantle beneath the Northern Pacific inferred by 3-D waveform inversion for radially anisotropic structure

*Yuki Suzuki[1], Kenji Kawai[1], Robert J. Geller[1] (1.Department of Earth and Planetary Sciences, Graduate School of Science,The University of Tokyo)

[SIT26-09] Spin transition in (Mg,Fe)O tilt grain boundaries across the Earth’s lower mantle

*Sebastian Ritterbex[1], Taku Tsuchiya[1] (1.Geodynamics Research Center, Ehime University)

[SIT26-10] **First principles study of the lattice thermal conductivity of ferropericlase**

★Invited Papers

*Kaihua He[1] (1.China University of Geosciences)

Tungsten isotopic compositions of Ethiopian and Aden Bay basalts and the Samoan ocean island: implications for core-mantle interaction in their source

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Tungsten has five stable isotopes, which have masses of 180, 182, 183, 184, and 186. Tungsten-182 is produced by β-decay of the extinct nuclide ^{182}Hf, which has a relatively short half-life of 8.9 million years (Vockenhuber *et al.* 2004). Because the abundance of ^{182}Hf is low, the expected variation of ^{182}W in natural samples is extremely small. The ^{182}W/^{184}W isotope ratio is, therefore, commonly shown as m^{182}W in parts per million (ppm) relative to the value for a standard: μ^{182}W (ppm) = (^{182}W/^{184}W$_{sample}$/^{182}W/^{184}W $_{standard}$ −1) ×10^{6}.

Hafnium is a lithophile and W is a siderophile; therefore, during segregation of the Earth's core, Hf remained in the silicate phase and W preferentially partitioned to the metal phase. It is expected that such Hf-W fractionation occurred prior to the extinction of ^{182}Hf on the early Earth and in lunar and meteorite bodies. Various investigators have reported positive and negative anomalies in μ^{182}W values relative to the present-day mantle value (μ^{182}W = 0) in terrestrial rocks. Most ancient rocks older than 2.5 Ga generally show relatively uniform μ^{182}W values of +10 to +15 (Willbold *et al.* 2011, Touboul *et al.* 2012, Touboul *et al.* 2014, Willbold *et al.* 2015, Liu *et al.* 2016, Rizo *et al.* 2016, Dale *et al.* 2017, Mundl *et al.* 2018, Puchtel *et al.* 2018, Reimink *et al.* 2018, Tusch *et al.* 2019). Some komatiites such as Schapenburg and Komati have negative μ^{182}W value and μ^{182}W that is unresolved from modern value, respectively (Touboul *et al.* 2012, Puchtel *et al.* 2018). On the other hand, certain ocean island basalts have negative μ^{182}W values (−25 to 0; *e.g.*, Mundl *et al.* 2017, Mundl-Petermeier *et al.* 2019, Rizo *et al.* 2019, Mundl-Petermeier *et al.* 2020).

In this study, we obtained the highly precise W isotope data for the Ethiopian and Samoan basalts to discuss core-mantle interaction beneath these locations. To identify the small variations in the μ^{182}W values of natural samples, an extremely precise method is required. Recent improvements in our techniques for analysis of W isotopes, including both the chemical procedures used for sample treatment and the mass spectrometric methods (Takamasa et al., under review), may facilitate the detection of small variations in W isotope ratios. We obtained accurate μ^{182}W for a basalt reference material (JB-2). Analysis of the Loihi basalt, which has a high ^{3}He/^{4}He ratio (35Ra), yielded a μ^{182}W value lower than the present-day mantle value, which is consistent with the results of previous study and demonstrate the reliability of the method we developed.

We applied our analytical technique for Samoan basalts. Though Mundl et al. (2017) mentioned that the W and He isotope data are also located on the line produced by the Hawaiian basalts, our data possess a different correlation curve from the Hawaiian one. It indicates that the isotopic signatures of the source of the Samoan in the deep mantle are different from those of the Hawaiian one or that the He and W fractionation occurs in the source regions, probably the core-mantle boundary. Tanaka (2002) reported

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the existence of Ultra Low Velocity Zone (ULVZ) at the lowermost mantle beneath Samoa and unordinary scatter in the lower mantle beneath the Samoan islands, which implies the ascent of lowermost mantle to the surface.

We also analyzed the W isotope of the Ethiopian basalts and the Aden Bay mid-ocean ridge basalts and found the small negative μ^{182}W for them. Similar to the Hawaiian and Samoan basalts, Afar plume, the source of the Ethiopian basalts, which also affects the Aden Bay basalts are likely to be derived from the core-mantle boundary and may contain the core material with the negative μ^{182}W.

Keywords: core-mantle interaction, 182W/184W isotope, Ethiopian basalt, Samoan basalt, Hf-W decay system, He isotope

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Ultrasonic velocity measurement of deep Earth hydrous phase (Al-bearing phase D) under high pressure and high temperature

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Water plays an important role in the Earth's interior, which affects the physical and chemical properties of the surrounding materials, for instance, elasticity, rheology, electrical conductivity, and melting behaviors (e.g. [1,2]). The dense hydrous magnesium silicates (DHMSs) are the primary water carriers into the mantle transition zone (MTZ) and could play an important role in delivering water down to the middle part of the lower mantle (LM) (e.g. [3,4]). Among DHMSs, phase D (PhD) is regarded as a potential carrier of water from the MTZ to the LM [4,5]. Recently, it was clarified that PhD can accommodate significant amount of Al_2O_3 (56.6 wt%) and the Al-bearing PhD is stable up to 2273 K at 26 GPa [6], which may possibly exist in a realistic slab composition and temperature.

To interpret seismic anomalies related to the presence of hydrated regions, direct velocity measurement of hydrous phases is needed. However, the sound velocity of PhD has been poorly investigated, because ultrasonic measurement requires well sintered samples with high purity, which was difficult to achieve for PhD. In this work, we succeeded to synthesize well-sintered Al-bearing PhD, and report the longitudinal (V_P) and shear (V_S) velocities, as well as the density of the Al-bearing PhD up to 22 GPa and 1300 K.

A polycrystalline Al-bearing PhD sample was synthesized at 24 GPa and 1373 K for 1 hour, from a mixture of MgO, SiO_2, $Mg(OH)_2$ and $Al(OH)_3$ by using the 2000-ton Kawai-type apparatus installed at the Geodynamics Research Center (GRC), Ehime University. The recovered sample appeared well-sintered, which is accompanied by little porosity, chemical homogeneity, and is free of accessory phase.

In situ ultrasonic experiments were conducted at the BL04B1 beamline of SPring-8 at high pressures and high temperatures up to 22 GPa and 1300 K. The sample was first squeezed at room temperature and then heated to high temperature. Then the temperature was decreased to 300 K in step of 200 K. The press load was increased after the first data collection cycle, and then, the temperature was increased to high temperature to start another data collection cycle during cooling.

The room temperature data up to 20.5 GPa were fitted to a third-order Birch-Murnaghan equation of state and yielded K_{T0} = 143 (5) GPa, and K_{T0}' = 5.8 (7), which is much lower K_{T0} than that of Mg-PhD (K_{T0} = 166 (3) GPa). The compressional (V_P) and shear (V_S) velocities increase with increasing pressure while they decrease with increasing temperature up to 22 GPa and 1300 K. Modeled velocities of Al-bearing PhD in hydrous pyrolite along normal mantle geotherm are calculated and will be presented.

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Keywords: high pressure hydrous phase, Elastic wave velocity measurement, deep Earth, high pressure and high temperature

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Mantle flows in the lowermost mantle beneath the Northern Pacific inferred by 3-D waveform inversion for radially anisotropic structure

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The lowermost several hundred km of the Earth's mantle immediately above the core-mantle boundary (CMB), commonly called the D" region, is the thermal boundary layer (TBL) of mantle convection and plays a major role in governing the modality of convection in the mantle. The D" region, especially beneath the subduction zones, provides clues for understanding the dynamics of the Earth's mantle, because thermally and chemically distinct slab materials can perturb the temperature and mantle flow.

The D" region beneath the northern Pacific is of particular geodynamical interest, because the paleo-Izanagi and present Pacific plates have been subducting beneath the northwestern margin of Laurentia since ~250 million years ago (Young et al. 2019), which implies that paleoslabs could have reached the lowermost mantle. Suzuki et al. (2016) inferred the detailed 3-D isotropic S-velocity structure in the lowermost 400 km of the mantle beneath the northern Pacific and found a sheet-like lateral high-velocity which they interpreted as paleoslabs and a prominent low-velocity anomaly adjacent to the high-velocity anomaly interpreted as a passive plume induced by slab sinking. In order to verify the above interpretation and also infer flow direction, it is required to infer the 3-D anisotropic S-velocity structure beneath the northern Pacific.

We conduct waveform inversion to infer the 3-D variation of the TI (transverse isotropy) elastic parameters such as the effective isotropic V_S and anisotropic parameter ξ straightforwardly in the lowermost mantle. We use the full USArray data which provide dense coverage of the D" region beneath the Northern Pacific. We used deep- and intermediate-focus events recorded at epicentral distances $70<\Delta<100$. The use of relatively short-period (20–200 s) radial and transverse components data for the S/ScS time window which is sensitive to the D" structure makes it possible to image smaller-scale structure than previous global tomography studies. We also conduct several tests to confirm the robustness of the inversion results.

The inferred anisotropic structure is considered as due to deformation-induced alignment of crystal caused by mantle flow for either Mg-perovskite, Mg-post-perovskite, ferro-periclase or a combination thereof because of the high-stress condition in the thermal boundary layer of the mantle convection. When we assume the dominant glide system of each mineral under the lowermost mantle conditions according to previous experimental results, the observed anisotropy can be interpreted as horizontal and vertical flow related to the subducted paleo-Izanagi plate and the upwelling flow of hot material, respectively.

Keywords: the lowermost mantle, anisotropy, waveform inversion

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Spin transition in (Mg,Fe)O tilt grain boundaries across the Earth's lower mantle

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Iron-bearing MgO periclase is the second most abundant phase of the Earth's lower mantle and is relatively ductile compared to the lower mantle silicates (Girard *et al*. 2016). Its rheological behavior is thus expected to play an important role in the dynamics of the Earth. Ferrous iron in ferropericlase undergoes an electronic spin transition across the pressure range of the lower mantle (*e.g*. Tsuchiya *et al*. 2006). Previous studies reported that changes in iron spin state induce an anomalous compressibility of ferropericlase across the spin transition, which is thought to affect its mechanical strength (*e.g* Wentzcovitch *et al*. 2009; Wenk *et al*. 2009). Lower mantle ferropericlase however is polycrystalline, making the properties of grain boundaries critical to describe its mechanical behavior, important to understand plastic deformation and seismic attenuation. Yet, little is known about the effect of the pressure-induced iron spin transition on the properties of grain boundaries in ferropericlase.

Prior to understanding the kinematics of iron-bearing grain boundaries in ferropericlase, their structural properties must be established at lower mantle conditions. Here, we apply a density functional based first-principles approach combined with the Hubbard type correction to the onsite Coulomb interaction between the iron 3*d*-orbitals to describe the correct electronic structures of ferropericlase. This method has been used to determine the pressure-induced spin transition of ferrous iron in the Σ5 {310}/[001] tilt grain boundaries, enabling variation in the iron grain boundary site configurations and local chemistry alike as a function of pressure.

We quantify the iron segregation energetics into the Σ5 tilt grain boundary and demonstrate their ability to host iron at specific boundary sites, affecting the grain boundary formation energies and volumes. We show that the resulting spin transition pressure is significantly higher than that of monocrystalline ferropericlase, suggesting a non-homogenous iron spin transition in polycrystalline ferropericlase throughout the pressure range of the lower mantle. The latter should be taken into account regarding the mechanical behavior of polycrystalline ferropericlase across the lower mantle.

Keywords: Spin transition, Grain boundaries, Ferropericlase

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First principles study of the lattice thermal conductivity of ferropericlase

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The thermal conductivity of minerals governs heat flux, which partially controls the thermal evolution and dynamics of the Earth’ s lower mantle. Although much progress has been achieved regarding the lattice thermal conductivity (k_{latt}) of periclase, perovskite (Pv) and post-perovskite (pPv) at high temperature and high pressure, the effects of iron incorporation on k_{latt} have not been elucidated. In this study, we carry out an extensive first principles study to calculate k_{latt} of ferropericlase (Fp) and discuss the mechanisms of variation in k_{latt} by incorporation of ferrous iron. Our calculations show that k_{latt} is significantly reduced by the incorporation of ferrous iron compared to that of iron-free periclase, which is consistent with previous measurements. Three different iron concentrations were considered in this study, and it can be found that a further decrease is predicted for increased ferrous iron content. Moreover, it is worth noting that the high spin (HS) to low spin (LS) transition results in an enhancement of k_{latt}.

Generally, under mantle conditions, C_V approaches the classical value k_B and does not influence k_{latt}. The volumes of HS Fp and LS Fp have slight changes compared to that of MgO. Surely, a weak variation in volume is not sufficient to explain the significant reduction in k_{latt} (~92%). The phonon dispersions indicate that the phonon frequencies and group velocities decrease by approximately 25% for both transversal and longitudinal acoustic modes due to the inclusion of ferrous iron, which then contribute to the reduction in k_{latt}. Stronger scattering rates are obtained for both HS Fp and LS Fp with respect to that of MgO, which also leads to a reduction in k_{latt}. Therefore, group velocities decrease and stronger scattering rates are the major factors for significant decrease in k_{latt}.

The scattering rates of Fp in the LS state are slightly smaller than those in the HS state; meanwhile, the phonon dispersion also indicates that the velocities in the longitudinal acoustic modes increase modestly with the spin transition, and those in the transverse acoustic modes are unaffected. The above mentioned characteristics account for the enhancement in k_{latt} by the spin transition.

k_{latt} of iron-bearing periclase in the mixed spin (MS) state is calculated by scaling relation and exhibits a strong anomaly along the spin transition region. The total k_{latt} of a pyrolitic composition along a geotherm shows a weak anomaly between 750 and 1500 km. Moreover, a reduction in k_{latt} at the CMB is expected due to the MS states.

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Keywords: First principles, Lattice thermal conductivity , Ferropericlase, Spin transition

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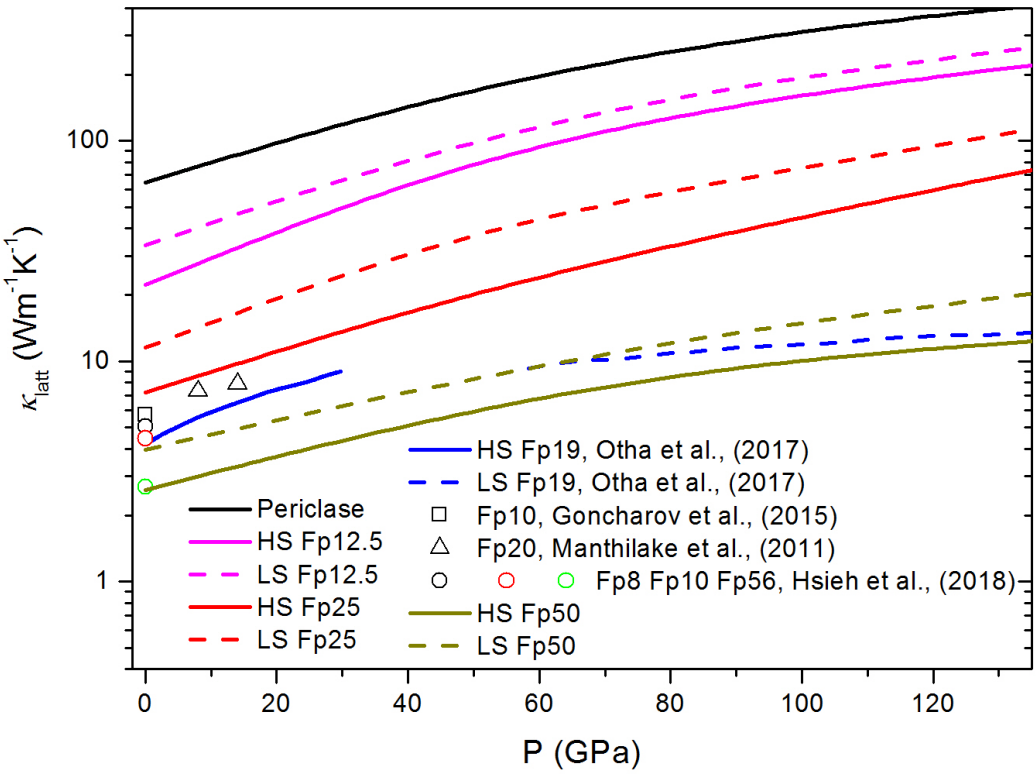

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[E] Oral | S (Solid Earth Sciences)：S-IT Science of the Earth's Interior & Techtonophysics

[S-IT26] Interaction and Coevolution of the Core and Mantle in the Earth and Planets

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Recent observational and experimental investigations have significantly advanced our understanding of the structure and constituent materials of the deep Earth. Yet, even fundamental properties intimately linked with formation and evolution of the planet, such as details of the chemical heterogeneity in the mantle and light elements dissolved in the core, remain unclear. Seismological observations have suggested a vigorous convection in the lower mantle, whereas geochemistry has suggested the presence of stable regions there that hold ancient isotope signatures. The amounts of radioactive isotopes that act as heat sources and drive dynamic behaviors of the deep Earth are also still largely unknown. We provide an opportunity to exchange the achievements and ideas, and encourage persons who try to elucidate these unsolved issues of the core-mantle evolution using various methods, including high-pressure and high-temperature experiments, high-precision geochemical and paleomagnetic analyses, high-resolution geophysical observations, geo-neutrino observations, and large-scale numerical simulations. Papers stimulating an interdisciplinary collaboration relating to establishment of the Japan-SEDI community are also welcomed.

[SIT26-11] Assessment and implication on the thermal and chemical state of the Earth’s core in the 1-D radial convective structure tracking over 4 billion years

*Takashi Nakagawa[1] (1.Department of Earth Sciences, The University of Hong Kong)

[SIT26-12] Elastic wave velocity of Al-bearing anhydrous bridgmanites under high pressure and high temperature

*Masamichi Noda[1], Toru Inoue[1], Steeve GREAUX[2], Chaowen Xu[3], Hideharu Kuwahara[2], Wei Sun[2], Yuji Higo[4] (1.Graduate School of Science, Hiroshima University, 2.Geodynamics Research Center, Ehime University, 3.Institute of earthquake forecasting, CEA, 4.JASRI)

[SIT26-13] **Detector study for geo-neutrino directional measurement**

*Naoya Maemura[1], Hiroko Watanabe[1] (1.Tohoku University)

[SIT26-14] Ratest results of geo-neutrino measurement with KamLAND

*Hiroko Watanabe[1] (1.Research Center for Neutrino Science, Tohoku University)

[SIT26-15] Is there primordial reservoir in lower mantle?

*Takashi Yoshino[1] (1.Institute for Planetary Materials, Okayama University)

Assessment and implication on the thermal and chemical state of the Earth’s core in the 1-D radial convective structure tracking over 4 billion years

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We investigate the possibility on finding the stable region beneath the core-mantle boundary (CMB) in one-dimensional radial convective structure of the Earth’s core as result of thermal and chemical evolution of the Earth’s core for over 4 billion years. With the realistic density profile in Earth’s core and time evolution for 4.6 billion years, the stable region may be found between 9.8 and 11.3 TW of the present-day CMB heat flow for no chemical coupling across the CMB and between 11.1 TW and 13.2 TW of the present-day CMB heat flow with the chemical coupling across the CMB. Those ranges are shifted to much higher value of CMB heat flow compared to the previous assessment of the convective structure of the Earth’s core with a simplified approach (Takehiro and Sasaki, 2018). For matching the current constraint of the CMB heat flow and geophysical observations on the stable region beneath the CMB, the thermal conductivity of the Earth’s core may be increased up to the upper-bound of experimental constraint (~220 W/m/K). Such a high thermal conductivity may be unlikely to have the thermal convection of the Earth’s core. Hence, the additional power source of dynamo actions would be required for getting the magnetic field in earlier Earth’s core, that is, the compositional convection caused by the dissolution of light elements in core alloy. Although this type of compositional convection seems to be unlikely to form the stable region beneath the CMB, the time-scale of chemical state of the Earth’s core changing from the over-saturated to under-saturated condition is very significant for finding the stable region at the present.

Keywords: Earth's core, Stable region, convective structure

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Elastic wave velocity of Al-bearing anhydrous bridgmanites under high pressure and high temperature

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Bridgmanite (Brg), the endmember formula is $MgSiO_3$, is considered to be a major constituent mineral in the Earth's lower mantle, and the most abundant mineral in the Earth. Al is one of the abundant elements in the Earth's interior, and in case of the pyrolite composition, almost Al in lower mantle can be incorporated in Brg in anhydrous condition (e.g. Irifune et al., 1994). Zhang and Weidner (1999) reported that the bulk moduli of Al bearing Brg (Al-Brg) (Al 0.1 pfu, O=3) is more than 10% smaller than that of Mg-endmember Brg (Mg-Brg). Moreover, hydrous Al-Brg was experimentally synthesized (Inoue et al.,2014), although Brg is considered as anhydrous mineral so far. Therefore, it is very important to clarify the physico-chemical properties of Al-Brg in understanding dynamics of the Earth's interior.
Our recent knowledge suggests that there are three types of Al substitution mechanisms, Tschermak and oxygen vacancy substitutions and hydrous substitution. In this study, we focused on anhydrous Al-Brg, because the anhydrous type, pure Tschermak and oxygen vacancy substitutions Brg, has not been reported so far in low Al content, when we checked the previous reported compositions carefully (e.g. Irifune et al, 1996; Kubo and Akaogi, 2000). The previous studies have used powder samples as the starting materials, so we considered that chemical compositions of Al-Brg were shifted to hydrous type by partial hydration by absorbed water.
The high pressure synthesis experiments were conducted at 28 GPa and 1600-1700℃ for 1hour using a Kawai-type multi-anvil apparatus. Glass rods were used as the starting materials to eliminate the absorbed water on the sample surface. Moreover, the glass rods were enclosed in a metal capsule to prevent the water incorporation from the surrounding cell assembly. In addition, all parts of the cell assembly were dried just before the synthesis experiments. As the results, we could synthesize the pure Tschermak and oxygen vacancy substitutions Brg, and obtained almost single phase and large volume of Al-Brg for the elastic wave velocity measurement using the ultrasonic interferometry. The elastic wave velocity measurements under high pressure and high temperature were conducted at BL04B1 in SPring-8 using Kawai-type multi-anvil apparatus (SPEED-1500). We investigated the elastic wave velocity of the Tschermak type (Al 0.1 pfu, O=3) and the oxygen vacancy type (Al 0.025 pfu, total cation of 2). Date acquisitions were carried out at pressures up to ~30 GPa and temperatures up to 1100 K. These results show that the V_P is slower than that of Mg-Brg, whereas the V_S is almost same of that one. We confirmed the effect of Al substitution for elastic wave velocity at the uppermost lower mantle pressure.

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Keywords: Al-bearing anhydrous bridgmanites, Elastic wave velocity, Ultrasonic interferometry, The uppermost lower mantle pressure

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Detector study for geo-neutrino directional measurement

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Antineutrinos are very permeable and can penetrate even astronomical objects with their source information. Observation of antineutrinos became a new tool to get unique information. Liquid scintillator (LS) detector is one of the great tools to detect antineutrinos. Although the LS detector has a power to investigate comprehensive anti-neutrino sources, such as the Earth, universe and nuclear reactors, it can not measure the direction of incoming antineutrinos in principle due to the high miss-identification in a neutrino’ s track reconstruction. In particular, direction-sensitive measurement of geo-neutrinos (antineutrinos emitted from radioactive isotopes in the Earth) can separate crust and mantle contributions. This technology allows us to know further information on the Earth's deep interior.The purpose of this study is to develop a new technology of anti-neutrino directional measurement. We have developed imaging detector which can improve accuracy of neutrino's track reconstruction.Three-dimensional reconstruction of the emission position in LS by gamma-rays from a 60Co source was performed using a prototype detector consisting of a 30L Li-loaded LS and two imaging detectors. The three-dimensional emission points are reconstructed by the data from two imaging detectors in consideration of the attenuation length of LS and the solid angle.We did the experiment in two cases (see case1 and case2) and determined that event-by-event and integrated emission points were successfully reconstructed in the different source position cases.The three-dimensional emission points are reconstructed by the data from two imaging detectors in consideration of the attenuation length of LS and the solid angle.We determined that event-by-event and integrated emission points were successfully reconstructed in the different source position cases. (see Imaging result)

Keywords: geo-neutrino, mantle

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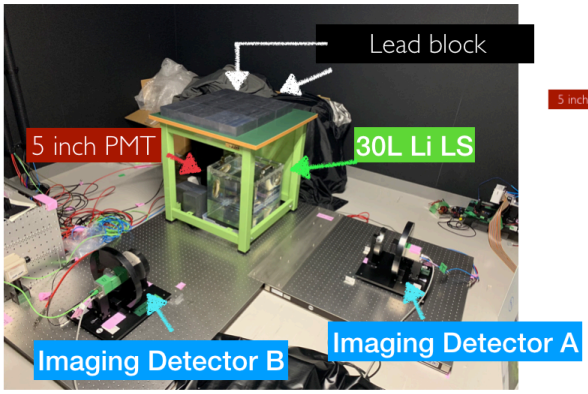
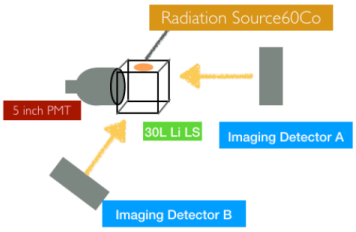


▶case1



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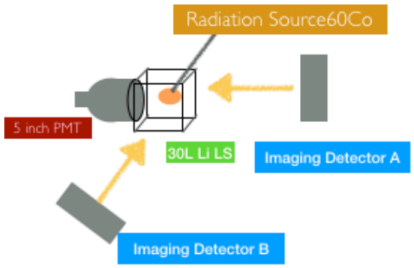
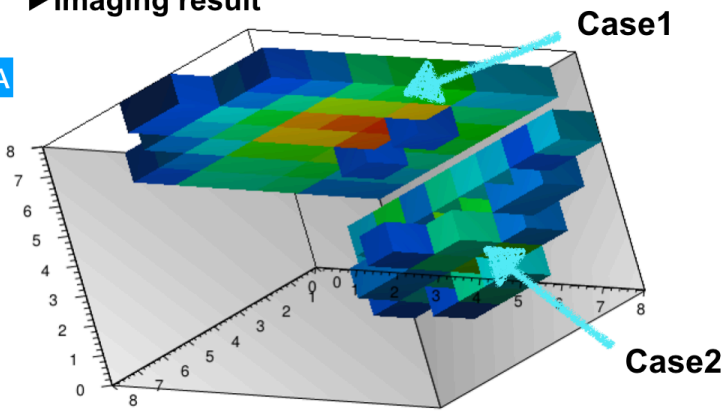


▶Imaging result



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Ratest results of geo-neutrino measurement with KamLAND

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KamLAND (**Kam**ioka **L**iquid sintillator **A**nti-**N**eutrino **D**etector) has been marked by the ability to detect comprehensive anti-neutrino signals in the wide energy range with 1,000-ton ultra pure liquid scintillator since its construction, 2002. Given the neutrino oscillation parameters are measured precisely and the properties of neutrinos are gradually characterized, recently the neutrinos started to be used as a tool to investigate deep interior of astronomical objects. Anti-neutrinos emitted from radioactive isotopes inside the Earth, geo-neutrinos, bring unique and direct information on the Earth’ s composition, which relate to the fundamental mysteries of its heat balance and thermal evolution.
KamLAND has been stably observing geo-neutrinos with highest sensitivity since it made the world's first observation in 2005. Owing to the recent long-term shutdown of Japanese reactors, the flux of reactor anti-neutrinos, which was most serious background for geo-neutrino observation, was significantly decreased. Our decade-long observation, including the reactor-off period, has potential for providing useful information on deep interior of the Earth.
In this presentation, the latest results of geo-neutrino observation with KamLAND will be presented.

Keywords: geo-neutrino, radioactive elements in the Earth, Earth's thermal evolution

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Is there primordial reservoir in lower mantle?

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Is there primordial reservoir in lower mantle?

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Tungsten isotope composition provide important constraints on the sources of the ocean-island basalts (OIB). If the core formation occurred within the first 60 Myr of the solar system formation, the silicate mantle should be characterized by high Hf/W and positive μ^{182}W, whereas the metallic core has very low Hf/W and negative μ^{182}W. Recently μ^{182}W of the young OIBs with high ^{3}He/^{4}He have shown two distinct features: positive μ^{182}W from Phanerozoic flood basalts (Ontong Java and Baffin Bay) indicating a presence of primordial reservoir [1], and negative μ^{182}W from modern OIBs (Hawaii, Somoa, Iceland) [2]. However, later study suggested that a positive μ^{182}W anomaly can potentially be caused by nuclear shift isotope fractionation affecting primarily the odd isotope (^{183}W) and basalts from Ontong Java have also shown negative μ^{182}W anomaly [3]. Thus, there is no evidence from tungsten isotopes to constrain the existence of a primordial reservoir in the lower mantle. On the other hand, negative μ^{182}W anomaly becomes a universal feature of the modern OIBs. One possibility to produce the negative μ^{182}W is chemical interaction of the mantle with the Earth’s outer core. An experimental study has shown that W grain boundary diffusion in the lower mantle phases is quite fast process and displays strong temperature dependence [4]. W isotope can be modified significantly at the base of the lower mantle through the whole Earth’s history. When highly-oxidized slabs accumulate at the CMB oxidizing the outer core at the interface, a large W flux with negative μ^{182}W can be added to the silicate mantle. As a result, the source region of the OIB would be effectively modified to a negative μ^{182}W. A good correlation of μ^{182}W and ^{3}He/^{4}He observed in modern OIBs invokes that ^{3}He is also provided by the outer core liquid. In this case, there is no necessity to envision a primordial reservoir in the deep lower mantle. Future studies should be accompanied by coupled investigations with diffusion of ^{3}He/^{4}He to further constrain core-mantle interaction.

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Keywords: core-mantle boundary, tungsten isotope, diffusion, penetration

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[E] Oral | S (Solid Earth Sciences)：S-IT Science of the Earth's Interior & Techtonophysics

[S-IT27] Oceanic lithosphere and asthenosphere

convener:Nozomu Takeuchi(Earthquake Research Institute, University of Tokyo), Ban-Yuan Kuo(Institute of Earth Sciences, Academia Sinica), Rob L Evans(Woods Hole Oceanographic Institution), Younghee Kim(Seoul National University)

The oceanic lithosphere/asthenosphere system (LAS) is one of the most fundamental features of plate tectonics. In recent years, the elucidation of the oceanic lithosphere/asthenosphere system has become one of the hot topics in solid earth science. New data from the ocean floor are being extensively obtained under the Pacific Array initiative (http://eri-ndc.eri.u-tokyo.ac.jp/PacificArray/) and others, and a great variety of views are proposed and discussed. In this session, we will discuss on observation technologies, views of the oceanic lithosphere/asthenosphere system, the strategies for interpretation of the observations (including seismic and/or electrical conductivity anisotropy), constraints/ideas on the role and abundance of water/melt in the mantle (including the transition zone), and other related topics for elucidating this enigmatic system. We call for contributions from diverse fields, including but not limited to seismology, magnetotellurics, petrology/mineralogy, dynamical modelling, and mineral physics.

[SIT27-01] *Pacific Array* update 2020

*Hitoshi Kawakatsu[1], - the international Pacific Array team (1.Earthquake Research Institute, The University of Tokyo)

[SIT27-02] Olivine fabric development during Newtonian (diffusion creep) corner flow.

*NAHYEON KIM[1], Takehiko Hiraga[1] (1.Earthquake Research Institute, University of Tokyo)

[SIT27-03] The seismic structure of the oldest Pacific: Preliminary results from the broadband Rayleigh-wave dispersion analysis of the Pacific Array, Oldest-1

*Yuki Kawano[1], Takehi Isse[1], Akiko Takeo[1], Hitoshi Kawakatsu[1], Hajime Shiobara[1], Nozomu Takeuchi[1], Hiroko Sugioka[2], YoungHee Kim[3], Hisashi Utada[1], Sang-Mook Lee[3] (1.Earthquake Research Institute, The University of Tokyo, 2.Kobe University, 3.Seoul National University)

[SIT27-05] A peridotite xenolith from garnet-stability field beneath Aitutaki (Cook islands): an implication for small-scale convection

*Norikatsu Akizawa[1], Kazuhito Ozawa[2], Simon Richard Wallis[2], Akihiro Tamura[3], Akira Ishikawa[4], Tetsu Kogiso[5] (1.Atmosphere and Ocean Research Institute, The University of Tokyo, 2.Department of Earth and Planetary Science, The University of Tokyo, 3.Faculty of Geosciences and Civil Engineering, Kanazawa University, 4.Department of Earth and Planetary Sciences, Tokyo Institute and Technology, 5.Graduate School of Human and Environmental Studies, Kyoto University)

[SIT27-06] Three dimensional shear wave structure in the upper mantle beneath the oldest Pacific plate

*Takehi Isse[1], Hitoshi Kawakatsu[1], Hajime Shiobara[1], Nozomu Takeuchi[1], Hiroko Sugioka[2], Younghee Kim[3], Hisashi Utada[1], Sang-Mook Lee[3], Kazunori Yoshizawa[4] (1.Earthquake Research Institute, the University of Tokyo, 2.Department of Planetology, Kobe University, 3.Seoul National University, 4.Faculty of Science, Hokkaido University)

Pacific Array update 2020

*Hitoshi Kawakatsu[1], - the international Pacific Array team

1. Earthquake Research Institute, The University of Tokyo

With a simple crustal structure and short geological history, ocean basins provide an unblemished view into mantle dynamics, including convective flow and melting processes that control deformation and evolution of Earth’ s surface. With the full spectrum of plate-boundary processes and abundant mid-plate volcanism sourced deep in the mantle, the Pacific basin provides an outstanding setting to explore connections between shallow dynamics and the deep interior. Exploiting advances in seafloor instrumentation, research groups in Japan, the US, and elsewhere have demonstrated the utility of broadband ocean-bottom seismic and EM arrays for providing new, high-resolution constraints on mantle structure and dynamics. These activities have coalesced into the international collaboration Pacific Array, which seeks to merge individual efforts into a large-scale "array of arrays" that will effectively cover the entire Pacific basin diachronously over a decadal time scale.

Between 2018-2019, this initiative moves forward with three new arrays. The first 30-station seismic array (young-ORCA) was deployed April 2018 –May 2019 on 40-Ma seafloor northeast of the Marquesas Islands by the US team, which was followed by another one (old-ORCA) for Nov 2019 –Dec 2020 on 110-Ma seafloor southwest of Tahiti. Data from both arrays will be openly available upon recovery. The second 12-seismic and 8-EM array was deployed in Oct-Nov, 2018 –Nov, 2019 as a collaboration between Japan and South Korea on the oldest seafloor in the western Pacific (Oldest1). Also two new arrays (at around the Galapagos Islands and the old H_2O seafloor observatory) have been funded by NSF. Further a second array on the oldest seafloor (Oldest2) at east of Oldest1 has been proposed as a collaboration between Japan and Taiwan. These new arrays are planned to be deployed in early 2021. We summarize these experiments possibly with early results, and describe goals, news and plans for expanding Pacific Array through broader participation of the international seismology and geodynamics community. Updated information can be found at http://eri-ndc.eri.u-tokyo.ac.jp/PacificArray/ .

Keywords: OBS, oceanic lithosphere, asthenosphere

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Olivine fabric development during Newtonian (diffusion creep) corner flow.

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Lattice-preferred orientation (LPO) is produced by the alignment of anisotropic minerals (e.g., olivine) and is regarded as the main reason for seismic anisotropy observed in the upper mantle. There are several mechanisms suggested for the LPO development (e.g., dislocation creep, dislocation-accommodated diffusion creep and diffusion creep) and our group has shown it develops during diffusion creep which is sensitive to the parameter of temperature as the mechanism of which involves grain rotation and preferential grain boundary sliding on low-index grain boundaries of tabular shaped olivine that occurs at higher temperatures (>0.92 Ts) (Miyazaki et al. 2013; Maruyama and Hiraga 2017 a and b).

To investigate the application of the LPO development during diffusion creep to various tectonic settings including mid-ocean ridges (MOR) where corner flow is introduced by the association of upwelling mantle flow and plate-driven motion, we did channel angular pressing shear deformation experiments called ECAP (Equal-Channel Angular Pressing) test. To conduct deformation experiments under diffusion creep in the laboratory, we synthesized fine-grained (~1 μm) forsterite + diopside specimen (Koizumi et al. 2010). Experimental temperatures were high enough to develop tabular-shaped forsterite grains (T > 0.92Ts). After experiments, we analyzed the LPO development and its evolution along a streamline of corner-flow. The forsterite grains away from the corner-flow region show relatively random fabric (J ~ 1.47), while it gets increasing along the streamline and gets maximum (J ~4.96) with indicating A-type LPO at the end of the corner-flow. The development of LPO is characterized by continuous rotation and clustering of forsterite a-axes along the streamline. From marker analysis, most of the strain was achieved during the corner flow, which also has been suggested by several studies of numerical modeling of mantle flow beneath MOR (e.g., Mckenzie. 1979).

Keywords: Mantle corner flow, Olivine fabric , Diffusion creep, Seismic anisotropy, Lattice-preferred orientation

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The seismic structure of the oldest Pacific: Preliminary results from the broadband Rayleigh-wave dispersion analysis of the Pacific Array, Oldest-1

*Yuki Kawano[1], Takehi Isse[1], Akiko Takeo[1], Hitoshi Kawakatsu[1], Hajime Shiobara[1], Nozomu Takeuchi[1], Hiroko Sugioka[2], YoungHee Kim[3], Hisashi Utada[1], Sang-Mook Lee[3]

1. Earthquake Research Institute, The University of Tokyo, 2. Kobe University, 3. Seoul National University

The international collaborative initiative, the Pacific Array, was launched in 2018. One of the aims of this initiative is to reveal the evolution process of the Pacific plate. To achieve this goal, the Oldest-1 array, situated on the 170 Ma seafloor of the Pacific Ocean off the Mariana trench, plays an essential role since its lithosphere-asthenosphere system is considered to record the entire evolution process of the Pacific plate from its birth to present. In November 2018, the Japan–South Korea joint team deployed 12 broadband ocean bottom seismometers and 7 ocean bottom electro-magnetometers that were successfully recovered a year later. We present the initial result of the seismic analysis of the uppermost mantle structure revealed by the Oldest-1 array via the broadband Rayleigh-wave dispersion analysis. At short periods (<30 s), we measure fundamental-mode and first-overtone Rayleigh-wave phase velocities using ambient noise cross-correlations. At long periods (>30 s), we measure the teleseismic Rayleigh-wave phase velocities. We then invert the broadband dispersion curves for a one-dimensional isotropic βv (Vsv) structure. A preliminary result using tilt-noise corrected data indicates that the structure shallower than 150 km is similar to the one obtained for the 140 Ma Northwestern Pacific seafloor by the NOMan project (Takeo et al., 2018, G-Cubed). We plan to incorporate compliance-noise corrected data for the teleseismic analysis of the deeper structure, as well as to measure azimuthal anisotropy.

Keywords: Lithosphere-asthenosphere system, Pacific Array, Broadband ocean bottom seismometer, Broadband dispersion analysis

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A peridotite xenolith from garnet-stability field beneath Aitutaki (Cook islands): an implication for small-scale convection

*Norikatsu Akizawa[1], Kazuhito Ozawa[2], Simon Richard Wallis[2], Akihiro Tamura[3], Akira Ishikawa[4], Tetsu Kogiso[5]

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Garnet peridotite xenoliths have been rarely reported from suboceanic mantle. Because of their rare occurrence, they provide precious petrographic and chemical information of deep suboceanic mantle, and contribute to our understanding of shallow mantle dynamics. We examined a peridotite xenoliths collected at Aitutaki, a member of the Cook-Austral volcanic chain, which are shown to be derived from the garnet-stability field in spite of their absence in garnet. The peridotite xenolith contains reddish fine-grained (<5 μm) mineral aggregate (FMA) consisting of olivine, plagioclase, spinel, native iron, and nepheline. The bulk major- and trace-element compositions of FMAs are close to those of pyrope-rich garnet. Chromian spinels enclosed in FMAs forming a cluster of grains apparently isolated in the thin section (2D) have similar crystallographic orientation, indicating that the cluster is a single crystal with extremely irregular 3D morphology. These observations support that the FMA were decomposed garnet and that the aluminous spinel was partially transformed into garnet leaving unreacted Cr-rich component (chromian spinel). Orthopyroxene and clinopyroxene are very homogeneous, but there are slight but discernible chemical zonings in pyroxenes, which are characterized by increase in Al, Ca, and Cr from the grain center to the rim for orthopyroxene and increase in Al, decrease in Ca, and M-shaped in Cr for clinopyroxene. The Al and Ca zoning patterns are modeled by diffusional exchange with the other phases induced by pressure and temperature changes. The results show that the peridotite xenolith underwent isothermal decompression on the timescale longer than millions of years. We propose that the peridotite xenolith had been once dragged down and then brought up by small-scale convection (SSC) roll aligning with oceanic plate motion beneath the Cook-Austral volcanic chain. The garnet was decomposed into FMAs triggered by influx of strongly reducing carbonaceous melt/fluid shortly before the xenolith extraction.

Keywords: Garnet peridotite, Nephelinite, Native iron, Carbonaceous melt, Carbonatitic metasomatism

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Three dimensional shear wave structure in the upper mantle beneath the oldest Pacific plate

*Takehi Isse[1], Hitoshi Kawakatsu[1], Hajime Shiobara[1], Nozomu Takeuchi[1], Hiroko Sugioka[2], Younghee Kim[3], Hisashi Utada[1], Sang-Mook Lee[3], Kazunori Yoshizawa[4]

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Pacific Array, which is a large-scale virtual array experiment covering the entire Pacific Ocean by repeating 1-year seafloor observations in various part of the ocean to reveal the physical nature of the lithosphere-asthenosphere system (LAS), has been launched in 2018.
As a first part of the Pacific Array, Japan-South Korea joint group conducted a one-year seafloor observation (Oldest1 Array) with 12 broadband ocean bottom seismometers and 7 ocean bottom electro-magnetometers in 2018 on the oldest seafloor in the Pacific ocean, located 1000 km east of the Guam island, to reveal the evolution of the oldest part of the Pacific plate. We measured the phase speed dispersions of Love and Rayleigh waves up to 4th higher mode with Oldest1 Array data, as well as available broadband data in the Pacific Ocean to determine the three dimensional upper mantle shear wave structure beneath the whole Pacific Ocean. The obtained model suggests that large-scale anomalies are similar to our previous model (Isse et al., 2019, EPSL). However, beneath the Oldest1 Array, we found that lithosphere is faster and thicker than those in the previous model. We plan to show preliminary results focused on small scale anomalies in the oldest Pacific Ocean.

Keywords: lithosphere-asthenosphere system, Pacific Array, surface wave tomography

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[E] Oral | S (Solid Earth Sciences)：S-IT Science of the Earth's Interior & Techtonophysics

[S-IT27] Oceanic lithosphere and asthenosphere

convener:Nozomu Takeuchi(Earthquake Research Institute, University of Tokyo), Ban-Yuan Kuo(Institute of Earth Sciences, Academia Sinica), Rob L Evans(Woods Hole Oceanographic Institution), Younghee Kim(Seoul National University)

The oceanic lithosphere/asthenosphere system (LAS) is one of the most fundamental features of plate tectonics. In recent years, the elucidation of the oceanic lithosphere/asthenosphere system has become one of the hot topics in solid earth science. New data from the ocean floor are being extensively obtained under the Pacific Array initiative (http://eri-ndc.eri.u-tokyo.ac.jp/PacificArray/) and others, and a great variety of views are proposed and discussed. In this session, we will discuss on observation technologies, views of the oceanic lithosphere/asthenosphere system, the strategies for interpretation of the observations (including seismic and/or electrical conductivity anisotropy), constraints/ideas on the role and abundance of water/melt in the mantle (including the transition zone), and other related topics for elucidating this enigmatic system. We call for contributions from diverse fields, including but not limited to seismology, magnetotellurics, petrology/mineralogy, dynamical modelling, and mineral physics.

[SIT27-07] A comprehensive portrait of the central Pacific lithosphere-asthenosphere system from NoMelt seafloor geophysical observations

James Gaherty[2], Joshua Russell[3], Hannah Mark[4], Zhitu Ma[5], Colleen Dalton[5], Daniel Lizarralde[1], Greg Hirth[5], John Collins[1], *Rob L Evans[1] (1.Dept of Geology and Geophysics, Woods Hole Oceanographic Institution, 2.School of Earth and Sustainability, Northern Arizona University, 3.Columbia Univ., Lamont Doherty Earth Observatory, 4.Dept. of Earth and Planetary Sciences, Washington University, St. Louis, 5.Dept. of Earth, Environmental, and Planetary Sciences, Brown Univ)

[SIT27-08] Seismic discontinuity at lithosphere-asthenosphere boundary predicted from laboratory-based anelasticity model

Hatsuki Yamauchi[1], *Yasuko Takei[1] (1.Earthquake Research Institute, University of Tokyo)

[SIT27-09] Shear attenuation and anelastic mechanisms in the central Pacific upper mantle

★Invited Papers

*Zhitu Ma[1], Colleen A Dalton[2], Joshua B Russell[3], James B Gaherty[3], Greg Hirth[2], Donald W Forsyth[2] (1.State Key Laboratory of Marine Geology, Tongji University, Shanghai, China, 2.Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI, USA, 3.Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY, USA)

[SIT27-10] Viscosity-depth profiles of the oceanic upper mantle deforming by grain-boundary diffusion creep

*Kosuke Yabe[1], Takehiko Hiraga[1] (1.School of Science, The University of Tokyo)

[SIT27-11] **Upper mantle velocity structure beneath the northern Ryukyu subduction zone revealed from multiscale finite-frequency traveltime tomography**

★Invited Papers

*Shu-Huei Hung[1], Ban-Yuan Kuo[2], Pei-Ying Patty Lin[3], Yuancheng Gung[1], Eh Tan[2], Kate Huihsuan Chen[3], Ching-Ren Lin[2], Chau-Chang Wang[5,4], Shuichi Kodaira[6], Yasushi Ishihara[6], Mamoru Nakamura[7] (1.National Taiwan University, Taipei, Taiwan, 2.Academia Sinica, Taipei, Taiwan, 3.National Taiwan Normal University, Taipei, Taiwan, 4.Taiwan Ocean Research Institute, National Applied Research Laboratories, Kaohsiung, Taiwan , 5.National Sun Yat-sen University, Kaohsiung, Taiwan, 6.Japan Agency for Marine-Earth Science and Technology, Yokohama, Japan, 7.University of the Ryukyus, Okinawa, Japan)

[SIT27-12] Future geophysical observation on oceanic lithosphere and asthenosphere study: Hawaii-Emperor Bend (HEB) Project

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A comprehensive portrait of the central Pacific lithosphere-asthenosphere system from NoMelt seafloor geophysical observations

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With a thin homogeneous crust and simple tectonic history, ocean basins provide an exceptional environment for imaging processes associated with mantle convection. Oceanic lithosphere retains fingerprints of melting, melt extraction, and deformation during spreading, while the asthenosphere provides a present-day view of the deforming mantle. Ocean-bottom seismographs and Magnetotelluric (MT) sensors provide unique new tools for imaging the oceanic lithosphere-asthenosphere system. The NoMelt experiment combines active- and passive-source seismic and passive-source MT imaging to provide a comprehensive portrait of the physical state and deformation processes associated with ~70 Ma Pacific lithosphere and asthenosphere. Seismic velocity, attenuation, and conductivity profiles through the upper 300 km suggest a cool, dry lithosphere, underlain by a moderately low-velocity, high-attenuation, and conductive asthenosphere that appears hydrated but does not contain significant partial melt. Seismic-velocity variations relative to this background structure are highly anisotropic. We find the strongest anisotropy located in the lithosphere with a direction consistent with fossilized seafloor-spreading fabric, a minimum in the strength of shear anisotropy within the center of the low-velocity zone, and a secondary peak in anisotropy deeper in the asthenosphere associated with pressure- or buoyancy-driven flow. The lithosphere-to-asthenosphere transition is located by several different data sets at ~80 km depth, suggesting a rheological change locked in by the dehydration boundary at a young age. Using the combined anisotropy constraints, we estimate an *in situ* elasticity tensor that is remarkably similar to field samples of abyssal peridotites, suggesting nearly complete alignment of the sample fabric at seismic length scales.

Keywords: lithosphere, seismic, oceanic

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Seismic discontinuity at lithosphere-asthenosphere boundary predicted from laboratory-based anelasticity model

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Seismic discontinuity has been observed around the depth of lithosphere-asthenosphere boundary (LAB). Recent seismological studies using both P to S and S to P converted waves (e.g., Rychert et al., 2007; Kawakatsu et al., 2009) have revealed that more than 5% Vs reduction occurs sharply (within a depth range of ~15 km) at about 60-80 km depth. Because the change of geotherm with depth is gradual, it has been difficult to explain such a sharp velocity reduction by temperature alone, and a discontinuous distribution of melt or water has been considered as a cause of the sharp LAB. However, recent experimental studies by using organic polycrystals as a rock analogue have shown that a reduction of seismic wave velocity by temperature can be much steeper than that considered in previous studies, because grain boundary premelting occurs from just below the solidus temperature and significantly enhances the polycrystal anelasticity (Yamauchi and Takei, 2016). We applied the anelasticity model obtained by Yamauchi and Takei (2016) to the oceanic mantle and investigated whether sharp LAB captured in seismology can be explained by grain boundary premelting.

The anelasticity model by Yamauchi and Takei (2016) is given as a function of normalized frequency f/f_M and normalized temperature T/Tm, where $f_M$and $T_m$represent the Maxwell frequency and solidus temperature, respectively. The Maxwell frequency is calculated by G_U/h, where $G_U$and h represent the unrelaxed shear modulus and diffusion creep viscosity, respectively. Yamauchi and Takei (2016) also gave the model of diffusion creep viscosity based on the experimentally observed enhancement of diffusion creep by premelting. Oceanic mantle geotherm T(z) was calculated for various plate ages by plate cooling models. Solidus profiles $T_m(z)$ were calculated by assuming some plausible distributions of volatiles (H_2O and CO_2). Substituting these results to the laboratory-based viscosity and anelasticity models, velocity and attenuation profiles Vs(z) and $Q^{-1}(z)$ at seismic frequency f were calculated and compared to the seismological observations. The results show that the sharp reduction in Vs can be explained by premelting. However, the predicted discontinuity depth is slightly deeper, and the predicted magnitude of velocity reduction is smaller than the seismological observations. We discuss these discrepancies from possible uncertainties in geophysical conditions and rheological models. We further compare the present results with another LAB model based on the other laboratory-based anelasticity model (Jackson and Faul, 2010).

Keywords: LAB, anelasticity, premelting, grain boundary

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Shear attenuation and anelastic mechanisms in the central Pacific upper mantle

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We determine the mantle attenuation (1/Q) structure beneath 70 Myr seafloor in the central Pacific. We use long-period (33-100 sec) Rayleigh waves recorded by the NoMelt array of broadband ocean-bottom seismometers. After the removal of tilt and compliance noise, we are able to measure Rayleigh wave phase and amplitude for 125 earthquakes. The compliance correction for ocean wave pressure on the seafloor is particularly important for improving signal-to-noise at periods longer than 55 sec. Attenuation and azimuthally anisotropic phase velocity in the study area are determined by approximating the wavefield as the interference of two plane waves. We find that the amplitude decay of Rayleigh waves across the NoMelt array can be adequately explained using a two-layer model: in the shallow layer, in the deeper layer, and a transition depth at 70 km, although the sharpness of the transition is not well resolved by the Rayleigh wave data. Notably, observed in the NoMelt lithosphere is significantly higher than values in this area from global attenuation models. When compared with lithospheric measured at higher frequency (~3 Hz), the frequency dependence of attenuation is very slight, revising previous interpretations. The effect of anelasticity on shear velocity (V_S) is estimated from the ratio of observed velocity to the predicted anharmonic value. We use laboratory-based parameters to predict attenuation and velocity-dispersion spectra that result from the superposition of a weakly frequency dependent high-temperature background and an absorption peak. We test a large range of frequencies for the position of the absorption peak (f_e) and determine, at each depth, which values of f_e predict and V_S that can fit the NoMelt and V_S values simultaneously. We show that between depths of 60 and 80 km the seismic models require an increase in f_e by at least 3-4 orders of magnitude. Under the assumption that the absorption peak is caused by elastically accommodated grain-boundary sliding, this increase in f_e reflects a decrease in grain-boundary viscosity of 3-4 orders of magnitude. A likely explanation is an increase in the water content of the mantle, with the base of the dehydrated lid located at ~70-km depth.

Keywords: Oceanic Lithosphere, Attenuation

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Viscosity-depth profiles of the oceanic upper mantle deforming by grain-boundary diffusion creep

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The mantle is known to have anisotropic elasticity, which is primarily explained by crystallographic preferred orientation (CPO) of olivine that forms during mantle flow. Because the CPO has long been considered to result uniquely from dislocation processes, diffusion creep has received less attention than dislocation processes. Recently, olivine CPO has been found to develop during diffusion creep under a condition that seems to correspond to the depth of seismically anisotropic mantle (Miyazaki et al., 2013). This motivated us to examine mantle viscosity in terms of olivine diffusion creep.
Diffusion creep of olivine is controversial. Differences of up to two orders of magnitude in viscosity at the same grain sizes and temperatures have been reported from experimental diffusion creep studies (Hirth & Kohlstedt, 1995; Faul & Jackson, 2007). Therefore, it remains difficult to determine the importance of diffusion creep as a mantle deformation mechanism from a mechanical perspective.
We synthesized fine-grained Fe-bearing olivine ($Mg_{1.8}Fe_{0.2}SiO_4$; so-called Fo_{90} olivine) aggregates that were variably doped with CaO and Al_2O_3 and conducted uniaxial deformation experiments at 1 atm. By comparing creep properties of undoped and doped olivine aggregates, we identified the roles of Ca and Al in enhancing grain-boundary diffusion creep at $>0.92T_s$ (in K), an effect became significant with increasing temperature. We considered the enhancement to result from grain-boundary disordering promoted by grain-boundary segregation. Based on the Arrhenius-like behavior of the disordering effect, we established an olivine diffusion creep law that suitably describes the creep rates in both temperature ranges of $<0.92T_s$ and $>0.92T_s$ using values of T_s and ΔQ. The latter term is an additional activation energy on top of that for the normal state of olivine diffusion creep.
We estimated solidus temperatures of the samples used in the previous diffusion creep experiments. These temperatures were used to compare previously reported diffusion creep rates for olivine with our established diffusion creep law. We found that the law explains a difference of up to two orders of magnitude in olivine creep rates at the same temperatures, stresses, grain sizes, and water contents in the previous studies. The geotherm normalized by the mantle solidus was calculated for the upper mantle with water contents up to 300 ppm wt., which predicts depths where weak (low-viscosity) mantle is expected to occur due to enhanced grain-boundary diffusion creep. Constructed viscosity-depth profiles reveal a mantle lithosphere with essentially zero thickness beneath mid-ocean ridges, with development of the lithosphere away from the ridge, leaving a low-viscosity region below. Given a grain size of 1 mm and depending on the water content, a viscosity of $1\text{-}5\times10^{19}$ Pas is predicted for the low-viscosity mantle beneath 50-million-year-old seafloor.

Keywords: olivine aggregate, grain-boundary diffusion creep, viscosity of the oceanic mantle

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Upper mantle velocity structure beneath the northern Ryukyu subduction zone revealed from multiscale finite-frequency traveltime tomography

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We conduct multiscale finite-frequency tomography of upper mantle structure beneath the northern Ryukyu subduction zone, where the Philippine Sea Plate (PSP) subducting beneath the Eurasian continent forms a trench-forearc-arc-backarc system. The data comprises of P and S waveforms of teleseismic earthquakes with an epicentral distance of 30°-95° and magnitude greater than 5.5 recorded by 3 stations from the F-net network of Japan and 21 broadband ocean-bottom seismometers from the Taiwan-Japan collaborative experiment deployed between Sept. 2018 and June 2019 in the study area. Relative traveltime residuals between the recording stations for each event are measured by cross correlating the band-pass filtered waveforms at periods of 8-20 s for P and 10-30 for S. Those with the cross-collelation coefficients > 0.8 are retained for the tomographic inversion of seismic velocity perturbations at least down to the depth of 300 km. Data-adaptive, finite-frequency traveltime kernels in conjunction with a horizontal multiscale wavelet-based and vertical convolutional quelling grid-based parameterization are adopted to resolve the multi-resolution velocity structure. The resulting preliminary P-wave model reveals a low-velocity anomaly in the forearc wedge and a high-velocity lid in the uppermost 80-km depth beneath the northern Okinawa Trough (NOT) and Ryukyu arc which may correspond to the overriding Eurasian continental lithosphere. Besides, a trench-parallel elongated fast anomaly extending at least down to ~200 km depth is observed under the NOT, probably associated with the subducted PSP slab. Further investigation of S-velocity tomography and assessment of model resolution will be undertaken to verify these resulting seismic features.

Keywords: Ryukyu subduction zone , broadband ocean bottom seismometer, multiscale finite-frequency traveltime tomography, Northern Okinawa Trough (NOT)

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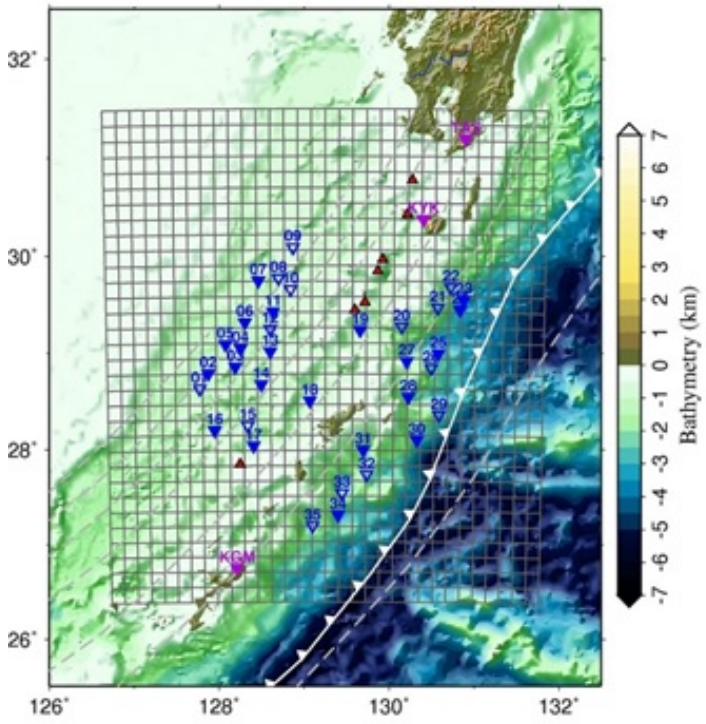

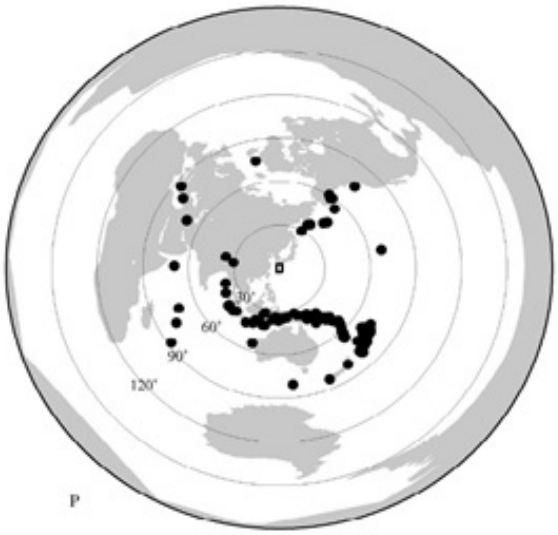

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Future geophysical observation on oceanic lithosphere and asthenosphere study: Hawaii-Emperor Bend (HEB) Project

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We introduce a future geophysical observation project planned under collaboration between Japan and Germany, which can be regarded as one of the regional arrays of the Pacific Array Initiative (http://eri-ndc.eri.u-tokyo.ac.jp/PacificArray/). This project aims to constrain the viscosity of oceanic asthenosphere through passive electromagnetic (EM) and seismological observations on the seafloor, based on a unique view point focusing on the geometry of the Hawaii-Emperor Bend and plume-plate interaction.

For the plume-plate interaction, once the plume material, which can be hotter and richer in volatile composition than the ambient mantle, reaches below the lithosphere, it can reheat the base of the lithosphere and the plume material itself can spread laterally mainly in the direction of the overlying plate motion dragged by the lithosphere. We can suppose two extreme scenarios about the fate of the plume material. If the mechanical coupling between the lithosphere and plume material is enough strong, i.e, the viscosity contrast between them is relatively small, the plume material (and ambient asthenospheric mantle material) would move laterally with a similar speed as the overlying lithosphere. While if the coupling is weak (the viscosity contrast is large), the asthenosphere moves slower than the lithosphere and hence the plume material would be left behind the lithosphere. If this is the case for the Emperor chain, because it is oblique to the current plate motion, the plume material is expected to locate in the east of the Emperor Chain, at a distance depending of the coupling between the lithosphere and asthenosphere.

The ocean bottom EM and seismological observations have succeeded to image the upper mantle structure around the hotspots in terms of electrical conductivity structure and seismic velocity structures. Both properties and viscosity in the mantle are dependent on the temperature, volatile composition, and partial melt if it exists, but in different ways. The plume material is thought to be hotter and richer in the volatile composition than the ambient mantle, and therefore, it is expected that the plume material can be imaged as high conductivity and low velocity anomalies. This study can provide more direct evidence to distinguish the scenarios mentioned above. Moreover, joint interpretation of the electrical conductivity and seismic velocity can give more quantitative discussion about the temperature, volatiles, and melts, and give suggestions about the viscosity of the asthenosphere with support of petrological and laboratory experiment, and geodynamic modeling studies.

We have carried out geodynamic simulations that reconstruct mantle flow in the central Pacific area since 100 Ma, including the Hawaii plume –a hot upwelling from deep in the mantle, the plate motion change at 47 Ma, and global mantle flow. The simulations show that a hot anomaly representing the plume material distributes in the asthenosphere beneath east of the Emperor chain and its horizontal location is dependent on the assumed viscosity profile (more east if the asthenosphere has a thin low-viscosity layer) as expected. The results encourage us to put the marine EM and seismological observations into practice. We further plan to conduct feasibility studies to examine how well the plume material can be resolved as the anomalies in electrical conductivity and seismic velocity from the observations.

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Keywords: Hawaii-Emperor Bend, Oceanic lithosphere and asthenosphere, Plume and plate interaction, Marine electromagnetic and seismic observations

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[E] Oral | S (Solid Earth Sciences)：S-IT Science of the Earth's Interior & Techtonophysics

[S-IT29] New perspectives on East Asia geodynamics

convener:Jonny Wu(University of Houston), Asuka Yamaguchi(Atomosphere and Ocean Research Institute, The University of Tokyo), Kyoko Okino(Atmosphere and Ocean Research Institute, The University of Tokyo), Timothy B Byrne(University of Connecticut)

East Asia is one of the most tectonically active regions on Earth and includes the Eurasian continental margin, the western Pacific subduction zones and many of Earth's marginal seas. The region has a long history of subduction, collision, backarc basin opening and closing, and other plate boundary interactions. In recent years, a wide range of new observations have been collected from the land, oceans and Earth interior, including detailed geologic data, zircon age spectra, earthquakes, high resolution crustal to mantle imaging, and Big Data. These new data show the detailed space-time evolution of subduction zones, mountain building, slab stagnation, crustal deformation, continental dynamics, backarc spreading, and other East Asian geodynamics cannot be fully explained by classic theories; new perspectives are needed. Here we seek to share new insights on the geologic history, paleomagnetism, and geophysical character of East Asia since the Paleozoic. We also invite geodynamic models that integrate diverse datasets into a more holistic view of this dynamic environment.

[SIT29-01] New insights into East Asian mantle structure and dynamics
★Invited Papers

*Dapeng Zhao[1] (1.Department of Geophysics, Tohoku University)

[SIT29-02] **NE Asian arc magmatic tempos and their relationship to Western Pacific-Izanagi plate tectonics since Cretaceous times**

*Jonny Wu[1], Tsung-Jui Wu[1] (1.University of Houston)

[SIT29-03] Mesozoic island arc rocks in Hokkaido: potential keys to reconstruct ancient oceanic plates offshore East Asia.
★Invited Papers

*Hayato Ueda[1], Ryusei KOTA[1], Mitsuhiko Ishino[1], Minato Munakata[1], Komei Nara[1], Yuta Akutsu[1], Yusuke Sugiyama[1], Nozomu Suzuki[1] (1.Department of Geology, Niigata University)

[SIT29-04] Mid-Cretaceous Tectonics of the Ryukyu arc reconstructed by geology of Kerama Islands, Okinawa

*Ippei Yamamoto[1], Kenichiro Tani[2], Yui Kouketsu[3], Asuka Yamaguchi[1] (1.Atmosphere and Ocean Research Institute, The University of Tokyo, 2.National Museum of Nature and Science, 3.Nagoya University)

[SIT29-05] The last unknown pieces of the Proto-Philippine Sea Plate: Huatung Basin and Gagua Ridge
★Invited Papers

*Kenichiro Tani[1], Osamu Ishizuka[2], Kyoko Okino[3], Hayato Ueda[4] (1.Department of Geology and Paleontology, National Museum of Nature and Science, 2.Geological Survey of Japan/AIST, 3.Atmosphere and Ocean Research Institute, The University of Tokyo, 4.Faculty of Science, Niigata University)

[SIT29-06] **Maturation of incipient island arcs: New insights from the southern Mariana arc**
★Invited Papers

*Julia Ribeiro[1], Osamu Ishizuka[2], Cin-Ty Lee[3], Guillaume Girard[4] (1.Guangzhou Institute of Geochemistry, the Chinese Academy of Sciences, Guangzhou, China, 2.Geological Survey of Japan, AIST, Ibaraki, Japan, 3.Rice University, Earth Science Department, Houston, Tx, USA, 4.Northern Illinois University, DeKalb, Illinois, USA.)

New insights into East Asian mantle structure and dynamics

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In the past a few years we have used new methods of seismic imaging to study the 3-D seismic structure and anisotropy of the mantle beneath East Asia, which provides new insights into seismotectonics, magmatism and mantle dynamics (e.g., Zhao et al., 2016, 2017a; Zhao, 2017, 2019; Ma et al., 2019; Wei and Zhao, 2020). High-resolution images of seismic tomography and receiver functions of the Asian region are obtained, revealing significant lateral heterogeneities in the crust and upper mantle, which are caused by active plate subductions and continental orogeny. A significant advance in the seismic imaging is tomographic inversions for three-dimensional distribution of seismic anisotropy in the crust and mantle, which provides important new information on the lithospheric deformation and mantle convection associated with the continental orogeny and plate subductions. The intraplate volcanism in Northeast Asia is caused by hot and wet upwelling flows in the big mantle wedge above the stagnant Pacific slab in the mantle transition zone (MTZ). The age distribution of the subducting Pacific slab beneath East Asia is estimated, shedding new light on the evolution of the Pacific slab, as well as the East Asian tectonics during the Late Mesozoic to the Cenozoic (Liu et al., 2017). The nucleation of great earthquakes, such as the 2008 Wenchuan earthquake (M 8.0), the 2011 Tohoku-oki earthquake (M 9.0) and the 2015 Nepal earthquake (M 7.9), is controlled by structural heterogeneities in and around the seismogenic fault zones. It is considered that fluids are involved in the nucleation and rupture processes of all types of earthquakes. The cause of deep earthquakes is still not very clear, though transformational faulting triggered by metastable olivine transforming to spinel in the cold, stressed core of the subducting slab is a viable mechanism, and a metastable olivine wedge is revealed within the western Pacific subducting slab at the MTZ depths. The 2015 Bonin deep earthquake (M 7.9, ~670 km depth) occurred at the MTZ bottom within the vertical Pacific slab which is penetrating into the lower mantle. This very unusual deep event was caused by joint effects of several factors, including the slab's fast deep subduction, slab tearing and thermal variation, stress changes and phase transformations in the slab, and complex interactions between the slab and the ambient mantle (Zhao et al., 2017b).

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Keywords: East Asia, Seismic imaging, Mantle dynamics

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NE Asian arc magmatic tempos and their relationship to Western Pacific-Izanagi plate tectonics since Cretaceous times

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The extensive belts of igneous rocks along the NE Asian margin since Cretaceous times are typically viewed as magmatic arcs produced by subduction of the western Pacific, Izanagi, and other plates. However, NE Asian plate tectonic reconstruction models during these periods are controversial. Furthermore, the NE Asian arc magmatic record has been less systematically cataloged relative to other regions. Therefore, it is still unknown whether any quantifiable relationship truly exists between the NE Asian arcs and plate tectonics. Indeed, arc tempos at other circum-Pacific margins (western North America and South America) show lulls and flare-ups that appear more closely linked to 'internal' cyclical processes, including crustal root eclogitization, compared to 'external' factors (i.e. plate tectonics).

Here we build a large (n>500) compilation of igneous rock ages and geochemistry along the NE Asian margin along Japan, Sikhote-Alin, and Korea. Our database includes 65 unpublished analyses from northern Sikhote-Alin, Russian Far East, from University of Houston labs. We compare the magmatism against our recently-developed 'tomographic' western Pacific-Izanagi plate reconstruction since ~100 Ma, which is a fully-kinematic model that implies spatiotemporal subduction rates along NE Asia.

Our analysis shows that Cretaceous NE Asian magmatism is dominated by higher average silica contents (~69%) relative to other continental arcs. Significantly higher areal addition rates occurred between 56 to 100 Ma (~1100 km2/m.y.) relative to younger <50 Ma periods (~400 km2/m.y.). U-Pb zircon age probability plots revealed a NE Asian arc flare-up at ~85 Ma that had intrusive fluxes reaching 1100 km2/m.y., which are comparable to the noteworthy Sierra Nevada arc flare-up during late Cretaceous times. More vigorous magmatism generally correspond to fast (~15±5 cm/yr) Izanagi-Eurasia plate convergence whereas less vigorous magmatism corresponds to slower (<10 cm/yr) Pacific-Eurasia plate convergence. Magmatic quiescence between 56 to 46 Ma corresponds to Izanagi-Pacific ridge subduction. We discuss the possible role of internal and external processes on NE Asian arc tempos based on our analyses of magmatism relative to plate tectonics.

Keywords: arc magmatism, NE Asia plate tectonics, western Pacific , Izanagi

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Mesozoic island arc rocks in Hokkaido: potential keys to reconstruct ancient oceanic plates offshore East Asia.

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Hokkaido Island is known as a Cenozoic arc-arc collision zone, where Kurile arc (Okhotsk Sea margin) collided to Euasian active continental margin. However, Mesozoic island arc rocks also occur as ophiolites, volcano-sedimentary successions, and sedimentary clasts.

The oldest arc rocks in central Hokkadio are Jurassic ophiolitic rocks (Oku-Niikappu Complex and several similar ophiolites) typically associated with boninites. 160-165 Ma zircon U-Pb ages have been obtained from tonalites and diorites.

Traces of earliest Cretaceous arc are found as andesitic sedimentary clasts in pelagic sediments overlying MORB-like basalts, together comprising the Sorachi Group. These arc detritus yields zircons of ~140 Ma without any older grains.

120-125 Ma arc rocks comprise thick volcaniclastic sequences of the Rebun-Kabato Belt. In Tohoku (Kitakami) district to the south of Hokkaido, they were deposited upon Jurassic accretionary complex of Eurasian margin. However, our observation in Rebun Island has not found any sign of continental materials.

Since 120-125 Ma, depositional setting of central Hokkaido drastically changed to peri-continental. In contrast, post-120 Ma arc rocks, as well as traces of Jurassic to earlies Cretaceous arc activities, are found in eastern Hokkaido. Nikoro Group (Tokoro Belt) sandstones consists essentially of arc detritus with zircons of ~87 Ma, 90-100 Ma, and trace grains as old as 154 Ma, without any older grains. Sandstone and mudstone contain trace amounts of clasts and blocks of granitoids (tonalite), one of which yielded 146 Ma zircons. Late Cretaceous (Campanian) arc volcanic rocks occur int the Nemuro Group, and arc detritus continued to be supplied until Paleogene.

To summarize, arc activities found in Hokkaido intermittently continued from Jurassic to Paleogene. Continent-derived materials with Precambrian detrital or inherited zircons first appears in 125 Ma in central Hokkaido and 65 Ma in eastern Hokkaido, and before these timings, no signs of continental basements and sedimentary sources are found. Therefore, both central and eastern Hokkaido probably originated from intraoceanic arc-backarc plate(s) distinct both from Eurasia and Izanagi plates. The central Hokkaido was attached to Eurasian margin at 125 Ma, and eastern Hokkaido at 65 Ma.

Why intraoceanic arc activities continued so long time? Intraoceanic subduction must have been inevitable so far as two major but mechanically individual oceans of Tethys (to Indian) and Panthalassa existed since Paleozoic until recent. Long-term activity of intraoceanic arcs and their step-by-step attachments onto the Eurasian margin can be comprehensible if we consider that the Hokkaido geology developed influenced by a general triple junction geometry among Eurasia –Tethys –Pacific (Izanagi) plates.

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Keywords: intraoceanic arc, oceanic plate reconstruction, Izanagi-Tethys junction

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Mid-Cretaceous Tectonics of the Ryukyu arc reconstructed by geology of Kerama Islands, Okinawa

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The basement rocks of the Japanese islands are characterized by an along-arc distribution of accretionary complexes and metamorphic belts with oceanward-younging polarity. An intermittent formation of metamorphic belts is interpreted to have been related with subduction of mid-oceanic ridge. The ages of such tectonic events have been estimated by U-Pb age analysis of detrital zircon after 2000s (Isozaki *et al.*, 2010), and the timing of Kula-Pacific ridge subduction was estimated to be 60-70 Ma. However, a numerical model by Seton *et al.* (2015) simulated that the age of Izanagi-Pacific ridge subduction was 50-60 Ma, which is inconsistent with geological evidence (Isozaki *et al.* 2010). Using a different geophysical model, Wu *et al.* (2016) suggested that there has been East Asian Sea plate, relatively stationary to Eurasian plate, covering large area of western paleo-Pacific Ocean at 52 Ma. They also insisted that the Ryukyu arc was passive continental margin at 52 Ma. Taking these recent discussions into considerations, the purpose of this study is to constrain plate tectonic setting of NW Pacific by reexamining Cretaceous geological records of the Ryukyu arc. In this study we focus on Kerama Islands, located at the southwestern edge of the distribution of the Shimanto accretionary complex.

The bedrock of Kerama Islands is made up of a pile of three lithological units, greenstone, metasandstone, and pelitic schist in ascending order. Metamorphosed pelagic sediment is not observed. Greenstone generally contains epidote, actinolite, chlorite, and, hornblende as metamorphic minerals. Previous study shows the greenstone in Kerama Islands has geochemical features of N-MORB (Chinen *et al.*, 2004). Our detailed observation of the contact between the top of greenstone unit and the bottom of sedimentary rock layer shows that the boundary records intrusion of basaltic lava, the protolith of the greenstone.

U-Pb ages of detrital zircon grains obtained from massive metasandstone and psammitic schist in Kerama Islands were analyzed. The measurement was carried out using LA-ICP-MS installed at the National Museum of Nature and Science. The concordant ages calculated from the result is ranging from 104 to 2565 Ma. The youngest age of zircon ranges 104-110 Ma (early Cretaceous) and no zircon grains with late Cretaceous age is obtained. The depositional age of original rocks of metasandstone in Kerama Islands is considered to be ~100 Ma.

We examined peak metamorphic temperature of pelitic schist in Kerama Islands. Raman spectra of carbonaceous materials in thin section of the samples are obtained using a Raman spectrometer with a 532 nm Nd-YAG laser installed at Nagoya University. Peak decomposition of Raman spectra was performed and peak metamorphic temperature was estimated following the method of Beyssac *et al.* (2002). The result shows that the bedrock of Kerama Islands suffered 470-525˚C, which correspond to the temperature range of proposed metamorphic facies of greenstone characterized by the combination of epidote and actinolite (Maruyama *et al.*, 1996; Hacker *et al.*, 2003). This peak metamorphic temperature of Kerama Islands is higher than any reported temperatures in the Shimanto belt.

According to numerical model of Iwamori (2000), metamorphic *P-T* condition of rocks of Kerama Islands achieved by subduction of mid-oceanic ridge for several millions of years. Ridge subduction is also

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supported by the existence of N-MORB intruded into trench-filled terrigenious sediment. Ridge subduction beneath paleo-Ryukyu trench at ~100 Ma, proposed by this research, would be a strong constrain for plate tectonic reconstruction of Cretaceous NW pacific.

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The last unknown pieces of the Proto-Philippine Sea Plate: Huatung Basin and Gagua Ridge

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Little is known about the Proto-Philippine Sea Plate (PSP), which existed as a counterpart to the Pacific Plate during subduction initiation of the Izu-Bonin-Mariana (IBM) Arc. IBM subduction is recently postulated to have occurred synchronously along the PSP margin at around 52 Ma (Ishizuka et al. 2011 EPSL).

To investigate the crustal structures of the PSP, we have conducted multiple research cruises since 2010 in the regions that were regarded as potential remnants of the PSP: Daito Ridges, Izu-Bonin forearc and Southern Kyushu-Palau Ridge. Submersible and ROV observations and rock sampling revealed that these regions expose deep crustal sections of continental rocks, spanning various volcanic, plutonic, metamorphic, and ultramafic rocks (e.g. Morishita et al. 2018 Am. Min.). Geochemistry and radiometric dating of these rocks clearly indicate that the PSP consists predominantly of Mesozoic arc rocks. Furthermore, amphibolite collected at the Southern Kyushu-Palau Ridge yielded Cambrian protolith zircons, suggesting that even older continental fragments may exist within the PSP.
These findings and tectonic reconstruction of the PSP (Deschamps and Lallemand 2002 JGR) suggest that subduction of the Izu-Bonin Arc initiated at the continental margin of Southeast Asia, and later acquired its intra-oceanic-like setting through formation of the backarc basins since the Eocene.

However, there are unresolved questions regarding the crustal structure of the PSP at Huatung Basin and Gagua Ridge, located at the northwestern margin of the current Philippine Sea Plate. Deschamps et al. (2000) EPSL suggested that Huatung Basin was formed in the Early Cretaceous, based on modeling of magnetic anomalies and radiometric dating of MORB-like gabbro collected at the southern part of the basin. If so, Huatung Basin is the only known oceanic domain in the PSP, indicating that the PSP was a complex of continental and oceanic crusts. In contrast, Doo et al. (2014) MGR and Kuo et al. (2009) GJI indicated much younger post-Eocene spreading of the basin based on reinterpretation of the magnetic anomalies and thin lithosphere under the basin. If the basin is formed after the Eocene, it is most likely part of the IBM backarc basins. Gagua Ridge, comprising the western margin of the basin, was interpreted to be oceanic crust uplifted along a transform fault (Deschamps et al. 1998 MGR), but dredge sampling conducted in 1980 recovered andesite and metamorphic rocks, suggesting a more complex crustal structure.

To unravel the crustal structure of the Huatung Basin and Gagua Ridge, geological and geophysical surveys are planned by R/V Hakuhomaru in November –December, 2020. Here we will summarize our ongoing research in the PSP and introduce our scientific objectives for the upcoming cruise.

Keywords: Huatung Basin, Gagua Ridge, Proto-Philippine Sea Plate

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Maturation of incipient island arcs: New insights from the southern Mariana arc

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Despite being defining features of the solid Earth, how juvenile island arcs evolve into thicker-crust, mature stratovolcanoes remains poorly understood. What is the composition of nascent island arc magmas and how do they evolve over time? The Southern Mariana arc is an incipient island arc, which possesses irregularly emplaced submarine volcanoes,that progressively evolves into stable, thicker-crust stratovolcanoes to the north.The juvenile Mariana arc magmas are progressively enriched in K_2O and in slab-fluid proxies (Ba/Th, Ba/Nb, Th/Yb) during arc maturation. This compositional evolution is associated with a change in the type of melting (i.e., from decompression to fluid-assisted mantle melting) and to a deepening in arc magma generation, which is accompanied by a retreat of the volcanic arc front. The more mature arc magmas thus progressively capture the deeply-sourced, slab fluids, as they overlie deeper portions of the subducted slab over time. We further propose that the steadiness and the location of the volcanic arc front is modulated by the growth of the serpentinized fore-arc mantle since arc inception. Arc stabilization promotes, in return, melt focusing, magma differentiation and crustal assimilation, which result in crustal thickening. The development of a serpentinized fore-arc mantle is thus essential to arc maturation, as it contributes to the growth of the arc crust, and as to the arc volcanoes maintain their location for millions of years.

Keywords: subduction infancy, Izu-Bonin-Mariana, arc maturation

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[E] Oral | S (Solid Earth Sciences)：S-IT Science of the Earth's Interior & Techtonophysics

[S-IT29] New perspectives on East Asia geodynamics

convener:Jonny Wu(University of Houston), Asuka Yamaguchi(Atomosphere and Ocean Research Institute, The University of Tokyo), Kyoko Okino(Atmosphere and Ocean Research Institute, The University of Tokyo), Timothy B Byrne(University of Connecticut)

East Asia is one of the most tectonically active regions on Earth and includes the Eurasian continental margin, the western Pacific subduction zones and many of Earth's marginal seas. The region has a long history of subduction, collision, backarc basin opening and closing, and other plate boundary interactions. In recent years, a wide range of new observations have been collected from the land, oceans and Earth interior, including detailed geologic data, zircon age spectra, earthquakes, high resolution crustal to mantle imaging, and Big Data. These new data show the detailed space-time evolution of subduction zones, mountain building, slab stagnation, crustal deformation, continental dynamics, backarc spreading, and other East Asian geodynamics cannot be fully explained by classic theories; new perspectives are needed. Here we seek to share new insights on the geologic history, paleomagnetism, and geophysical character of East Asia since the Paleozoic. We also invite geodynamic models that integrate diverse datasets into a more holistic view of this dynamic environment.

[SIT29-07] Post-back-arc spreading magmatism: an example of the Seifu Seamount in the Sea of Japan

★Invited Papers

*Tomoaki Morishita[1,2,3], Naoto Hirano[4], Hirochika Sumino[5], Hiroshi Sato[6], Tomoyuki Shibata[7], Masako Yoshikawa[7], Shoji Arai[1], Akihiro Tamura[1] (1.Kanazawa University, 2.JAMSTEC, 3.Columbia University, 4.Tohoku University, 5.University of Tokyo, 6.Senshu University, 7.Hiroshima University)

[SIT29-08] Tectonics in the Median Tectonic Line and surrounding areas, southwest Japan during the Late Cretaceous to Paleogene periods

*Toru Takeshita[1], Yasuuchi Kubota[2] (1.Department of Natural History Sciences, Graduate School of Science, Hokkaido University, 2.Oyo Co., Ltd.)

[SIT29-09] **Doming induced by rapid exhumed serpentinite bodies in the subduction mélange and the associated structures: a case study of the Yuli Belt in eastern Taiwan**

*Jian-Cheng Lee[1,6], Gong-Ruei Ho[1,6], Kai-Hsiang Yang[1,6], Yuan-Hsi Lee[2,6], En-Chao Yeh[3,6], Wei Lo[4,6], Ching-Ho Tsai[5,6] (1.Academia Sinica, 2.National Chung Cheng University, 3.National Taiwan Normal University, 4.National Taipei University of Technology, 5.National Dung Hwa University, 6.The Yuli Exhumation Study team (YES Team))

[SIT29-10] A high strain shear zone in the metamorphic core of Central Range, Taiwan: A possible Plio- Pleistocene transform fault

*Gong-Ruei Ho[1], Jian-Cheng Lee[1], Timothy B Byrne[2] (1.Institute of Earth Sciences, Academia Sinica, 2.Department of Geography, University of Connecticut)

[SIT29-11] Exhumation and deformation partitioning in an arc-continent collision during highly oblique plate convergence ~6 to ~2 Ma, Taiwan

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[SIT29-12] Two steps of onset of the modern geodynamic framework; ~6Ma and ~2.5Ma in east Asia and western Pacific margin

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Post-back-arc spreading magmatism: an example of the Seifu Seamount in the Sea of Japan

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The Sea of Japan in the northern part of the Western Pacific region is a typical back-arc basin formed between an island arc and continent (Uyeda and Kanamnori, *JGR*, 1979; Tamaki and Honza, *Tectonophys.* , 1985). The continental breakup and oceanic spreading began at the eastern margin of the continent at 32-28 Ma, and back-arc magmatism ceased at 18-15 Ma (Tamaki et al., *Proceedings ODP Sci. Rep.*, 1992). Many studies have been conducted to elucidate the magmatism during back-arc rifting (e.g., Martinez et al., *Nature*, 2001). However, a chain of seamounts and islands are formed in these basins after the main phase of the back-arc magmatism. The Seifu Seamount is located at the northeastern margin of Tsushima Basin, and an alkali basalt (SSM basalt hereafter) with an $^{40}Ar/^{39}Ar$ plateau age of 8Ma was dredged by the KT85-15 cruise of R/V Tansei Maru of the Ocean Research Institute, University of Tokyo, in 1985 (Shimamura et al., *Bull Earthq. Res. Inst.*, 1987). The SSM basalt was formed in a post-back-arc magmatism by the low-degree of partial melting of a depleted MOR mantle-like mantle containing an enriched mantle component (EM1) (Morishita et al., *Solid Earth*, 2020). The SSM basalt contains mantle xenoliths (Ninomiya et al., Jap. Mag. Mineral. Petrol. Sci., 2007). It is also interesting to note that alkali basalts were also reported from the Philippine Sea Plate (Sato et al., *Geochem. J.*, 2002; Ishizuka et al., *EPSL*, 2009) and the Pacific Plate (Hirano et al., *Science*, 2006; Machida et al., *EPSL*, 2009). The SSM basalt is similar to those of the Kinan Seamount Chain. In this presentation, we will introduce the nature of the SSM basalt and discuss the formation processes of the Sea of Japan back-arc basin and their implications for developing the Western Pacific region.

Keywords: back-arc basin, Western Pacific

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Tectonics in the Median Tectonic Line and surrounding areas, southwest Japan during the Late Cretaceous to Paleogene periods

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The Median Tectonic Line (MTL) in Southwest Japan, a major east–west trending arc-parallel fault, has been defined as the boundary fault between the Cretaceous Sambagawa metamorphic rocks and the Ryoke granitic and metamorphic rocks, which are unconformably covered by the Upper Cretaceous Izumi Group. It has been well known that the MTL has been reactivated as a major dextral fault in the Quaternary period (e.g. Okada, 1973), and a huge inland earthquake occurred at the western extension of the MTL in Kumamoto city in April, 2016. However, the development of the MTL since Late Cretaceous, in particular, that during the Paleogene period, has been little known. We have recently conducted very detailed fieldwork and microstructural studies of the fault rocks, and dated some of the fault gouges along the MTL and branch faults in western Shikoku.

It has been well known that the proto-MTL was initiated as the southern marginal shear zone in the Ryoke metamorphic belt in Late Cretaceous, which is characterized by a sinistral strike-slip sense of shear (Hara et al., 1980). Kubota and Takeshita (2008) have found that there are two major phases for the reactivation of the MTL during the Paleogene period: the Ichinokawa and pre-Tobe phases. While the Ichinokawa phase is defined by large-scale, top-to-the-north normal faulting, the pre-Tobe phase is represented by large-scale, high-angle right-stepping *en échelon* faults almost parallel to the MTL in the Upper Cretaceous Izumi Group. We also found that left-handed *en échelon* folds have developed along the right-stepping faults, which contain 25–60 m wide cataclasite and fault gouge. All the map-scale *en échelon* faults, folds and microstructures (e.g., composite planar structures) in the fault rocks suggest that they were formed by sinistral-reverse faulting with top-to-the-SW kinematics. Furthermore, based on the new K-Ar age dating of authigenic illite from the fault gouge along the MTL and right-stepping faults, it can be concluded that the MTL was activated in two discrete stages at approximately 59 (Ichinokawa phase) and 47–46 Ma (pre-Tobe phase).

It is interesting note that geologic structures related to both movement phases of the MTL were also recorded in those in the Sambagawa metamorphic rocks. Yagi and Takeshita (2004) and El-Fakharani and Takeshita (2008) reported that normal faulting with a top to N to NW kinematics is very intense in the limited areas, in particular, those proximity to the MTL (e.g. Niihama area). These normal faulting activities in the Sambagawa metamorphic rocks are well correlated that along the MTL at the Ichinokawa phase. Further, the formation of WNW-ESE trending *en échelon* folds is pervasive in the Sambagawa metamorphic rocks in central Shikoku including the Oboke antiform, and occur in the areas more than 20 km apart from the MTL. This folding becomes very intense with a fold wavelength less than 100 m in proximity to the MTL (El-Fakharani and Takeshita, 2008), indicating a sinistral transpression along the MTL, which perhaps occurred at pre-Tobe phase. In fact, we obtained a fission-track resetting age of 47.2 ±3.8 Ma for zircon grains in psammitic schist collected from the Oboke antiform (Takeshita et al., 2011), which is coeval with the age of the pre-Tobe phase.

Currently, we inferred that large-scale normal faulting along the MTL at the Ichinokawa phase may have been caused by a buoyant subduction of the Izanagi-Pacific ridge recently inferred by Whittaker et al. (2007) and Seton et al. (2015), while the extensive sinistral transpression along the MTL at the pre-Tobe

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phase may be related to the 50 Ma event as proposed by Müller et al. (2016).

Keywords: Median Tectonic Line, kinematics, paleogene

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Doming induced by rapid exhumed serpentinite bodies in the subduction mélange and the associated structures: a case study of the Yuli Belt in eastern Taiwan

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Based on field investigations, microscopic observations, petrological analyses, and geochronological data, this study intends to characterize the seemingly dooming structures induced by the relatively higher strength serpentinite bodies surrounded by pelitic rocks in the subuction mélange, which exhumed to the surface. Our case study is the Yuli Belt of eastern Taiwan in the Eurasian continental margin (e.g., the eastern Central Range in Taiwan). During subduction and exhumation of the Yuli Belt, the Philippine Sea plate has been approaching in the vicinity of Taiwan since the Miocene time. The Yuli belt is composed of continental margin rocks that contain high-pressure minerals (omphacite, glaucophane, garnet) with Miocene-Pliocene ages (15-10 Ma) suggesting rapid exhumation from mantle depths of 40-50 km.

We conducted detailed field surveys around the Serpentinite bodies within the Yuli belt in the Chingshui River area. We found that the km-scale-wide serpentinite bodies served as stronger competent rock bodies. So that the surrounding pelitic schist, which served as weaker incompetent rock units, shows bending or folding of the main cleavage set S2. Note that we tentatively called the main deformational composition layers S2 (for the sake of field investigations), which also developed a regional penetrative cleavage set. It is worth noting that the edge of the serpentinite bodies has formed a series of layers of metasomatism products, such as chlorite schist and talc schist. These serpentinite-edge-schist developed a dominant vertical cleavage, with orientations generally parallel or sub-parallel to the edge shape of the serpentinite body. We also commonly observed breccia deformation bands sub-parallel to the main cleavage in the serpentinite edge, implying strongly mechanical shearing has been occurred around the edge of serpentinite in contact with the surrounding pelitic schist.
The deforming and bending of the S2 cleavage (i.e., main composition layers and the most penetrative cleavage) of the pelitic schist surrounding the km-wide serpentinite bodies indicates that the pelitic rocks encountered the serpentinite bodies after they have already formed the S2-related structures, probably during the exhumation process rather than the subduction process? Finally, in the regional scale, the shallow dipping S2 (and S3) outside the serpentinite bodies reveal a dome-shape (or anticlinal-form shape) character, strongly suggesting a upward serpentinite bodies and unroofing process during the rapid exhumation of the eastern Central Range of Taiwan.

Keywords: Doming, Serpentinite , Exhumation, Yuli belt, Taiwan

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A high strain shear zone in the metamorphic core of Central Range, Taiwan: A possible Plio- Pleistocene transform fault

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Subduction of the South China Sea beneath the Philippine Sea plate in the mid-Miocene led to the oblique collision of the Chinese continental margin and the Luzon arc, and the birth of the Taiwan orogen. Traditionally, the collision in Taiwan has been interpreted to be a relatively continuous process with an invariant plate convergence vector for at least the last 5 Mya (Suppe, 1984; Teng, 1996), suggested an orogen with a relatively steady shape and size (Suppe, 1981). However, more recent plate reconstructions with 50˚ counterclockwise plate motion change (Wu et al., 2016) and detailed geochronology studies with simultaneous exhumation history (Lee et al., 2015), suggest alternative tectonic histories are possible.

Observations of meso- and microscopic structures along the eastern Central Range of Taiwan (a strip area of about 200-km-long, 30-km-wide) show two generations of superposed folds with type-1/type-3 interference patterns in the hinge and asymmetric folds in the limb of the metamorphic core complex, which was associated with corresponding two cleavage sets. The transition between the surrounding Slate Belt and the higher-grade metamorphic core of Tailuko Belt are marked by a well-developed, penetrative crenulation cleavage, S2, that dips moderately northwest. The stretching lineation plunges moderately south-southwest is oblique to both the gently plunging lineation in the Tailuko Belt and to the steeply plunging lineation in the Slate Belt (Pulver et al., 2002). A high-strain shear zone can be identified with the consistency of the asymmetric structures and paleotemperature in the detail-studied areas. Stereonets reveal highly concentrated shear planes and asymmetric structures in the high-strain zones suggested top-to-southwest sense of shear. The mineral grain size/boundary mobility and illite-crystallinity index suggested the metamorphic temperature has exceeded 400˚C, which is higher than the closure temperature of the biotite (~350˚C). Therefore, the biotite $^{40}Ar/^{39}Ar$ age in the gneiss mylonite yield well-defined plateau dates ranging from 4.1-3.0 Ma (Wang et al., 1998), suggested a syntectonic age for this high-strain zone. The results indicate systematic left-lateral kinematics from north to south in the eastern Central Range (from Hoping, Liwu, Mugua, Shoufeng, Wanrung, Hongye, Chinshui, Xinwulu, to Dalun rivers), that suggested a possible major transform fault in the Tananao metamorphic belt.

Keywords: Tananao metamorphic belt, high strain shear zone, left-lateral strike slip motion

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Exhumation and deformation partitioning in an arc-continent collision during highly oblique plate convergence ~6 to ~2 Ma, Taiwan

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New low-temperature thermo-chronological and structural data from the Slate and Tailuko Belts integrated with previously published data suggest strain partitioning with contemporaneous exhumation during highly oblique plate convergence in Taiwan.

Deformation partitioning is recorded in the Slate and Tailuko Belts by the contemporaneous development of markedly different deformation histories. For example, the Slate Belt is characterized by regional-scale upright to overturned folds that typical verge northwest. Penetrative strain is marked by a well-developed cleavage (S1) with a down-dip stretching lineation (L1) and incremental strain markers record a top-to-the north-west sense of shear (Clark et al., 1992; Tillman and Byrne, 1995). In contrast, the Tailuko Belt is characterized by regional-scale isoclinal folds with a steep to moderately northwest dipping axial planar cleavage, S2, and a stretching lineation that plunges gently northeast. Asymmetric structures associated with S2 and S2-related mylonite zones consistently show a top-to-the left sense of shear. Contemporaneity of the deformation in the two belts is suggested by two geochronologic studies. A recent 40Ar/39Ar study of synkinematic mica porphyroblasts associated with develop to the Slate Belt in the Hsuehshan Range shows growth during a protracted period lasting from ~6.0 to ~2.5 Ma (Chen et al., 2016). In a separate 40Ar/39Ar study of an S2 mylonite zone in the Tailuko Belt, Wang et al. (1998) argued that recrystallized biotite in the mylonite grew below the closure temperature for biotite to argon. They proposed, therefore, that the plateau and isochron ages, ranging from 4.1 to 3.0 Ma, recorded the time of mylonite formation. The different strain patterns, and their apparent contemporaneity, argue for partitioning into orogen-normal (Slate Belt) and orogen-parallel (Tailuko Belt) components, consistent with proposed oblique convergence of the Philippine Sea (i.e., Luzon arc) wrt Eurasia in the Pliocene.

Age-elevation transects (AET) from the Slate and Tailuko Belts are also consistent with strain partitioning although the two belts record markedly different exhumation cooling histories. For example, new AETs from the Hsuehshan and southern Central Ranges, based on both new and previously published fission track and (U-Th)/He dates of completely reset detrital zircon grains, indicate moderate rates of cooling ~6 to 2 Ma (rates of ~1.1 to 1.5 mm/yr) and are consistent with a previously published AET from the Slate Belt exposed at Mt Yu (Hsu et al., 2016). In contrast, previously published AETs from the Tailuko Belt in the eastern Backbone Range indicate significantly slower rates of exhumation cooling (rates of ~0.1 mm/yr) during the same time period (Hsu et al., 2016).

We propose that the different rates of exhumation cooling reflect fundamentally different tectonic processes and that both regimes relate to deformation partitioning along the margin during oblique convergence in the Pliocene. That is, in the Tailuko Belt, where along-strike stretching argues for little change in crustal thickness, rates of exhumation cooling are extremely low. In contrast, in the Slate Belt, where down-dip stretching suggests crustal thickening, rates of exhumation cooling are significantly higher.

Keywords: collision, exhumation, strain partitioning

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Two steps of onset of the modern geodynamic framework; ~6Ma and ~2.5Ma in east Asia and western Pacific margin

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Cenozoic east Asia and western Pacific margins are complicatedly active region on the Earth and several geodynamic events are keys to understand the whole tectonic framework; back-arc rifting and spreading, space-time transition from extensional to compressive stress regime, and a culminated collision as a result of subduction in modern geodynamic framework.
Ocean drilling in the Nankai Trough forearc suggests a new scenario for the evolution of the Nankai subduction zone. Seismic reflection studies coupled with drilling have demonstrated that two episodes have controlled the recent evolution of the Nankai forearc: a resurgence of subduction at ~6 Ma after cessation since ~12 Ma and rapid growth of the accretionary prism since ~2.0-2.5 Ma because of the influx of large amounts of terrigenous sediments from the Japan Alps to the Nankai Trough (Kimura et al., 2018). Both episodes were synchronous with large-scale plate reorganizations; westward subduction of the Philippine Sea Plate initiated both in the Ryukyu and the Philippine trenches at ~5-6 Ma. Rifting in the Okinawa and Mariana troughs started at ~6 Ma. Compressive tectonics in northeast Japan started at ~3–2 Ma (e.g. ,(Sato, 1994; Regalla et al., 2013; Boston et al., 2017) and resultant mountain building with active surface erosion commenced in central Japan at ~2 Ma. The ~5-6Ma is the timing when the subduction of the Pacific Plate along the Izu-Bonin Trench switched from the trench retreat to advance as well-inferred from a geometry of subducted slab in the Izu-Bonin Trench (Miller et al., 2006; Faccenna et al., 2017). The recent compressive tectonic phase might be due to the initiation of convergence of the Amurian Plate with the Okhotsk Plate along the eastern margin of the Japan Sea and the strong punctuated collision and indentation of the Izu-Bonin Arc at ~6.0 Ma and ~1.0 Ma in central Japan.
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Keywords: Amurian Plate, Nankai Trough, Subduction, Collision, East Asia, Western Pacific

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[E] Oral | S (Solid Earth Sciences)：S-IT Science of the Earth's Interior & Techtonophysics

[S-IT30] Tectonic collision systems in continents and oceans

convener:Ling Bai(ITP Institute of Tibetan Plateau Research, Chinese Academy of Sciences), James Mori(Earthquake Hazards Division, Disaster Prevention Research Institute, Kyoto University), Xiaodong Song(University of Illinois at Urbana-Champaign), Yuzo Ishikawa(The National Institute of Advanced Industrial Science and Technology)

Collisions between continental plates and between continental and oceanic plates resulted in the formation of significant orogen and subduction systems worldwide, including the deepest trough and highest mountain in East Asia. The tectonic structures and seismic hazards associated with the collision processes have long been studied in order to understand fundamental features in these different tectonic environments. We invite contributions from scientists working across various temporal and spatial scales on problems related to lithosphere and mantle dynamics and surface processes for the collision zones. This session will provide a platform to encourage collaborations in all related disciplines, including geomorphology, paleoseismology, structural geology, tectonics, seismology, geodesy, and modeling.

[SIT30-01] **Seismic recordings of ice collapses along Yarlung Tsangpo Grand Canyon**

*Ling Bai[1], Yong Jiang[1], James Mori[2] (1.ITP Institute of Tibetan Plateau Research, Chinese Academy of Sciences, 2.Disaster Prevention Research Institute, Kyoto University)

[SIT30-02] Mountain height at convergent plate boundaries is controlled by the megathrust shear force

★Invited Papers

*Armin Dielforder[1], Ralf Hetzel[2], Onno Oncken[1] (1.Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences, Germany, 2.Institute of Geology and Paleontology, University of Muenster, Germany)

[SIT30-03] **Episodic Lithospheric Deformation in Eastern Tibet Inferred from Seismic Anisotropy**

★Invited Papers

*Xuewei Bao[1], Xiaodong Song[2,3], David Eaton[4], Yixian Xu[1], Hanlin Chen[1] (1.Key Laboratory of Geoscience Big Data and Deep Resource of Zhejiang Province, School of Earth Sciences, Zhejiang University, Hangzhou 310027, China, 2.Institute of Theoretical and Applied Geophysics, School of Earth and Space Sciences, Peking University, China, 3.Department of Geology, University of Illinois at Urbana-Champaign, USA, 4.Department of Geoscience, University of Calgary, Canada)

[SIT30-04] **Deformation of Tibetan plateau from recent seismic images: “thin skinned” or lithospheric tectonics?**

*Xiaodong Song[1,2], Jiangtao Li[3] (1.Peking University, China , 2.University of Illinois at Urbana-Champaign, USA, 3.Wuhan University, China)

[SIT30-05] **Subduction thermal regime, slab metamorphism and interplate earthquakes beneath Mariana based on 3-D numerical simulation**

*Yingfeng Ji[1] (1.Institute of Tibetan Plateau Research, Chinese Academy of Sciences)

[SIT30-06] Structural variation along the Main Himalayan Thrust in the source region of 2015 Gorkha earthquake, Nepal

*Chintan Timsina[1], James Mori[2], Masumi Yamada[2] (1.Department of Geophysics, Graduate School of Science, Kyoto University, 2.Disaster Prevention Research Institute, Kyoto University)

Seismic recordings of ice collapses along Yarlung Tsangpo Grand Canyon

*Ling Bai[1], Yong Jiang[1], James Mori[2]

1. ITP Institute of Tibetan Plateau Research, Chinese Academy of Sciences, 2. Disaster Prevention Research Institute, Kyoto University

Mass-wasting events occur often in the Tibetan Plateau in response to the active tectonics and global warming. On October 16, 2018 a large landslide induced by ice collapses occurred in the Yarlung Tsangpo Grand Canyon at the Sedongpu Basin, blocked the Yarlung Zangbo River, and generated a flood with water levels rising 40 m above the original water level.

Here we present a study of the dynamic processes using broadband seismic waveforms recorded by seismic stations we deployed around the Yarlung Tsangpo Grand Canyon. These stations are located very close to the source area with good azimuthal coverage. Data show emergent onsets with a duration about 400 s and a clear late phase. The time history of the high-frequency spectrum is distinct from the time history of the low-frequency spectrum. The estimated moment is about $2.5*10^{15}$ Nm, which is equivalent to a moment magnitude of 4.2.

In the same way we identified several other later events at similar locations. These events have duration times of 250-400 s. The seismic analyses allowed us to recognize a new form of glacier instability in terms of their dynamic source process. It is likely that the plate tectonics, the monsoon rains and the glacier melts may all have contributed to the triggering mechanism of these kind of disasters.

Keywords: ice collapses, Yarlung Tsangpo Grand Canyon, Seismic recordings

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Mountain height at convergent plate boundaries is controlled by the megathrust shear force

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1. Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences, Germany, 2. Institute of Geology and Paleontology, University of Muenster, Germany

Force balance considerations suggest that the height of mountain ranges at convergent plate boundaries depends on the shear force acting along the plate boundary megathrust. Whether this dependency indeed controls mountain height is, however, currently unknown and highly debated. In particular, climate-dependent erosional processes, such as glacial and fluvial erosion, are often assumed to exert a first-order control on mountain height, although this assumption has remained difficult to validate. To test whether mountain height is controlled by the megathrust shear force or by erosion, we constrained the shear force along active megathrusts from their rheological properties. We then determined the theoretical elevation supported by the megathrust shear force using a force balance model and compared it to the actual height of mountain ranges. Our results indicate that mountain height around the globe closely matches the force-controlled elevation, irrespective of climatic conditions and erosion rates. This finding indicates that mountain height is primarily governed by the megathrust shear force and that the upper plate is close to force equilibrium. We therefore propose that temporal variations in mountain height reflect long-term changes in the force balance, but are not indicative for a direct climate control on mountain elevation.

Keywords: Megathrust, mountain building, erosion

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Episodic Lithospheric Deformation in Eastern Tibet Inferred from Seismic Anisotropy

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Mechanisms for uplift and deformation of the Tibetan Plateau remain vigorously debated; hypotheses include stepwise growth, distributed thickening and crustal channel flow, each with a distinct anisotropic signature. We have developed a new azimuthally anisotropic shear-velocity model for the lithosphere beneath eastern Tibet, based on ambient-noise tomography from 643 seismic stations. In our model, the Tibetan upper crust is characterized by strong anisotropy with fast axes that correlate with surface geology and mantle anisotropy, suggesting the occurrence of coherent deformation. However, a much different picture emerges in the middle and lower crust, where anisotropy is disordered and weaker beneath the plateau than along its margins, inconsistent with the prediction of large-scale eastward crust flow in eastern Tibet. We propose a new deformation model for the plateau, in which early heterogeneous crustal thickening was a primary driver for plateau uplift and later disordered crust flow smoothed previous irregular structural relief and reset the mid-lower crustal anisotropy. Compatible with this model, we suggest that the southeastern plateau margin was raised likely by asthenospheric upwelling.

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Deformation of Tibetan plateau from recent seismic images: “thin skinned” or lithospheric tectonics?

*Xiaodong Song[1,2], Jiangtao Li[3]

1. Peking University, China , 2. University of Illinois at Urbana-Champaign, USA, 3. Wuhan University, China

Mechanisms for deformation and growth of the Tibetan Plateau (TP) have been debated for decades. The channel flow model has been popular, which suggests that the TP growth has been driven by mid-lower crustal flow and the upper crust deformation is decoupled from the lithosphere mantle, thus we may call it a “thin skinned” model. Here we present high-resolution seismic velocity images from our joint inversions in the TP margin, the interior, and in the Indian-Eurasia collision front, which suggest lithosphere-scale deformation throughout the TP. In NE margin of the TP, Deng et al. (GRL, 2018) found crustal low-velocity zones (LVZs) with variable strengths, anomalous Vp/Vs ratios that are correlated with LVZs, a large Moho jump, strong mantle lithosphere anomalies, and correlation of crustal and mantle velocities. The results suggest a lithospheric-scale deformation of continuous shortening as well as localized faulting, which is affected by the strength of the lithosphere blocks. The thickened mantle lithosphere can be removed, which facilitates the formation of middle-lower crustal LVZ and flow. However, such flow is likely a consequence of the deformation rather than a driving force for the outward growth of the TP. In the TP interior, strong correlations are also found between seismic velocities, Vp/Vs ratios, and seismicity in lithospheric blocks. In Southern TP, Li and Song (PNAS, 2018) found clear images of the Indian mantle lithosphere (IML), which suggest that the subducted IML is torn into at least four pieces. Intermediate-depth earthquakes in the lower crust and mantle are located almost exclusively in the high-velocity (strong) part of the Indian lithosphere. The tearing of the IML provides a unified mechanism for rifting, current crustal deformation, and seismicity in the southern and central TP and suggests that the deformations of the crust and the mantle lithosphere are strongly coupled.

Keywords: Tibetan plateau , deformation, lithosphere

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Subduction thermal regime, slab metamorphism and interplate earthquakes beneath Mariana based on 3-D numerical simulation

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The Marina arc system represents a typical mode of intra-oceanic convergent boundary characterizing cicum-Pacific subduction zones, together with the Izu-Bonin, Kuril and Tonga-Kermadec margins well known for the tectonically formed deep trenches. Active back-arc extension driven by hydrothermal mantle upwell comprises one of the significant features of Mariana caused by steep subduction. Previous studies document that the narrow subduction constrains the seismicity in Mariana to be less than M7. However, the subduction thermal regime remains still unclear in detail. Based on the 3-D thermal model constructed for Mariana, we found that the highly curved Mariana arc presenting such a particular tectonic setting caused by trench retreat produces a cold thermal structure beneath the central and northern Mariana influenced by an oblique subduction. The deep earthquakes (>100km) are therefore frequently detected compared with the southern Mariana. The subducted Pacific plate entraining the oceanic crust components is calculated to obtain their pressure-temperature conditions for different petrological faces undergoing multiple phase transition including the paths from amphibolite to eclogite or harzburgite at a high temperature of >500℃ which is conjectured to facilitate the deep earthquakes at Mariana. The dewatered oceanic plate is expected to releases ample fluids for the backarc volcanism and hydrous circulation at Mariana mantle wedge. The 3-D temperature structure of Mariana obtained in this study sheds lights on regional earthquake genesis and slab metamorphism in such an intro-oceanic subduction system featured by deep events.

Keywords: thermal regime, metamorphism, 3D modeling

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Structural variation along the Main Himalayan Thrust in the source region of 2015 Gorkha earthquake, Nepal

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1. Department of Geophysics, Graduate School of Science, Kyoto University, 2. Disaster Prevention Research Institute, Kyoto University

The 2015 Gorkha earthquake (M_w 7.8) in the central part of Nepal is the most studied earthquake in the Himalaya due to the availability of precise and multifaceted geodetic and seismic data. This earthquake is widely considered as the repetition of similar sized 1833 earthquake. Partial rupture, only at the down-dip portion of Main Himalayan thrust (MHT), during both 2015 and 1833 events contrasting the complete unlocked of whole seismogenic zone during great (M_w>8) earthquakes in the Himalaya strongly suggest the bimodal seismic behavior of the fault. Although, Gorkha earthquake occurred on relatively well-known section of MHT, both along and across-strike rupture segmentation models for MHT in this area are still a subject of hot debate.

Multiple studies on the Gorkha earthquake aftershock sequence have produce catalogs either from local and/or teleseismic arrival time data. All catalogs have similar features like two separate seismic belts located north and south of main coseismic slip area and narrow to broad along strike variation of northern belt, however, depths of the events among these catalogs vary significantly. Yamada et. al., (2019) produced the aftershock catalog by using an automatic onset and hypocenter determination procedure from continuous waveform recorded by 42 broadband and short period seismic stations deployed under the *Nepal Array Measuring Aftershock Seismicity Trailing Earthquake* (NAMASTE) network spanning the whole aftershock region from 25 June 2015 to 14 May 2016. In this study, we choose nearly 1500 aftershocks from around 15000 events of that catalog which are detected by more than 20 recording stations. The epicenters of these events cover the entire aftershocks zone and represent sufficient characteristics of aftershock sequence. We visually and manually inspect all the waveform and repick seismic phases arrivals. Using regional-scale double difference tomography, we simultaneously relocate the hypocenter and invert for both P and S-wave velocity models from these manually picked arrivals in the source regions of Gorkha earthquake. We compare our results with previously published catalogs and competing models for lithospheric structure in this area.

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[E] Oral | S (Solid Earth Sciences)：S-IT Science of the Earth's Interior & Techtonophysics

[S-IT31] Planetary cores: Structure, formation, and evolution

convener:Hidenori Terasaki(Faculty of Science, Okayama University), Eiji Ohtani(Department of Earth and Planetary Materials Science, Graduate School of Science, Tohoku University), Gerd Steinle-Neumann(Bayerisches Geoinstitut, Universitaet Bayreuth), William F McDonough(Department of Earth Science and Research Center for Neutrino Science, Tohoku University, Sendai, Miyagi 980-8578, Japan)

There are fundamental links between the formation and evolution of planets and their satellites to that of their cores both in terms of magnetic field generation and chemical and physical structure. Defining physical and chemical properties of the cores and core materials of these terrestrial bodies are therefore fundamental for understanding their internal structures and thermal profile. Recent advances in experimental and theoretical studies provide new insights into the Earth's cores and other terrestrial bodies, including the role of light elements in the early history of planets and at current times. Recent, current and future space missions have and will continue to obtain data on the internal structure of terrestrial planets (e.g., Mars and Mercury) and planet-satellite systems. We anticipate presentations on recent advances on the physical and chemical properties of cores and discussions regarding the latest views of their formation and evolution. We welcome contributions from mineral/rock physics, geophysics, geochemistry, geodynamics, and planetary science.

[SIT31-01] Compositional model for the terrestrial planets

*William F McDonough[1,2], Takashi Yoshizaki[3] (1.Department of Earth Science and Research Center for Neutrino Science, Tohoku University, Sendai, Miyagi 980-8578, Japan, 2.Department of Geology, University of Maryland, College Park, MD 20742, USA, 3.Department of Earth Science, Graduate School of Science, Tohoku University, Sendai, Miyagi 980-8578, Japan)

[SIT31-02] Anomalous is normal in planetary dynamos: A case of Mercury

★Invited Papers

*Futoshi Takahashi[1], Hisayoshi Shimizu[2], Hideo Tsunakawa[3] (1.Faculty of Sciences, Kyushu University, 2.Earthquake Research Institute, University of Tokyo, 3.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency)

[SIT31-03] Liquid Iron Alloys with Light Elements at Outer Core Conditions by First Principles

★Invited Papers

*Koichiro Umemoto[1], Kei Hirose[1,2] (1.Earth-Life Science Institute, Tokyo Institute of Technology, 2.Department of Earth and Planetary Science, The University of Tokyo)

[SIT31-04] **High-pressure melting experiments on Fe-Si-C; Implications for Si in the core**

*Masahiro Hasegawa[1], Kei Hirose[2], Kenta Oka[1] (1.Department of Earth and Planetary Science, The University of Tokyo, 2.Earth-Life Science Institute, Tokyo Institute of Technology)

[SIT31-05] Sound velocity of B2-FeNiSi alloy at high pressure determined with inelastic X-ray scattering: Implications for the composition of the Earth's inner core

Serena Dominijanni[1], *Eiji Ohtani[2], Daijo Ikuta[2], Tatsuya Sakamaki[2], Hiroshi Fukui[3], Catherine McCammon[1], Leonid Dubrovinsky[1], Hiroshi Uchiyama[4], Alfred Q.R. Baron[5] (1.Bayeriches Geoinstitit, University of Bayreuth, 2.Department of Earth and Planetary Materials Science, Graduate School of Science, Tohoku University, 3.University of Hyogo, 4.Japan Synchrotron Radiation Research Institute, 5.RIKEN)

Discussion

Compositional model for the terrestrial planets

*William F McDonough[1,2], Takashi Yoshizaki[3]

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Oxygen, iron, magnesium, and silicon comprised ~90% of the mass and atomic proportions of chondrites, the building blocks of the terrestrial planets, with about one of every two atoms being oxygen and 10% to 15% each of the atoms being iron, magnesium, and silicon. Chondrites have ~25% variation in Mg/Si and up to a factor of 3 difference in Fe/Si. This wide compositional variation in iron matches that seen in the core mass fractions of the rocky planets. The magnetic field strength of the protoplanetary disk, which scales as a function of radial distance from its central star, likely controlled this heterogeneous distribution of iron in the accretion disk and lead to decreasing core size of the terrestrial planets with radial distance outward from the Sun.

Keywords: planetary core, protoplanetary disk, magnetic field strength

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Anomalous is normal in planetary dynamos: A case of Mercury

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1. Faculty of Sciences, Kyushu University, 2. Earthquake Research Institute, University of Tokyo, 3. Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency

Recent satellite missions to planets and moons have discovered huge diversity in planetary magnetic fields. In particular, Hermean magnetic field is unambiguously different from the geomagnetic field in many respects. The most striking feature of the Hermean magnetic field is the north-south asymmetric morphology discovered by the MESSENGER mission. Such an asymmetric field is expressed by an axial dipole offset from the center of the planet by 0.2 planet’ s radius, whereas the geomagnetic field at the Earth’ s surface is well approximated by the geocentric axial dipole. Since the planetary magnetic field is generated in the outer core, such a notable difference in morphology should be explained by that in the dynamo action.

Here we use numerical dynamo models to see why Mercury has such an anomalous magnetic field. In the model, convection is thermocompositionally-driven in the liquid core with a thermally stably stratified upper layer. The present models well produce the magnetic field similar to observations. The dynamo-generated magnetic fields force the flows via the Lorentz force to interact so as to break the equatorial symmetry. As a consequence, core flows have significantly north-south asymmetric helicity, resulting in the maintenance of the asymmetric magnetic field due to biased dynamo action. This symmetry breaking magnetic self-regulation causes the flow to generate and maintain the Mercury’ s axially offset dipolar field. The result indicates that the Mercury’ s anomalous magnetic field is a natural consequence of the dynamo mechanism in the core.

Keywords: Mercury, dynamo, offset dipole, equatorial symmetry

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Liquid Iron Alloys with Light Elements at Outer Core Conditions by First Principles

*Koichiro Umemoto[1], Kei Hirose[1,2]

1. Earth-Life Science Institute, Tokyo Institute of Technology, 2. Department of Earth and Planetary Science, The University of Tokyo

Since the density of the outer core deduced from seismic data is about 10% lower than that of pure iron at core pressures and temperatures (*P-T*), it is widely believed that the outer core includes one or more light elements. Although intensive experimental and theoretical studies have been performed so far, the light element in the core has not yet been identified. Here we examine the density and bulk sound velocity of iron alloys with light elements, $(Fe,Ni)_x(H, Si, O, S, C)_{1-x}$, at Earth's outer core pressure and temperature conditions (~100 to 350 GPa, 4,000 to 7,000 K) based on first-principles molecular dynamics calculations. From molecular-dynamics results of binary alloys, density and bulk sound velocity of $(Fe,Ni)_x(H, Si, O, S, C)_{1-x}$ are estimated by ideal mixing. By comparing them with PREM, we constrain chemical compositions of the outer core which are compatible with PREM. Our results show that hydrogen and oxygen is a very potential candidate of light elements in the outer core, when the inner-core boundary temperature is relatively low and high, respectively. On the other hand, carbon is less preferable than other candidates. Based on the present results, we will be able to constrain light element composition further by taking into account other conditions: coexistence (e.g., Si and O cannot coexist in liquid iron alloys under the outer core condition), melting points, element partitioning between outer and inner cores, geochemical consideration, etc.

Keywords: Chemical composition of Outer core, Liquid iron alloys under high pressure, First principles

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High-pressure melting experiments on Fe-Si-C; Implications for Si in the core

*Masahiro Hasegawa[1], Kei Hirose[2], Kenta Oka[1]

1. Department of Earth and Planetary Science, The University of Tokyo, 2. Earth-Life Science Institute, Tokyo Institute of Technology

We performed melting experiments on the Fe-Si-C ternary system in a laser-heated diamond-anvil cell (DAC) at ~50, ~135, and ~200 GPa. Samples were recovered from a DAC and their cross-sections were prepared by focused ion beam (FIB). The chemical composition of quenched liquid and coexisting crystals were determined with a field-emission-type electron probe micro-analyzer (FE-EPMA). The results demonstrate the liquidus phase relations (showing a solid phase that crystallizes from liquid with a certain composition) in the Fe-Si-C ternary at each pressure. The Fe-Si-C ternary eutectic point moves toward more C-rich composition at higher pressure, which is in good accordance with the eutectic melting temperatures in the Fe-C and Fe-Si binary systems. In addition, in contrast to our previous work by Ozawa et al. (2016) that suffered contamination by carbon, we found that the Fe-Si binary eutectic point shifts toward the Si-rich side with increasing pressure. It likely includes more than 15 wt% Si at 330 GPa, suggesting that Si can be a major light element in the core, which explains the high Mg/Si ratio observed in the upper mantle.

Keywords: Outer core, Light elements, Melting experiments, Fe-Si-C ternary system

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Sound velocity of B2-FeNiSi alloy at high pressure determined with inelastic X-ray scattering: Implications for the composition of the Earth's inner core

Serena Dominijanni[1], *Eiji Ohtani[2], Daijo Ikuta[2], Tatsuya Sakamaki[2], Hiroshi Fukui[3], Catherine McCammon[1], Leonid Dubrovinsky[1], Hiroshi Uchiyama[4], Alfred Q.R. Baron[5]

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Geochemical and geophysical studies provide evidence that Earth’s core contains iron with 5-7 wt.% of nickel [1] and a small amount of light elements (such as silicon, sulfur, oxygen, hydrogen, and carbon) that can justify the observed density deficit with respect to pure iron [e.g., 2]. The cosmochemical abundance of Si and its involvement in chemical reactions at the core mantle boundary (CMB) indicate that it can be considered as one of the major alloying elements in the Earth’s core [1].

We measured the sound velocity of $Fe_{78}Ni_7Si_{15}$ alloy with a B2 structure at room temperature up to 90 GPa employing inelastic X-ray scattering to constrain the constitution of the inner core. The density of the alloy was also determined by X-ray diffraction under the same conditions. The relation of the P-wave velocity (v_P) and density (ρ) of B2-$Fe_{78}Ni_7Si_{15}$ alloy follows Birch’s law. We discuss the possibility that the inner core is composed of the B2-$Fe_{78}Ni_7Si_{15}$ alloy or the mixture of hcp and B2 alloys based on Birch’s law determined here for B2-$Fe_{78}Ni_7Si_{15}$ alloy and that for hcp-Fe and FeSi alloys reported previously [3, 4]

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Keywords: Sound velocity, Inner core, B2-FeNiSi alloy, High Pressure, Inelastic X-ray scattering

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[E] Oral | S (Solid Earth Sciences)：S-IT Science of the Earth's Interior & Techtonophysics

[S-IT31] Planetary cores: Structure, formation, and evolution

convener:Hidenori Terasaki(Faculty of Science, Okayama University), Eiji Ohtani(Department of Earth and Planetary Materials Science, Graduate School of Science, Tohoku University), Gerd Steinle-Neumann(Bayerisches Geoinstitut, Universitaet Bayreuth), William F McDonough(Department of Earth Science and Research Center for Neutrino Science, Tohoku University, Sendai, Miyagi 980-8578, Japan)

There are fundamental links between the formation and evolution of planets and their satellites to that of their cores both in terms of magnetic field generation and chemical and physical structure. Defining physical and chemical properties of the cores and core materials of these terrestrial bodies are therefore fundamental for understanding their internal structures and thermal profile. Recent advances in experimental and theoretical studies provide new insights into the Earth's cores and other terrestrial bodies, including the role of light elements in the early history of planets and at current times. Recent, current and future space missions have and will continue to obtain data on the internal structure of terrestrial planets (e.g., Mars and Mercury) and planet-satellite systems. We anticipate presentations on recent advances on the physical and chemical properties of cores and discussions regarding the latest views of their formation and evolution. We welcome contributions from mineral/rock physics, geophysics, geochemistry, geodynamics, and planetary science.

[SIT31-06] Rising or falling snow: Constraints on core composition from the F-layer

*Irene Bonati[1], Marine Lasbleis[2], John W Hernlund[1], Kei Hirose[1] (1.Earth-Life Science Institute,Tokyo Institute of Technology, 2.LPG Nantes)

[SIT31-07] **Fe alloy snow and fractional solidification at the lowermost outer core**

*Youjun Zhang[1], Peter Nelson[2], Nick Dygert[3], Jung-Fu Lin[2] (1.Sichuan University, China, 2.The University of Texas at Austin, USA, 3.University of Tennessee, USA)

[SIT31-08] Light elements in iron-hydrous silicate system: Searching for core formation process using in-situ high-pressure and high-temperature neutron and X-ray observations
★Invited Papers

*Riko Iizuka-Oku[1], Hirotada Gotou[2], Chikara Shito[1], Hiroyuki Kagi[1], Akio Suzuki[3] (1.Geochemical Research Center, Graduate School of Science, The University of Tokyo, 2.The Institute for Solid State Physics, The University of Tokyo, 3.Department of Earth Science, Graduate School of Science, Tohoku University)

[SIT31-09] Mass Transport and Structural Properties of Liquid Iron Alloys at high pressure from *ab-initio* simulations

*Gerd Steinle-Neumann[1], Esther S. Posner[1] (1.Bayerisches Geoinstitut, Universitaet Bayreuth)

[SIT31-10] Experimental examination of self-diffusion coefficient of iron under high pressure and its implication to the viscosity of the Earth’s inner core: a preliminary result

*Yohan Park[1], Kenji Ohta[1], Shoichi Itoh[2], Kei Hirose[3] (1.Tokyo institute of technology, 2.Kyoto University, 3.University of Tokyo)

Discussion

Rising or falling snow: Constraints on core composition from the F-layer

*Irene Bonati[1], Marine Lasbleis[2], John W Hernlund[1], Kei Hirose[1]

1. Earth-Life Science Institute,Tokyo Institute of Technology, 2. LPG Nantes

The crystallization of Earth’s solid inner core fuels convective motions inside the well mixed outer core and maintains dynamo activity through the fractionation of buoyant light elements. Seismic velocity reductions on top of the inner core boundary (ICB) have been attributed to the presence of a dense, stably stratified region, referred to as the F-layer. The generation and long-term stability of such a layer is thought to be driven by the continuous flux of solid particles, which buffers its composition to the liquidus. This can occur by means of a “falling snow” of solid hcp-Fe settling from the top of the F-layer towards the ICB, or through a “rising snow” of buoyant alloy-rich crystals fractionated from the crystallizing inner core. The different alloy concentrations with respect to the eutectic implied by these two scenarios, and the resulting processes taking place within the F-layer would provide useful insights on core composition.

We employ constraints from mineral physics and seismology to determine core binary alloy compositions that are consistent with different solid particle fluxes within the F-layer. By allowing for the propagation of uncertainties of physical and chemical alloy properties at ICB pressures, we compute the thermal and compositional gradients across the layer. We find that a rising snow scenario is associated with the presence of a Si-rich core alloy, whereas the crystallization of hcp-Fe at the top of the F-layer favors an O-dominated core. These differences have strong implications for the resulting heat flow budget and for the driving forces for convection, which are of compositional nature for an Si-rich core, and are dominated by high heat fluxes and core secular cooling for an O-rich scenario.

Keywords: Earth's core, F-layer, Core composition

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Fe alloy snow and fractional solidification at the lowermost outer core

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Refined seismological data shows a reduced compressional-wave gradient at the base of the outer core and seismic wave velocity asymmetry between the east-west hemispheres at the top of the inner core relative to the Preliminary reference Earth model (PREM) [1-6]. Based on recent high-pressure mineral physics data, we found that fractional crystallization of liquid Fe alloy (e.g., Fe-Si-O) with light element partitioning and a compositional gradient can explain the observed reduced velocity gradient at the base of the outer core. A fractionally crystallizing outer core implies the formation of a compacting cumulate pile at the boundary between the inner and outer cores, which may exhibit later variations between the east and west hemispheres. We propose that a slurry layer (F layer) and a compacting cumulate pile (F' layer) exist through Fe alloy snow and fractional solidification across the inner-core boundary [7]. Applying our model to seismic interpretations suggests the inner core has relatively high viscosity (~10^{23} Pa s, depending on the age of the inner core). These results are important to understanding the mechanism of the inner core formation and subsequent evolution. In this presentation, we will use recent mineral physics data and geodynamical models to constrain the formation processes of the F layer and address some seismic and geodynamic features of the uppermost inner core.

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Keywords: Inner core boundary, Slurry layer, Iron alloy snow, High pressure, Seismology

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Light elements in iron-hydrous silicate system: Searching for core formation process using in-situ high-pressure and high-temperature neutron and X-ray observations

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The Earth's core is considered to consist of Fe alloy with some light elements (H, C, O, Si, S). Hydrogen (H) is the most abundant element in the universe and one of the promising candidates for light elements in the Earth's core. However, its amount in the core and the process/contribution are still unknown because H cannot be experimentally detected using X-ray and it easily escapes from iron by the release of pressure. Recently, H contents in face-centered cubic (*fcc*)-Fe at high pressure and high temperature (high-PT) have been determined using in-situ neutron diffraction measurements [1–3]. Our previous study [2] suggested that H had preferentially dissolved into iron before the other light elements have dissolved in the early stage of Earth's evolution. Our final goal is to clarify the behaviors of multi light elements during the formation of Earth and other planetary cores. We have focused on sulfur (S) and investigated its effect on hydrogenation of iron (iron hydride) in Fe-hydrous silicate system using *in-situ* high-PT neutron and X-ray observations.

A starting material simulates an ideal composition of the primitive Earth, iron-enstatite ($MgSiO_3$) system with water. An Fe powder was pelletized and placed in the center of the capsule. Powder mixture of quartz (SiO_2), brucite $Mg(OD)_2$ (or MgO for comparison of water existence) surrounds the Fe pellet to avoid the contamination of carbon from the capsule into Fe. High-PT neutron diffraction experiments up to 6.5–11.5 GPa, 750 ˚C were performed using our original multi-anvil 6-6 type assembly [2] and a six-axis multi-anvil press "Atsuhime" installed at PLANET (BL11), J-PARC. The diffraction data obtained were refined using the Rietveld method to determine structural and atomic parameters of Fe polymorphs. *In-situ* X-ray imaging and diffraction measurements were also conducted at NE7A, PF-AR, KEK in order to identify the products and reaction process. A camera system with a high spatial resolution was newly developed to clearly observe the formation and motion of iron droplets in the silicate melts within the area of ~1 mm square. All the recovered samples were analyzed using an X-ray diffractometer and a SEM-EDS to more precisely identify the products, their compositions, and the elements partition.

A series of reactions (phase transitions of Fe, dehydration of $Mg(OD)_2$, and formation of FeS-V and silicates) were observed with temperature increase. X-ray radiography successfully visualized that Fe droplets coalesce together, migrate by thermal convection, and then sink to the core. The solubility of D in *fcc*-Fe increased with temperature (i.e., endothermic reaction) and also had positive correlation with pressure. The maximum D content *x* in *fcc*-FeD_x was about 0.25 at 11.5 GPa, 750 ˚C for the sample without sulfur, accompanied with a slow hydrogenation process through the redox reaction. On the other hand, the cell volume of FeS-V did not increase regardless of time, although sulfur seemed to inhibit the hydrogen dissolution into iron. Recovered samples exhibited that S and Fe were not mobile and could not react with each other without water, suggesting that the formation of FeS was promoted in the presence of water. Sulfur seemed to be a siderophile element and selectively concentrated at the Fe surface to reduce the interfacial energy. Both H and S can be preferentially incorporated into solid Fe and lower the melting point. It suggests that the other light elements (C, O, Si) could have dissolved into molten iron hydride and/or FeS in the later process of Earth's core-mantle differentiation at much higher-PT condition.

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Keywords: light elements, Core-mantle formation, in-situ high pressure and high temperature observation, hydrogen

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Mass Transport and Structural Properties of Liquid Iron Alloys at high pressure from *ab-initio* simulations

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Earth´s core is composed mostly of an Fe-Ni alloy with substantial yet unknown concentrations of additional elements.The question of core composition is particularly important because it directly relates to the conditions under which the core formed during accretion. It is well known from a comparison of seismic observations and shock wave or static experiments that the Earth's core must contain significant amounts of elements lighter than iron. The onset and evolution of Earth's geodynamo is also intimately related to the core's light alloy budget due to their chemical buoyancy associated with fractional crystallization of the inner core. Geophysically significant elements alloying with Fe and Ni in Earth´s core must satisfy a number of requirements: (i) high cosmochemical abundance, (ii) solubility in liquid iron under conditions of the core-mantle differentiation, and (iii) matching density and sound wave velocities of the bulk alloy liquid with seismic observations.The geophysically most interesting and discussed alloy components for the Earth's core are H, C, N, O, Mg, S, Si, and Ni. The incorporation of alloying elements in solid metals is well understood to be controlled by the radius ratio of a central and packing atoms. Although liquids fundamentally lack long-range periodicity, their short-range order can be used to make realistic predictions of "liquid packing structure" which in turn can be used to estimate the dominant incorporation mechanism (i.e., substitutional or quasi-interstitial) of a given alloying element. Importantly, when the compressibilities of two atom types differ significantly, coordination values will vary as a function of *P* and *T*, which can affect solubility and partition coefficients. The compression behavior of liquid iron alloys over a planetary-scale *P-T* range is therefore particularly relevant for estimating alloying element behavior under conditions beyond those accessible in the laboratory. We determine mass transport and structural properties of binary liquid iron alloys over a wide density (5.055-11.735 g/cm^3) and *T*-range (2,500–6,500 K) using first-principles molecular dynamics. Compositions consist of 96 at% Fe and 4 at% light element (H, C, N, O, Mg, Si, S, or Ni). Self-diffusion coefficients (*D*) of Fe and the alloying elements range from $3.5{\cdot}10^{-9}$ to $1.9{\cdot}10^{-7}$ m^2/s, and results show a relation between mean atomic radius and *D* ratios for the alloying element and iron: Si and Ni are “iron-like” with similar atomic radii and *D* compared with those of Fe; H, C, N, O, and S are “small non-iron-like” with smaller atomic radii and larger *D*; Mg transitions from “large non-iron-like” with a larger atomic radius and smaller *D* at low density to iron-like under conditions of the Earth's core. The effect of pressure on *D* for C, N, and O is negligible for densities below ~8 g/cm^3, accompanied by an increase in average coordination numbers to ~6, and an increase in mean atomic radii. For densities above ~8 g/cm^3, *D* and atomic radii of these elements decrease monotonically with *P*, which is typical for the iron-like alloying elements as well as for H, Mg, and S over the whole compression range.While atomic radius ratios move toward unity with compression, diffusivity ratios for the alloying element relative to iron tend to increase for the “non-iron-like” elements with density.

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Keywords: iron alloys, liquid metals, diffusion, liquid structure

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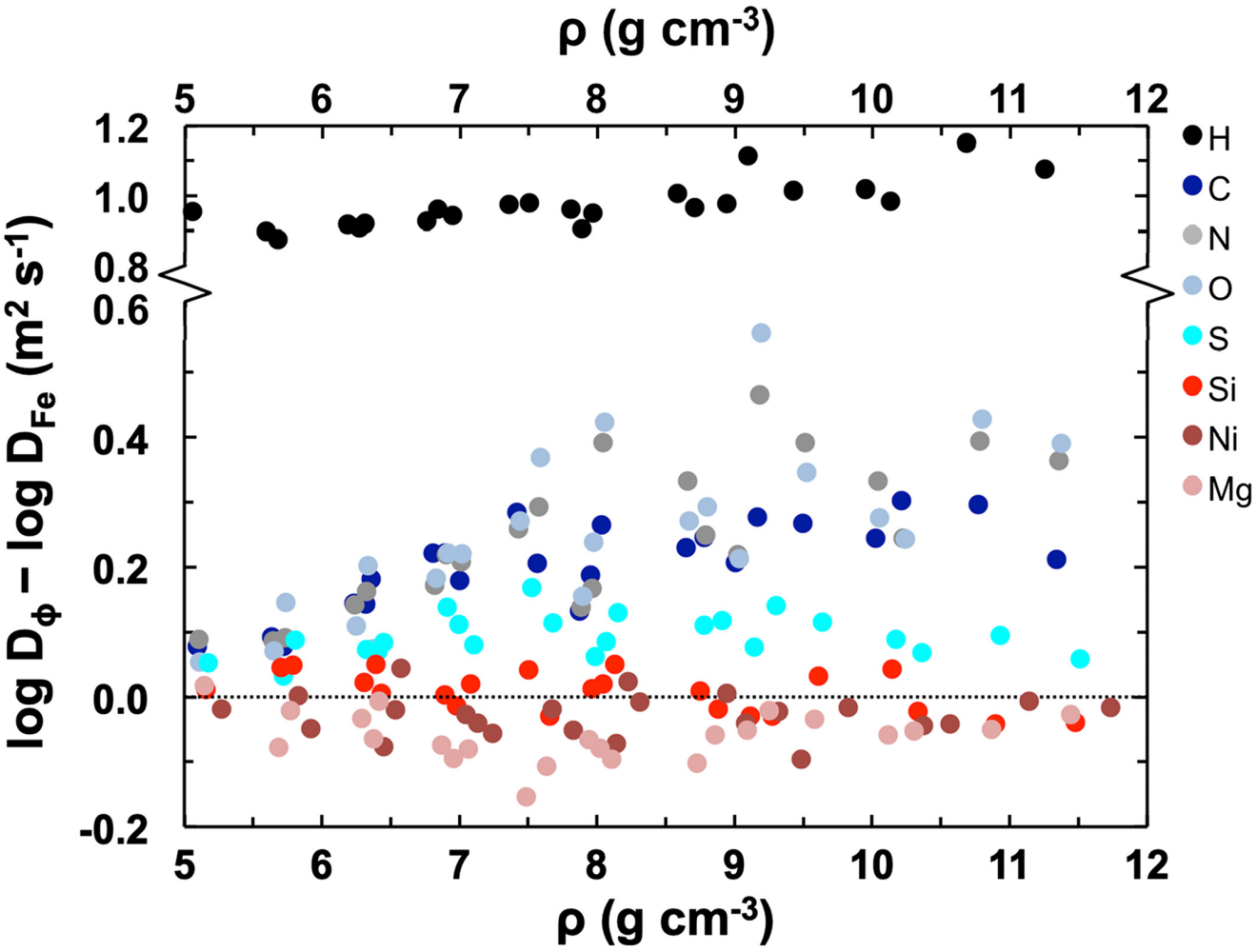

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Experimental examination of self-diffusion coefficient of iron under high pressure and its implication to the viscosity of the Earth’s inner core: a preliminary result

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Complex seismic anisotropy of the Earth’s inner core suggests various possible mechanisms for its dynamics. However, viscosity of the inner core, the key parameter to investigate its dynamical processes, is one of the most vaguely known physical properties. Knowing self-diffusion coefficient of iron, the main component of the Earth’s core, under high pressure is crucial to understand viscous flow in the inner core since pressure effects on viscous behavior of metals are generally related to pressure dependence of its self-diffusion coefficient. While Fe-Ni inter-diffusion experiments under high pressure have been conducted as a proxy of iron self-diffusion, to our knowledge, pressure effects on self-diffusion coefficient of iron have never been experimentally studied. Here, we performed diffusion experiments on iron under high pressure by using internally resistive heated diamond anvil cell (IHDAC) to evaluate pressure effects on self-diffusion coefficient of iron. Diffusion couple composed of ^{56}Fe-rich and ^{57}Fe-rich layers was loaded into IHDAC and heated by joule heating from its own electrical resistivity. Temperature of ~1840 K was maintained under pressure condition of ~30 GPa during diffusion experiment. Planck radiation from the heated hot spot was collected and used for temperature estimation. After heating, the sample was recovered and subsequently polished to make a cross section across the diffusion boundary. Secondary Ion Mass Spectrometry (SIMS) analysis on the cross section of the heated diffusion couple was conducted to obtain iron isotopes distributions, hence diffusion profiles. Quantitative reliability of our diffusion profiles is currently under estimation. The diffusion coefficients of iron will be extrapolated to the actual inner core pressure-temperature conditions and applied further to the known flow law of metals for estimating viscosity of the inner core.

Keywords: self-diffusion, inner core, viscosity, diamond anvil cell, SIMS

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[E] Oral | S (Solid Earth Sciences)：S-GL Geology

[S-GL33] Geologic structure and tectonic history of East Asia and Japanese Islands

convener:Jun Hosoi(Geological Survey of Japan, Institute of Geology and Geoinformation, AIST), Makoto Otsubo(Geological Survey of Japan, Research Institute of Earthquake and Volcano Geology)

The main aim of this session is to discuss geologic structure and tectonic history of East Asia, especially of Japanese Islands, on the basis of the recent results of geology and other earth sciences.

[SGL33-01] **Sedimentary History of the Ryukyu Group on Okinawa Island, southwestern Japan**

*SHUYIN CHENG[1], Yasufumi Iryu[2], J Bruce H Shyu[1] (1.National Taiwan Univ., 2.Tohoku Univ.)

[SGL33-03] Temporal changes of Cenozoic volcanic rock petrochemistry in Oki-Dogo, SW Japan

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[SGL33-04] Highly scattered paleomagnetic directions of middle Miocene volcanic rocks in the Inase area in Northeast Japan: vertical-axis rotations?

*Hiroyuki Hoshi[1], Miki Ohashi[2] (1.Department of Earth Sciences, Aichi University of Education, 2.Graduate, Aichi University of Education)

[SGL33-05] Stratigraphy and sedimentary facies of the Late Jurassic Nakanosawa Formation, Somanakamura Group: Facies changes from wave-dominated siliciclastic facies to lagoonal carbonate facies and their significance

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[SGL33-06] Origin of alkali basalts in Late Jurassic to Early Cretaceous accretionary complex in Amami–Oshima Island, Ryukyu Arc

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Sedimentary History of the Ryukyu Group on Okinawa Island, southwestern Japan

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Limestone consists mainly of skeleton and shells of marine calcifiers and their fragments. Therefore, the *in situ* composition of limestones is generally sensitive to sea level fluctuations and their lithofacies can be used as an important indicator of sedimentary environments. Okinawa Island is located at the boundary between coral-reef and non-coral-reef region in the present-day northwestern Pacific. Previously, Sagae et al. (2012) investigated many field outcrops and drill cores of the Pleistocene Ryukyu Group in southern Okinawa Island, and interpreted limestone lithofacies, environmental succession, and sequence stratigraphy. This study builds on these results and adds new field and drill core data to further consider the influence of regional sedimentary environment and tectonic movements to the limestone formation in southern Okinawa Island. We aim to integrate and reconstruct the sedimentary history of the Ryukyu Group, and to compare it with global paleoclimate change.

The Pleistocene Ryukyu Group can be divided into the Itoman, Naha, and Minatogawa formations in ascending order. The deposition of the Ryukyu Group began after the warm Kuroshio Current had flowed into the Okinawa Trough in the early Pleistocene. The initial period is characterized by the contemporaneous deposition of both the Itoman Formation and the lower part of the Naha Formation, but in different environments (reef and off-reef environment, respectively). The Itoman Formation mainly consists of coralline algae with low species diversity formed in a shallow setting (20-50 m water depth), which is an important character in the initial phase of the Ryukyu Group. Subsequently, the main part of the Naha Formation deposited at largely varied water depths (0–150 m). This formation is divided into four lithologic units and can be correlated with marine isotope stages (MIS). The widely distributed unconformity between Unit 3 and Unit 4 is likely caused during the sea-level lowstand at MIS 16. The Minatogawa Formation overlies the Naha Formation with a clear unconformity and deposited during the highstand at MIS 5, 7, or 9. The general sedimentary architecture described above is present throughout the Ryukyu Islands but with spatial and temporal variations, and may provide information toward reconstructing detailed tectonic evolution models for the Ryukyu Islands.

Keywords: Ryukyu Islands, Okinawa, Ryukyu Group, Itoman Formation, Naha Formation, sedimentary environment

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Temporal changes of Cenozoic volcanic rock petrochemistry in Oki-Dogo, SW Japan

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Introduction

Oligocene-Pleistocene volcanic rocks and sedimentary rocks are distributed in Oki-Dogo island, SW Japan, overlying on Paleo-Mesozoic Oki metamorphic rocks and Paleocene-Eocene Dogo Minamidani Granites. Alkaline basalts after Pliocene frequently include peridotite xenoliths brought from upper mantle. These peridotites are considered the residue of abundant basaltic magma, which was produced during Japan Sea back-arc basin opening (e.g., Abe et al., 2003).

Cenozoic volcanism changed from sub-alkalic magma activity with some alkalic rocks at pre- to syn-opening of Japan Sea back-arc basin to completely alkalic magma activity at post-opening back-arc basin (Suzuki et al., 2009). However, petrochemical features of Cenozoic volcanic rocks are still not well reported. In this study, we discuss about petrochemical temporal changes of Cenozoic volcanic rocks in Oki-Dogo island, associating with Japan Sea back-arc basin opening.

Geology and petrography

We study about Oligocene-Pleistocene volcanic rocks from Oki-Dogo island in this study. Tokibariyama Formation (Oligocene-Early Miocene) is composed of moderately altered andesitic pyroclastic rocks, sometimes accompanying the accretionary lapilli. Phenocryst assemblages are altered plagioclase, clinopyroxene, orthopyroxene and hornblende. Kori Formation (Early Miocene) is mainly composed of basaltic lava and pyroclasts. Phenocryst assemblages are plagioclase, clinopyroxene, olivine and orthopyroxene. Olivines are absolutely altered.

Keywords: Mantle Xenolith, Japan Sea Back-Arc Basin Opening, Oki island, Cenozoic Volcanic Rocks

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Highly scattered paleomagnetic directions of middle Miocene volcanic rocks in the Inase area in Northeast Japan: vertical-axis rotations?

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We present paleomagnetic data showing highly scattered remanent magnetization directions obtained from middle Miocene (ca. 15 Ma) andesitic rocks in the Inase area in Northeast Japan. The aim of this study was originally to elucidate the timing of termination of counterclockwise rotation of entire Northeast Japan that occurred in association with backarc opening of the Japan Sea by determining a paleomagnetic direction of dated volcanic succession. Surprisingly, however, andesitic lavas and intrusive rocks in this area showed a fairly large dispersion of site-mean directions of characteristic remanent magnetizations (ChRMs).

Oriented rock samples were collected at 22 sites, and standard paleomagnetic analyses including stepwise demagnetization experiments were conducted to obtain reliable ChRMs. Of 20 site-mean directions determined, 19 were successfully corrected for gentle post-emplacement tilt. They have both positive and negative inclinations and show considerable scatter in the declinations, although many of the directions are northerly to easterly when the directions with negative inclinations are flipped. It seems that the scatter in the inclinations is relatively small compared to that in the declinations; the directions yield a best-fit small circle with an almost vertical conical axis. An inclination-only calculation gives a mean inclination of ca. 47˚, which is close to the middle Miocene inclination value expected in the study area. Demagnetization data indicate that the main magnetic mineral carrying ChRMs is magnetite or Ti-poor titanomagnetite.

Two possible mechanisms can explain the observed scatter of the directions. One is that the sampling sites are within ancient hummocks in volcanic debris avalanche deposits. During a debris avalanche event, hummocks can rotate around vertical axes like teacups of an amusement ride, and such movement can result in the distribution of site-mean directions along a small circle. However, we do not prefer this mechanism because we have no geological observations supporting a debris avalanche origin of the volcanic formation in this area. Another mechanism that can cause the distribution of directions along a small circle is vertical-axis tectonic rotations. These rotations could be related to what a recent model suggests: the western half of Northeast Japan was broken into several “dominos” by middle Miocene strike-slip faulting. The Inase area is located near the eastern end of the possible dominos, and domino rotations might have resulted in vertical-axis rotations of smaller blocks near the end of the dominos. This hypothesis could be tested by structural mapping in the Inase area.

Keywords: middle Miocene, Northeast Japan, paleomagnetism, vertical-axis rotation

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Stratigraphy and sedimentary facies of the Late Jurassic Nakanosawa Formation, Somanakamura Group: Facies changes from wave-dominated siliciclastic facies to lagoonal carbonate facies and their significance

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The Somanakamura Group, distributed along the eastern margin of the Abukuma Mountains from Minami-soma City to Soma City, Fukushima Prefecture, is one of infrequent well-exposed successions of the Middle Jurassic to lowest Cretaceous strata in Japan. It constitutes of 1) Awazu, 2) Yamagami, 3) Tochikubo, 4) Nakanosawa,5) Tomizawa,6) Koyamada Formation in ascending order. Because the marine (1,2,4,6) and fluvial (3,5) strata are alternated, the Somanakamura Group records the sedimentary cycles of fluvial, shallow-marine, lagoonal sedimentary environments along the eastern margin of paleo-Asian continent. The Nakanosawa Formation includes dark gray lagoonal limestone in the upper Koike Limestone Member regarded as the Torinosu-type Limestone typically known in Shikoku, Southwest Japan, and the Torinosu-type bivalve fauna mainly from the lower Tatenosawa Sandstone Member. The Nakanosawa and Koyamada formations are correlated with the Kimmeridgian to Tithonian, and Berriasian, respectively, based on ammonite biostratigraphy.

Resulting from the correlation of sedimentary facies distribution along six well-exposed study sections, the Tatenosawa Member about 100 to 150 m thick forms a coarsening-upward succession above the underlying fluvial sandstone of the Tochikubo Formation with a sharp and flat erosional ravinement surface, composed of five sedimentary facies associations (FA) in ascending order, 1) FA-E: granule-bearing coarse to medium sandstone (transgressive lag); 2) FE-D: alternated hummocky cross-stratified fine sandstone and bioturbated fine sandstone/sandy siltstone (lower shoreface to inner shelf); 3) FA-C: trough cross-stratified medium to coarse sandstone (upper shoreface); 4) FA-B: bioturbated fine sandstone with bivalve shell beds (inner bay); 5) FA-A: carbonate sandstone to limestone (carbonate lagoon). This facies trend indicates continuous shallowing and regressive changes of sedimentary environments under wave-dominated shallow sea after the rapid transgression following the fluvial setting of the Tochikubo Formation.

The Koike Limestone Member (FA-A) 30 to 50m thick generally constitutes of five repetitive successions of oncoid facies with swarmed bivalve and nerineid gastropod shells and nodular facies bearing in situ coral. These successions suggest that five at least minor relative sea-level changes possibly less than 20 m amplitude occurred from wave-dominated barriers and nearby to stagnant central lagoon and the further coastward area.

The formation contains four type of bivalve fossil beds each of which has an unique association: E) Shell concentrations with a basal transgressive lag and d) *Protocardia tosensis* -*Plagiostoma enormicosta* Association; D) Scatterd shells in HCS fine sandstone and c) *Astarte sakamotoensis* -*Nipponitrigonia sagawai* Association; B) Lenticular shell concentrations in calcareous silty sandstone and mix of b) *Neocrassina subdepressa* - *Protocardia tosensis* Association and *Gervillia tatenosawaensis* - *Pinna* cf. *mitis* Association; A) Patchy shell concentrations in silty limestone and a) *Pteria masatanii* -*Trichites* sp.

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Association.

Based on the recognized facies successions, their inferred sedimentary environments, and bivalve facies changes, interpreted sequence stratigraphy, the Nakanosawa Formation can be interpreted as a third-order depositional sequence formed by a series of transgression and subsequent regression during the late Jurassic time. Furthermore, we consider the paleogeographic significance of the Nakanosawa Formation as well as the Torinosu-type Limestone and Torinosu-type bivalve fauna.

Keywords: Jurassic, sequence stratigraphy, paleogeography, Somanakamura Group, Nakanosawa Formation, Northeast Japan

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Origin of alkali basalts in Late Jurassic to Early Cretaceous accretionary complex in Amami–Oshima Island, Ryukyu Arc

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Basaltic rocks in exhumed accretionary complexes are important for understanding past volcanism on oceanic plate. The basalts intruding into pelagic chert were found from Late Jurassic to Early Cretaceous accretionary complex in Amami–Oshima Island, Ryukyu Arc. However, origin of the basaltic intrusive rocks remains unkown. Here, we conducted geological and geochemical studies on the basalts by using X-ray fluorescene and Inductively Coupled Plasma-Mass Spectrometry. At Naon and Oganeku, the basaltic intrusive rocks are distributed as 100–500m sized blocks in the mélange. In Naon, a massive basalt underlies pelagic radiolarian chert, and two basaltic dikes cut both the massive basalt and chert. In Oganeku, 3–m–thick basaltic sill intrudes pelagic radiolarian chert, which overlie above dolerite. The age of radiolarian chert indicates that intrusion of basalts occurred after Permian. These features suggest that basaltic inrusive rocks were originated from intraplate volcanism and then were incorporated as blocks in overlying plate. In chondrite–normalized rare earth element (REE) patterns, the massive basalt and basaltic dikes in Naon and basaltic sill in Oganeku exhibit light REEs–enriched pattern similar to alkali basalts, while dolerite in Oganeku shows no enrichment in REEs that is similar to N–MORB. In primitive mantle–normalized muti–trace element patterns, the massive basalt in Naon shows negative Zr, Hf, and Ti anomalies, which is similar to petit spot basalts in northwest pacific plate. On the other hand, basaltic dikes in Naon and basaltic sill in Oganeku do not show negative Zr anomaly. Geological and geochemical features of basalts in Naon and Oganeku sugegst that alkali basalts intruded after deposition of pelagic radiolarian chert, but the intrusive event was before subduction, suggesting that part of which could represent petit spot volcanism in incoming oceanic plate.

Keywords: Alkali basalt, Late Jurassic to Early Cretaceous accretionary complex

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[E] Oral | S (Solid Earth Sciences)：S-GL Geology

[S-GL33] Geologic structure and tectonic history of East Asia and Japanese Islands

convener:Jun Hosoi(Geological Survey of Japan, Institute of Geology and Geoinformation, AIST), Makoto Otsubo(Geological Survey of Japan, Research Institute of Earthquake and Volcano Geology)

The main aim of this session is to discuss geologic structure and tectonic history of East Asia, especially of Japanese Islands, on the basis of the recent results of geology and other earth sciences.

[SGL33-07] Cretaceous Amur sedimentary complex in the Kiselevka area, Far East Russia: Cretaceous history of accretion and rearrangement

*Shigeru Otoh[1], Yuko Miyake[2], Mitsuhiro Nagata[2], Alexei Didenko[3], Alexander Kudymov[3], Mikhail Arkhipov[3], Koshi Yamamoto[4] (1.Academic Assembly, Faculty of Sustainable Design, University of Toyama, 2.Graduate School of Science and Engineering, University of Toyama, 3.Kosygin Institute of Tectonics and Geophysics, FEB, Russian Academy of Science, 4.Graduate School of Environmental Studies, Nagoya University)

[SGL33-08] Geological and thermal structures along the Butsuzo Tectonic Line in the eastern Kyushu

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[SGL33-09] Early Paleozoic zircon U-Pb age for high P/T-type metagabbro from western Tokyo

*Hikaru Sawada[1], Yukio Isozaki[2], Shuhei Sakata[2] (1.Japan Marine Science and Technology Center, 2.The University of Tokyo)

[SGL33-11] **3-D magnetic imaging of Taiwan region**

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Discussion

Cretaceous Amur sedimentary complex in the Kiselevka area, Far East Russia: Cretaceous history of accretion and rearrangement

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Introduction

Jurassic to Cretaceous sedimentary complexes cut by the Central Sikhote-Alin Fault (CSF) widely occur in the Kiselevka area (around 51° 25′ N, 139° 00′ E), the northeastern part of the Khabarovsky Kray, Far East Russia. These sedimentary complexes, striking northeast and dipping to the west, comprise the Kiselevka–Manoma, Amur, and Badzhal complexes, in apparent ascending order.

The Jurassic to Early Cretaceous Badzhal Complex in this area is the northern extension of the Nadanhada accretionary complex (AC) in Northeast China and the Tamba-Mino-Ashio AC in the Inner Zone of Southwest Japan. The Cretaceous Amur Complex lies beneath the Badzhal Complex and consists of an AC and a graben-fill, coarse sedimentary sequence. The AC mainly comprises turbidite, with minor chert, siliceous mudstone, bivalve-bearing siltstone, HCS sandstone, and conglomerate. The complex occupies 100 km in width (E–W) and 650 km in length (N–E). The Cretaceous Kiselevka–Manoma Complex is a relatively thin AC consisting mainly of basalt, red chert, and red siliceous shale with minor amounts of limestone, mudstone, and sandstone. Jurassic to Middle Aptian radiolarians have been reported from the complex (Zyabrev et al., 2015; Bragin and Bragina, 2017), and Zyabrev et al. (2015) suggested that the age of accretion of the complex was Late Aptian–Middle Albian.

The AC of the Amur complex can be correlated with the northern part of the Cretaceous Shimanto AC in the Outer Zone of Southwest Japan, the Northern Shimanto Terrane of Yanai (1984). The two complexes commonly contain shallow-marine rocks and overlap in age. Such a thick Cretaceous AC is absent in the Inner Zone of Southwest Japan. We hence think that the Kiselevka area is one of the best fields to study the late Mesozoic history of accretion and rearrangement in the eastern margin of Asia.

Samples and Methods

The Amur Complex in the Kiselevka area consists of three formations: the Zhorma, Silusu, and Utitza formations from the oldest (e.g., Kirillova and Anoikin, 2011). The Zhorma (western) and Silusu (eastern) formations are AC, whereas the Utitza Formation is a graben-fill sedimentary sequence. The AC is assumed to have formed in the Late Aptian to Middle Albian on the basis of radiolarian fossils from pelagic siliceous rocks and mudstone (Zyabrev et al., 2015). We collected five sandstone samples from the Zhorma Formation, six from the Silusu Formation, one from the Utitza Formation, and one sandstone pebble from the conglomerate of the Utitza Formation. We extracted zircons from these samples and conducted U–Pb dating with the LA-ICPMS equipped in the Graduate School of Environmental Studies of Nagoya University.

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Results

We calculated the weighted mean of the 206Pb/238U ages of the youngest age cluster for each rock sample and regarded it as the maximum depositional age (MDA). The MDA of the sandstone samples of the Zhorma, Silusu, and Utitza formations fall between 115–100 Ma (latest Aptian–earliest Cenomanian), 97–85 Ma (Cenomanian–Santonian), and 73–67 Ma (latest Campanian–Maastrichtian), respectively. The MDA of the sandstone pebble from the Utitza Formation is 98–87 Ma (Cenomanian–Coniacian).

Discussion

Our study revealed that the age of sedimentation of the Amur complex, at least partly, lasted until Late Cretaceous. The MDA of sandstone samples of the Silusu Formation (97–85 Ma: Cenomanian–Santonian) suggests that the formation accreted significantly later than the Kiselevka–Manoma Complex, indicating post-accretionary, Cenomanian or later rearrangement of ACs. The movement of the CSF, long supposed to be of Early Cretaceous in age (e.g., Khanchuk et al., 2016), must have lasted until Cenomanian or later.

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Keywords: U-Pb age, zircon, Cretaceous, accretionary complex, Central Sikhote-Alin Fault

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Geological and thermal structures along the Butsuzo Tectonic Line in the eastern Kyushu

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INTRODUCTION The age gap of 20-30 My exists between the Butsuzo Tectonic Line (BTL), bounding the Southern Chichibu and Shimanto Belts distributed in the outer zone of southwestern Japan. The cause of the gap has been explained by tectonic erosion with the subduction of the plateau (Wakita et al., 2018) or reactivation of the BTL (YORG, 2012), but no clear conclusion has been found. Recently, the thermal structure has been estimated along the BTL in the Kanto Mountains and Shikoku region (Sakaguchi, 1996; Hara et al., 1998).
In the eastern Kyushu region, the gap of maximum temperature exists across the BTL (Ohmori, 1999). Elucidation of the causes of these gaps is important to understand the tectonics of the Jurassic to Cretaceous accretionary complexes. However, the thermal structure along the BTL has not been investigated enough. Then, in this study, geological survey and Rm measurement were carried out to investigate the thermal structure of the Southern Chichibu and Shimanto Belts distributed in the Saiki area, Oita Prefecture.

GEOLOGICAL SETTING The Southern Chichibu Belt (the Shakumasan and Yukagi units, with Tsui formation) is separated from the Cretaceous Shimanto Belt (Lower Saiki subgroup) on the south by the BTL. The Shakumasan unit (the imbrication of oceanic plate stratigraphy) and the Yukagi unit (the mé lange facies) are overlain by the Tsui formation (the shelf and forearc facies). The U-Pb ages of each unit are 158 Ma for the Shakumasan unit, 144 Ma for the Yukagi unit, 140 Ma for the Tsui formation, and 108 Ma for the Lower Saiki subgroup.

METHOD 1-8 samples were collected from the sandstone of each unit for the Rm measurement. The pulverized samples were sieved and the carbonaceous materials were separated using heavy liquid. The carbonaceous materials were observed by a reflection microscope, and the reflectance of vitrinite was measured. The equation of Sweeney and Burnham (1990) was used for temperature conversion.

RESULTS In the Southern Chichibu Belt, the Rm values were 3.14% for the Shakumasan unit and 2.83-3.04% for the Yukagi unit. The Rm values of the Tsui formation were 1.24-2.03%, those are 0.8-1.9% lower than those of the Shakumasan and Yukagi units. On the other hand, the Rm value of the Lower Saiki subgroup was 2.08%, that is 0.75-0.96% lower than those of the Yukagi unit.

DISCUSSION The thermal structure of the central Shikoku indicated no change in the Rm values across the BTL. This is explained that the previous thermal structure was overprinted by the subduction of the Kula-Pacific ridge under the Cretaceous accretionary prism (Sakaguchi, 1996).
On the other hand, in the eastern Kyusyu, the Rm values drastically changed across the BTL. This suggests that the BTL cut the original thermal structure. This thermal structure could be explained by two possible scenarios. The first one is that the timing of heating due to the subduction of the Kula-Pacific ridge or the young oceanic plates was different. Kinoshita and Ito (1986) proposed the model of the Kula-Pacific ridge subduction, which assumes that the ridge moves from west to east in relation to the trench. Based on this model, it is possible that the subduction of the oceanic ridges and the associated overheating of geology occurred earlier in the eastern Kyusyu than in the central Shikoku. The second one is that the timing of

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the BTL activity differs. Although the BTL has not been active after the subduction of the oceanic ridges or the young oceanic plates in the central Shikoku, it had been active after the subduction of them in the eastern Kyusyu. The reactivation of the BTL has been reported in the Kii Mountains (YORG, 2012). These findings suggest the possibility of regional heterogeneity in the activity of the BTL.

Keywords: Eastern Kyusyu, Southern Chichibu Belt, Butsuzo Tectonic Line, Vitrinite reflectance, Thermal structure, Ridge subduction

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Early Paleozoic zircon U-Pb age for high P/T-type metagabbro from western Tokyo

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The Japanese Islands are composed of the subduction-related orogenic belt which has evolved since the Early Paleozoic. Among them, most parts of the Paleozoic ones have been fragmented through orogenic activities as represented by the Kurosegawa belt which is a discontinuous serpentinite mélange zone with disrupted tectonic blocks. In this presentation, we discuss zircon U-Pb age and trace element analysis for high P/T-type metagabbro from Hinode town in western Tokyo which is considered to be the eastern extreme of the Kurosegawa belt. The zircon grains were obtained from lawsonite vein in the high P/T-type metamorphic rocks which are white, pale purple or pale green in colour and up to 10 cm in width, and some void parts of the vein contain ~3 mm euheral crystals of lawsonite. The zircons were dated ca. 490-480 Ma (late Cambrian-early Ordovician), which is coeval with ages of similar rocks in the Kurosegawa belt in Kii Peninsula and Kyushu. This result indicates that the high P/T-type metamorphic belt with protolith of early Paleozoic ophiolite existed in the Paleo-Japan arc which had over 1,000 km length from Kyushu to Tokyo region.

Keywords: Kurosegawa belt, zircon age, Lawsonite, Cambrian, Ordovician

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3-D magnetic imaging of Taiwan region

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Taiwan is located in a collision area of the Eurasian Plate and the Philippine Sea Plate. To understand the geological structure of Taiwan, we construct a 3-D magnetic tomography underlying around the Taiwan region (21.8˚ N–25.3˚ N and 120.0˚ E–122.0˚ E). The region was divided into 55×28×10 grids with a grid size of 7×7×5 km^3 from surface to 50 km in depth. The island-wide magnetic anomaly data were used to constrain magnetic induction field from the magnetization of each grid by using a conventional inversion method. The L-curve criterion was used to determine the distribution in depth of high-level magnetization. The inversion results show that materials with high-level magnetization is located beneath the Kuan-Yin, Pei-Kang, the Southern end of the Central Mountain Range, the southwestern of Taiwan, and the eastern margin of Taiwan. The depth of high-level magnetization ranges from 5 km to 35 km. The bottom of magnetic materials is generally thought to be an isothermal surface of the Curie temperature. We considered that the Curie isothermal surface around the Taiwan region is ranged between 10 km and 35 km in depth.

Keywords: Taiwan, Magnetization inversion, Magnetic anomaly

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[E] Oral | S (Solid Earth Sciences)：S-RD Resources, Mineral Deposit & Resource Exploration

[S-RD35] Mineral Resources for Society: Ore deposit formation and exploration

convener:Yasushi Watanabe(Faculty of International Resource Sciences, Akita University), Kotaro Yonezu(Deaprtment of Earth Resources Engineering, Faculty of Engineering, Kyushu University)

Mineral resources are fundamental to Society, particularly for a modern way of life, as they are used in every facet of life, from housing and transport to low-C energy sources to mobile phones. Metals and non-metals are mined from surface or underground ore deposits. The largest production - aside from industrial minerals - is iron ore from iron formations, 2,400 million tonnes (Mt) yearly (USGS), and P2O5 (263 Mt). This is followed by Al (60 Mt), Cr (30 Mt), Cu (20 Mt), Zn + Pb (19 Mt) and Ni (2 Mt); Mo and Sn (each 290 kilotonnes, kt), REEs (130 kt), Co (111 kt), Li (43 kt) and Ag (25 kt). Smaller amounts of essential metals include In (720 t), Ga (300 t) and Ge (126 t). Reserves (i.e., amounts proven by drilling to be economically feasible to mine) for many elements are 2-3+ decades, with known Resources typically up to 100 years or more (e.g., Fe, P), at present consumption rates.

Future global mineral resources depend on the consumption rate minus the recycling rate for given elements; shortfalls need to be made up over time by discovery of new resources. Discovery occurs by exploration; although technology assists this task, geologists must still work in the field and map, assess alteration and geochemical anomalies, and test these plus geophysical anomalies by drilling. Few anomalies ever reach a feasibility study, and many deposits with a feasibility study eventually are not mined for economic, social, environmental, political or other reasons. In order to be geologically successful at exploration, geologists must understand the characteristics of the ore deposit style sought, and appreciate the variations that occur within the deposit style they are seeking. This requires understanding how ore deposits form, and how characteristics may vary depending on different geologic settings. This session invites presentations on ore deposits and features that assist their discovery.

[SRD35-01] **Hydrothermal Mineralization and Alteration of the Sediment-Hosted Fe-Cu-Co Target H Prospect, Mumbwa Iron-Oxide Copper-Gold District, Zambia**

*Mukuka Simusokwe[1], Yasushi Watanabe[1], Takuya Echigo[1] (1.Graduate School of International Resource Sciences, Akita University)

[SRD35-02] **Multi-stage mineralization of the sediment-hosted stratabound Zone 5 copper-silver deposit, Kalahari Copperbelt, NW Botswana**

*Mpho Keeditse[1], Yasushi Watanabe[1], Antonio Arribas[2] (1.Akita Univ., 2.Univ. of Texas at El Paso)

[SRD35-03] Variations in mineral assemblages and oxygen and hydrogen isotopes of wall rock alteration in the Hishikari epithermal gold deposit, Japan

*Yuji Gonoi[1], Akira Imai[1], Kotaro Yonezu[1], Thomas Tindell[1], Koichiro Watanabe[1] (1.Kyushu University)

[SRD35-04] Calcium: Trigger of porphyry Cu and peralkaline granite REE mineralization

*Yasushi Watanabe[1] (1.Graduate School of International Resource Sciences, Akita University)

[SRD35-05] Differentiated sedimentary models and inner architectural characteristics of wave-dominated shoreface deposits: a case of Devonian 'Donghe sandstones' deposits in Tarim Basin, China

*Weilu Li[1] (1.National Marine Data and Information Service)

[SRD35-06] **A new orogenic gold belt in mainland SE Asia: The Vangtat gold deposit in southern Laos**

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Hydrothermal Mineralization and Alteration of the Sediment-Hosted Fe-Cu-Co Target H Prospect, Mumbwa Iron-Oxide Copper-Gold District, Zambia

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Abstract

The geology of the sediment-hosted Fe-Cu-Co Target H Prospect, Mumbwa Iron-Oxide Copper-Gold District, Zambia, is underlain by limestone, dolomitic siltstone, and breccia belonging to the Neoproterozoic Kundelungu Group of the Katanga Supergroup. Limestone consists of medium-grained calcite and minor dolomite, and quartz. Dolomitic siltstone which conformably overlies limestone is composed of fine-grained dolomite, quartz, illite, muscovite, K-feldspar, and chlorite. Breccia develops as a distinct lithology in extremely fractured zones of limestone and dolomitic siltstone. Mineralogy of the breccia varies depending on the composition of the cement. In the core of the breccia zone, siderite is the dominant mineral in the cement but the composition changes to dolomite-rich in the margin.

The primary mineralogy of the host rocks has been modified by three types of hydrothermal alteration. The earliest alteration occurs as overgrowths of muscovite and K-feldspar on fine-grained illite and chlorite. Muscovite and K-feldspar alteration is observed in the dolomitic siltstone and breccia clasts. The second alteration involved recrystallization of dolomite and calcite as a breccia cement and an infill in stockwork veins embedded in dolomitic siltstone and limestone. The last type of alteration is characterized by partial to complete replacement of dolomite and calcite by siderite and ankerite in the breccia cement and stockwork veins.

Mineralogical and geochemical studies of the sediment-hosted Fe-Cu-Co Target H Prospect show evidence of multistage epigenetic mineralization which is related to hydrothermal processes in an iron-oxide copper-gold system. Ore mineralization comprises primary and secondary ore stages. The primary ore stage is of two types: (1) hematite-rich ore which consists of crystalline hematite and pyrite overprinted by disseminated chalcopyrite in the breccia; and (2) chalcopyrite-rich ore comprising of chalcopyrite and minor bornite replacing disseminated pyrite in dolomitic siltstone, limestone, and stockwork veins. In the first stage primary ores, chalcopyrite occurs as intergrowths and inclusions in hematite and pyrite. Pyrite contains high concentrations of cobalt (up to 5 wt. %). Secondary ore stage comprises of chalcocite, covellite, goethite, malachite, and native copper.

Statistical interpretation of the whole-rock geochemical data using principal component analysis (PCA) reveals three distinct element groupings reflecting the three types of hydrothermal alteration. The first group constitutes the main elements in the muscovite and K-feldspar alteration minerals. These include Si, Al, Na, K, Ti, and P. Trace elements; Sc, Be, V, Cr, Ga, Ge, Rb, Zr, Nb, and Cs are included in the muscovite and K-feldspar alteration minerals. The second group consisting of Mg and Ca represents dolomite and calcite alteration. Trace elements; Zn, Sr, and Y, are included in dolomite and calcite. The last group consists of Fe, Mn, C, and S. This category comprises of the main elements in siderite and ankerite. Minor and trace elements; Co, Ni, Cu, As, Mo, In, Sn, Sb, W, Pb, and U cluster in this group. PCA results are consistent with petrographic evidence which indicates that the primary Fe, Cu, and Co

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minerals at Target H Prospect are associated with siderite and ankerite alteration in the breccia.

Keywords: Mumbwa Iron-Oxide Copper-Gold District, Fe-Cu-Co Target H Prospect, Hydrothermal Mineralization and Alteration

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Multi-stage mineralization of the sediment-hosted stratabound Zone 5 copper-silver deposit, Kalahari Copperbelt, NW Botswana

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The Zone 5 copper-silver deposit is located within a series of linked and inverted Meso-Neoproterozoic volcano-sedimentary basins of the Kalahari Copper belt (KCB) of NW Botswana. Zone 5 deposit contains a resource of 91 Mt at 2.13% Cu and 21.9 g/t Ag and it was discovered in 2013 from a soil anomaly 35 km SE of the former Ghanzi Cu mine within the Khoemacau project of Cupric Canyon. At Khoemacau, Zn and Pb form halos around high copper grades and have been identified as fundamental exploration tools. The economic Cu-Ag mineralization in the Zone 5 deposit concentrated at a stratigraphic contact between oxidized, redbed sandstone and overlying reduced shale, siltstone and sandstone, which acted as a chemical trap for copper-bearing fluids that propagated along the stratigraphy and structures such faults, shear zones, and the fold axial planar cleavage. The Zone 5 ore body is characterized by a vertical sulfide zoned sequence consisting, from bottom to top, of chalcocite, bornite, chalcopyrite, pyrite, sphalerite, and galena. The majority of the ore was introduced synchronously with quartz-calcite veining and hydrothermal alteration. Texturally, the sulfide minerals display replacement, intergrowth (co-existence) as well as inclusion-host relationships. Two main hypogene Cu-Ag mineralization episodes occurred at Zone 5. The earlier episode is characterized by fine disseminations of bedding-parallel, syn-sedimentary cubic and framboidal pyrite that occurs interstitially and occasionally overgrows the lithological layering. Fine-grained cubic pyrite is occasionally replaced by bornite, chalcocite, and chalcopyrite, whereas it also exists as inclusions in copper sulfides. The later (main) episode is syn-orogenic, stratabound mineralization represented by coarse-grained sulfides hosted prevalently in fabric sub-parallel quartz-calcite veins, shear fabrics, and axial planar foliation/cleavage lenticles. The bedding-parallel sulfide-bearing veins may be overprinted by crosscutting veins, indicating multiple veining episodes. Crosscutting sulfide-bearing veins often impregnate ore along bedding and foliation planes, suggesting an association between vein-hosted and disseminated ore parallel to fabric. Disseminated and vein-hosted ore is often stretched, recrystallized and transposed into cleavage lenticles suggesting that the mineralization was contemporaneous with deformation. The earlier-stage fine-grained cubic pyrite (n=1) sample has $\delta^{34}S$ value of -25.6‰, whereas the late-stage hypogene sulfides (n=14) from quartz-calcite veins display a large variation of generally depleted $\delta^{34}S$ values from -28.1 to +2.9‰, which partly overlap with the $\delta^{34}S$ signature displayed by the earlier-stage pyrite. Taking into account the sedimentary environment and lack of significant evaporitic sources, these preliminary $\delta^{34}S$ values are consistent with a reservoir of bacterially reduced sulfur. The variability from sample to sample may imply that syn-sedimentary sulfur as reflected by a wide range of very light $\delta^{34}S$ values was bacterially reduced and $\delta^{34}S$ values closer to 0 ‰resemble sulfur introduced during the hydrothermal event.

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Variations in mineral assemblages and oxygen and hydrogen isotopes of wall rock alteration in the Hishikari epithermal gold deposit, Japan

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The Hishikari deposit is an epithermal vein-type gold deposit with extremely high-grade Au ore (30-40g/t of gold), which is composed of three deposits, Honko, Sanjin and Yamada. This work is a challenge to establish a new alteration mineral zoning in the Hishikari mine for more efficient exploration. Samples were collected from almost horizontal four underground crosscuts and inclined twelve drill holes from the Hishikari mine. Detailed analysis of wall rock alteration was conducted by means of microscopic observation, X-ray diffraction (XRD), electron probe micro analyzer (EPMA) and oxygen and hydrogen isotope analysis.

As a result of XRD analysis, major alteration clay minerals are smectite, chlorite, illite, chlorite-smectite interstratified mineral (C/S), illite-smectite interstratified mineral (I/S), among which dominant are C/S and I/S. In the Honko and Sanjin deposits, both are dominant, whereas in the Yamada deposit C/S is more dominant than I/S. The proportions of chlorite in C/S and illite in I/S are variable in each area and depth, including chlorite-rich or illite-rich interstratified mineral, smectite-rich interstratified mineral and regularly interstratified mineral with the chlorite (or illite) and smectite ratio of 1:1. Chlorite and illite slightly contain smectite layers, supported by ethylene glycol treatment in the XRD analysis and EPMA analysis.

In the Yamada deposit, the proportion of chlorite in C/S is tend to increase as being deeper from the surface. In addition, several veins are surrounded by the C/S zone with high proportion of chlorite. Therefore, this could be a useful exploration index especially in the Yamada deposit.

In the southern part of the Sanjin deposit, epidote was remarkably recognized, coexisting with chlorite and illite. This implies the responsible heat source of the Hishikari deposit was located in south-eastern part, and epidote may be a potential new exploration index mineral for the division of alteration zoning in the Hishikari deposit.

The $\delta^{18}O$ and δD values of clay minerals in the wall rock mainly in the Sanjin deposit were measured and the $\delta^{18}O$ and δD values of fluid were calculated by established fractionation factors. The results showed that the values of fluid in this work are closer to the meteoric line than those of clay minerals within veins reported by previous researches. This implies the overlapping of the isotopic fractionation in the Hishikari deposit by convective circulation of meteoric water after the contribution of magmatic derived fluid.

In conclusion, the characteristics of wall rock alteration in the Hishikari deposit are different in each deposit. In the Yamada deposit, the abundance of chlorite in interstratified clay minerals increases with being closer to the veins. In the Sanjin deposit, the temperature of the wall rock alteration was higher than other two deposits. The fluid responsible for the alteration zoning was dominated by meteoric water.

Keywords: Hishikari deposit, wall rock alteration, interstratified clay mineral, epidote, oxygen and hydrogen isotope

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Calcium: Trigger of porphyry Cu and peralkaline granite REE mineralization

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Calcium plays an important role in metallic mineralization in several hydrothermal deposits, although calcium ion is not the ligand that form metal complex such as Cl^- and HS^- in hydrothermal fluids.

In the Eocene El Salvador porphyry Cu system in Chile, anhydrite and Cu sulfides are intimately occur in veinlets in plagioclase with K-feldspar and albite. Such Cu mineralization occurs at a high temperature ranging from 600˚C to 400˚C in the deposit. In this temperature condition, drastic changes in temperature, pH and salinity of the hydrothermal fluids, which are the common triggers of Cu mineralization, are not expected. An increase of H_2S in the magmatic-hydrothermal system, which is an alternative trigger of Cu mineralization, may occur by reduction of SO_4^{2-} and/or disproportionation of magmatic SO_2. Disproportionation of SO_2 inevitably occurs by condensation of SO_2-bearing magmatic vapor by meteoric water at about 350˚C or lower. Alternatively, SO_2 disproportionation may occur at a high temperature (>500˚C) at the top of a porphyritic intrusion where SO_2 reacts with Ca-bearing minerals, especially plagioclase, to form anhydrite and sulfides.

In the Devonian Khaldzan Burgei peralkaline system in Mongolia, quartz syenitic pluton is intruded by Ca-free peralkaline granite and REE-Zr-Nb mineralization is observed mainly in the metasomatized quartz syenite near the contact to the granite. In the metasomatized quartz syenite, Ca-bearing minerals such as amphibole, augite and plagioclase are replaced by aegirine and albite with abundant hematite, fluorite and zircon and with REE carbonates such as bastnäsite and synchysite. These replacements indicate that during the metasomatism, Ca was extracted from the original minerals in the quartz syenite by the reaction between the quartz syenite and metasomatizing fluids derived from the granite. The elevated Ca concentration in the fluids made zirconium and REE fluoride complexes unstable, resulting in the formation of zircon, REE carbonate as well as fluorite.

Thus, these two examples shows that reaction of Ca extracted from the precursor minerals in the intrusive rocks with hydrothermal fluids triggered porphyry Cu and peralkaline granite Zr-REE-Nb mineralization.

Keywords: calcium, mineralization, trigger

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Differentiated sedimentary models and inner architectural characteristics of wave-dominated shoreface deposits: a case of Devonian 'Donghe sandstones' deposits in Tarim Basin, China

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The wave-dominated shoreface deposits shows differentiated sedimentary characteristics in different backgrounds. Taking the Devonian Donghe sandstones which located in Tarim Basin as example, based on seismic, core and logging data, the regional distribution, lithological features and sedimentary structures in different target areas were compared to analysis, the influence of main controlling factors like relationships between material supply and sea level fluctuation, hydrodynamic force conditions and ancient landform features to wave-dominated shoreface deposits were dissected, and three types of genetic models for wave-dominated shoreface deposits were raised, including wave-dominated shoreface deposits with reworked delta background, transgressive-regressive wave-dominated shoreface deposits with shoal background, and transgressive wave-dominated shoreface deposits with gentle-slope background. The superposition of the sand bodies under controls of different sedimentary mechanism causes the complexity of oil-water distribution in current situation, which greatly limits further exploitation. Under the guidance of genetic models and application of drilling and dynamic data, three levels of architecture are characterized, which are composite sand bodies (fifth-order architectural unit), single sand body (fourth-order architectural unit) and internal component unit (third-order architectural unit). The identification marks and spatial distribution of the architectural units in wave-dominated littoral reservoir are discussed to establish the corresponding sedimentary models. Methods for recognizing the single bar sands and its inner units like pattern matching control, surface identification using well data and production data analysis are summarized. In composite sand bodies of transgression, the superposition of single sand bodies shows spatial distribution patterns like continuous on-lap, step migration and filling thick layer, while that in composite sand bodies of regression shows thick layer accumulation, step migration and continuous superposition. The single sand body can be divided into one or several internal component units by the third-order interface, with the pattern of low-angle migration towards sea or land. Controlled by the architecture of sand bodies, isolated fluid systems are divided by the fourth-order interface between single bars and the internal third-order interface interior of single bar, thereby leading to the differences in oil-bearing properties.

Keywords: Wave-dominated shoreface deposits, Differentiated sedimentary models, Reservoir architecture, Donghe sandstones, Tarim Basin

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A new orogenic gold belt in mainland SE Asia: The Vangtat gold deposit in southern Laos

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The Vangtat orogenic gold deposit is located within a low-grade metamorphic (greenschist facies) terrane along the western margin of Kontum massif, which is characterized by subduction and collision orogenesis of the Poko suture zone (PKSZ) during the Indosinian orogeny (270 to 230 Ma). Gold mineralization follows the N-S striking Vangtat shear zone, which is subparallel to the regional PKSZ, and extends for several kilometers along strike and a few hundred meters across. The Vangtat shear zone cuts across an early- to mid-Palaeozoic metamorphosed volcano-sedimentary sequence consisting of greenschist, pelitic schist, slate, quartzite, and metagabbro. The deposit is hosted in pelitic schist, which is made up of chlorite, muscovite, quartz, albite with minor epidote, carbonates and K-feldspar, and has been deformed with lineation and foliation formed by chlorite and muscovite.

Hydrothermal alteration and gold mineralization occur within the shear zone with a progression from proximal to distal assemblages; the intensity of alteration decreases with distance from the gold mineralized bodies. Highest grade gold mineralization (avg. >3 g/t Au) occurs in discrete quartz-sulfide veins that cut the metamorphic foliation of the immediate host rock. The quartz-sulfide veins occur in a zone 3+ kilometers long and up to 300 meters wide. The veins are surrounded by a graphite-carbonate alteration envelope, in which graphite and carbonates penetrate the host pelitic schist, especially where the foliation planes are enhanced by microshears. Precipitation of graphite and carbonates is commonly associated with sulfide dissemination and lower grade (<1 g/t) gold mineralization. Adjacent to the graphite-carbonate zone the host pelitic schist is weakly hydrothermally altered by an assemblage similar to the major silicates of the host pelitic schist and minor amounts of hydrothermal pyrite, titanite, rutile, ilmenite, hematite, magnetite, and barite.

Pyrite is the major sulfide associated with gold mineralization and is accompanied by minor chalcopyrite and arsenopyrite. Other sulfides, such as bismuthinite, galena, sphalerite, and pyrrhotite, occur as trace amounts in inclusions in pyrite. Gold in the Vangtat deposit occurs as anhedral grains in sulfides, most of the gold inclusions appear to have been incorporated during the initial growth of the sulfides. Gold also occurs in fractures, as a coating on the exterior surface of sulfides, and in the matrix of fractured sulfides. Rarely visible gold grains occur in the quartz-sulfide veins and along the alteration halo. Gold to silver ratio ranges from 5:1 to 25:1, with an average of 10:1.

The fluid inclusion study of quartz-sulfide veins shows that the fluids responsible for the mineralization are characterized by an aqueous-carbonic fluid with relatively consistent H_2O-NaCl-CO_2 and minor CH_4-N_2, low to moderate salinity (0.7 to 10.0 wt% NaCl equivalent) that homogenized to liquid at moderate temperatures (190 to 320˚C). The S isotope compositions of pyrite from quartz-sulfide veins, alteration halo and host rock range from 1.3 to 10.7‰, suggesting a magmatic sulfur origin.

K-Ar age dating on pure white mica mineral separates from the quartz-sulfide veins in the Vangtat shear zone resulted in two age ranges: 235 to 205 Ma and 348 to 280 Ma. The timing of gold mineralization is interpreted to be constrained by the younger episode (235 to 205 Ma) which corresponds to the final

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stage of the collision of the Indosinian orogeny. The older episode (348 to 280 Ma) may represent the age of well-crystallized muscovite, suggesting the mixing of muscovite from the host rocks.

Keywords: Vangtat deposit, Orogenic gold, Hydrothermal alteration, Graphite, K-Ar age dating

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[E] Oral | S (Solid Earth Sciences)：S-MP Mineralogy & Petrology

[S-MP36] Physics and Chemistry of Minerals

convener:Seiji Kamada(Frontier Research Institute for Interdisciplinary Sciences, Tohoku University), Masahiro KAYAMA(Department of General Systems Studies, Graduate School of Arts and Sciences, The University of Tokyo)

In this session, we will discuss the physics and chemistry of the Earth and planetary materials (including amorphous and melts) based on the results obtained from various experimental methods such as X-ray diffraction, FT-IR, Rman spectroscopy, electron microscopic observations, and computer simulations.

[SMP36-01] Synthesis and structural characterization of a new zinc silicate phase A ($Zn_7Si_2O_8(OH)_6$) by ^{1}H and ^{29}Si NMR and synchrotron powder X-ray diffraction

*Xianyu Xue[1], Masami Kanzaki[1], Jianjun Jiang[1,2] (1.Institute for Planetary Materials, Okayama University, 2.Department of Geosciences, Princeton University)

[SMP36-02] Pressure-induced structural changes in hemimorphite and dehydrated hemimorphite: first-principles calculation

*Masami Kanzaki[1] (1.Institute for Planetary Matereials, Okayama University)

[SMP36-03] Molecular Dynamics Simulations of Sodium Water Glass

*Fumiya Noritake[1] (1.Graduate Faculty of interdisciplinary Research, University of Yamanashi)

[SMP36-04] Structural change processes of iron sulfide nanoparticle under hydrothermal conditions

Yoshinari Sano[1], *Atsushi Kyono[1], Yasuhiro Yoneda[2], Sota Takagi[1], Gen-ichiro Yamamoto[1] (1.Division of Earth Evolution Sciences, Faculty of Life and Environmental Sciences, University of Tsukuba, 2.Japan Atomic Energy Agency)

[SMP36-05] **Crystal structure of nesquehonite, $MgCO_3 \cdot 3(H,D)_2O$ by neutron diffraction, Raman spectroscopy, and thermal analysis**

*Gen-ichiro Yamamoto[1], Atsushi Kyono[1], Jun Abe[2], Asami Sano-Furukawa[3], Takanori Hattori[3] (1.University of Tsukuba, 2.CROSS, 3.JAEA)

[SMP36-06] High-*PT* neutron diffraction experiments on guyanaite: Pressure-temperature dependence of hydrogen bonding in hydrous minerals

*Chikara Shito[1], Hiroyuki Kagi[1], Asami Sano-Furukawa[2], Sho Kakizawa[1], Kazuki Komatsu[1], Katsutoshi Aoki[1], Riko Iizuka-Oku[1], Shinichi Machida[3], Noboru Furukawa[4], Akio Suzuki[5] (1.Geochemical Research Center, Graduate School of Science, The University of Tokyo, 2.Japan Atomic Energy Agency, 3.Comprehensive Research Organization for Science and Society, 4.Graduate School of Science, Chiba University, 5.Graduate School of Science, Tohoku University)

Synthesis and structural characterization of a new zinc silicate phase A ($Zn_7Si_2O_8(OH)_6$) by ^1H and ^{29}Si NMR and synchrotron powder X-ray diffraction

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Water is an important component determining the habitability of the surface environment and dynamics of the interior of the Earth, and may be stored in the deep Earth in the form of various hydrous phases and nominally anhydrous phases. Well known for the former are the various dense hydrous magnesium silicate (DHMS) phases (e.g. phase A, B, superhydrous B, D, E). It is also of crystal chemical interest to understand the stability and crystal structure of hydrous phases in silicate systems with other cations (e.g. Fe^{2+}, Zn^{2+}). Zinc is of particular interest, because although the ionic radii of Zn^{2+} is slightly larger than that of Mg^{2+}, it has a tendency of occupying tetrahedral sites, rather than octahedral sites like Mg. P-T phase relations in the Zn_2SiO_4 and $ZnSiO_3$ systems show different behavior from those of the analogous Mg silicates, although high-pressure phases of the same structure (e.g. M_2SiO_4 with modified spinel structure) for both systems are also known. A common natural hydrous zinc silicate mineral is hemimorphite ($Zn_4Si_2O_7(OH)_2 .H_2O$), which is known to be stable under ambient condition.
Here we report the synthesis of a new hydrous zinc silicate phase ($Zn_7Si_2O_8(OH)_6$) at 9 GPa and 500 ˚C, and show from the ^1H and ^{29}Si NMR and powder X-ray diffraction data that it has a crystal structure resembling that of phase A ($Mg_7Si_2O_8(OH)_6$) (denoted as Zn-phase A hereafter).
The sample was synthesized using a multi-anvil press at 9 GPa and 500 ˚C for 4 hours using natural hemimorphite as starting material. The recovered sample was characterized by micro-Raman, ^1H and ^{29}Si MAS NMR using a Bruker Avance NEO 400 spectrometer, and powder X-ray diffraction using a Bragg–Brentano–type diffractometer (SmartLab, Rigaku Co.). For structural refinement, synchrotron X-ray diffraction pattern was also acquired at BL5S2 of Aichi Synchrotron Radiation Center using a Debye-Scherrer type diffractometer equipped with four two-dimensional solid-state detectors. The wavelength was 0.69997 Å, as calibrated on CeO_2 (NIST SRM 674b).
Micro-Raman measurement revealed that the sample contains $ZnSiO_3$ clinopyroxene and a hydrous phase. The ^1H MAS NMR spectra contain two peaks near 3.1 and 5.8 ppm with similar intensities, and ^1H-^{29}Si CPMAS NMR spectra revealed two ^{29}Si peaks at -59.1 and -66.2 ppm with similar intensities. These suggest that the hydrous phase likely contains two tetrahedral Si sites and two H sites. For the powder X-ray diffraction pattern, about half of the observed peaks can be readily assigned to the diffraction peaks calculated from $ZnSiO_3$ pyroxene (C2/c) structure. The remaining peaks can be indexed with a hexagonal cell and match well with the simulated diffraction pattern of phase A ($Mg_7Si_2O_8(OH)_6$ after replacing the Mg by Zn), which has two tetrahedral Si sites and two H sites, consistent with the NMR results. The refined lattice parameters for the Zn-phase A ($Zn_7Si_2O_8(OH)_8$) from Rietveld refinement of the synchrotron X-ray diffraction pattern are as follows: a =7.9837(3), c = 9.6452(3) Å. These values are slightly larger than those reported for the Mg-phase A, and are consistent with the slightly larger ionic size of Zn^{2+} than Mg^{2+}. The M1 site of Zn-phase A is more distorted than M2 and M3, and may be considered as a (4+2) octahedron with four shorter M1-O bond distances of 1.98 - 2.13 Åand two longer distances of 2.42 and 2.65 Å. Similar behavior is also known for $ZnSiO_3$ phases.
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Keywords: crystal structure, hydrous silicate phase, high pressure

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Pressure-induced structural changes in hemimorphite and dehydrated hemimorphite: first-principles calculation

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Mineral hemimorphite ($Zn_4Si_2O_7(OH)_2•H_2O$) contains both OH and molecular H_2O in the structure. Dehydrated form ($Zn_4Si_2O_7(OH)_2$) can be obtained by heating hemimorphite at around 600 °C, but still keeping original structure. Thus, these phases provide us good opportunity to explore hydrogen bondings in minerals. In this study, pressure-induced structural changes for those two phases were studied using first-principles calculations. For hemimorphite, a pressure-induced phase transition to "hemimorphite II" has been reported (Seryotkin & Bakakin, 2011), and the transition is characterized by rotation of a rigid block made of $Zn_4Si_2O_{13}(OH)_2$. Similar transition is expected for the dehydrated hemimorphite, as the structure is essentially identical except molecular H_2O. It should be noted that dehydrated hemimorphite is metastable phase at ambient condition, and it is not clear whether any stable phase exists for this composition (also see Xue's talk in this session). Hereafter, hemimorphite is abbriviated as "HEM", whereas dehydrated hemimorphite is abbriviated as "DHEM".

For the calculations for HEM, both ambient pressure phase (HEM I), and high-pressure form (HEM II) are considered. For the calculations for DHEM, its structure at ambient condition (DHEM I), and a high pressure form (DHEM II) which is modeled from HEM II by removing H_2O, are considered. Additionally, we considered bertrandite ($Be_4Si_2O_7(OH)_2$) structure as a possible stable phase at high pressure.
It should be noted that DHEM I has protons which is a half occupied. So we need to consider at least several possible proton distribution models for the calculation. Three models are considered with OH bonds pointing different directions. First-principles calculations were conducted using Quantum-Espresso 6.4.1 package, and in order to take into account for van der Waals interaction, we employed nonlocal correlation functional "rVV10" combined with PBE (PAW) potentials from pslibrary (ver. 1.0.0). Crystal structures were optimized at each pressure, and compressed to 10 GPa with 0.5-GPa step.

For HEM, at first we used an ideal structure obtained from X-ray diffraction study. But then we found HEM II has lower enthalpy than HEM I even at 1 bar. This is likely due to our less satisfactory model for HEM I. In realistic model, OH and H_2O is forming hydrogen bonding, and lowering their symmetry at local structure level. Our new model considered this, and now the enthalpy was lower than HEM II at 1 bar. We found a transition for HEM II at about 10 GPa, and a half of Zn becomes tetrahedral to five-fold coordination at this transition.

For DHEM, bertrandite phase has lowest volume and enthalpy than that of other phases even at 1 bar. Thus we may expect that bertrandite phase could be a candidate for stable high-pressure phase for this composition. However, our preliminary piston cylinder experiments revealed that there is no stable DHEM phase up to 1.5 GPa. We found that starting from one of three hydrogen configuration models of DHEM I, Si-O-Si angle is significantly changed, and volume of the structure becomes almost same to that of DHEM II. This suggested another possible phase transition for DHEM at low temperature, but it is not stable phase.

For DHEM II, hydrogen bond distance is geometrically related to rotation of the rigid unit, and larger rotation results stronger hydrogen bonding. The another phase (Si-O-Si kinked), the kink in Zn-O-Zn is

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related to hydrogen bond distance, and more kinked angle resulted stronger hydrogen bonding. Apparently hydrogen bonding is governing structural evolution of those phases with pressure.

Keywords: hemimorphite, pressure-induced phase transition, hydrogen bonding, first-principles calculation

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Molecular Dynamics Simulations of Sodium Water Glass

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Basic sodium silicate can easily dissolve in water and forms water glass. The Water glass is used to make silica gel, in passive fire protection, to make cements, as lubricant for drilling, etc.. From view point of mineral science, water glass can be considered as analogue of aqueous fluids or wet melt. Structure of the water glass is not clearly understood but some results obtained by small angel X-ray scattering (SAXS) indicates that the oxide forms nano-scaled clusters. Gerber et al., (1994) reports that dilute sodium metasilicate water glass (> 6.5 mol/l) has only broad peak from near neighbor and Si-Si intermediate structure. However, water glass dried at ~323 K has the pre-peak that reflects ~ 1.0 nm ordered structure.

To reveal the actual structure that forms pre-peak of X-ray scattering, I performed force-field molecular dynamics simulations for sodium water glass system. The MD simulation appropriate method for study of structure of amorphous materials because it gives trajectories of each atoms in the simulation cells of each atom at any point in simulation time. MD simulations of sodium water glass consist of approx. 20,000 particles were performed using MXDORTO code (Noritake & Kawamura, 2016). I used the “dissociative” potential model proposed by Mahadevan et al., (2019), which can reproduce various properties of wet/dry silicate system and DFT calculation derived forces.

The simulated water glass (~approx. 15 mol/l) successfully reproduced the SAXS pattern which has pre-peak. The simulated water glass consists of nano scaled (~2.0 nm) Na_2O cluster, large sized silicate anion terminated by hydroxyls that surrounds Na_2O clusters, and interstitial water molecules. The contribution for pre-peak is mainly intra-cluster Na-Na structure.

Keywords: Molecular Dynamics, Silicate Glass, Water

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Structural change processes of iron sulfide nanoparticle under hydrothermal conditions

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We investigated the structure changes and phase transformations from nanocrystalline mackinawite to pyrite and greigite using hydrothermal experiments, synchrotron X-ray diffraction (XRD) technique, atomic Pair Distribution Function (PDF) method, Extended X-ray Absorption Fine Structure (EXAFS) analysis, and transmission electron microscopic (TEM) observation. The first hydrothermal ageing experiment was performed by heating the nanocrystalline mackinawite at 120 ˚C for 12 h. The nanocrystalline mackinawite remained essentially unchanged for 12 h. The d_{001} and FWHM values of XRD peaks decreased for the first 2 h and subsequently maintained almost constant. There was no linear relationship between lattice parameters and hydrothermal heating time. The crystallite size quickly increased by the heating of 2 h, leading to the increase of crystallinity and appearance of the medium-range order in the nanocrystalline mackinawite. The nanocrystalline mackinawite preferentially grew in the horizontal direction along the sheet structure. The Fe atoms were distributed in the tetrahedral sites with a site occupancy of approximately 80%. The pre-edge peak energy of Fe *K*-edge suggested that about 10% of Fe^{3+} / Σ Fe was included in the nanocrystalline mackinawite to compensates the charge deficiency of Fe^{2+}. The second hydrothermal ageing experiment was performed by heating the nanocrystalline mackinawite at 120 ˚C under the presence of elemental sulfur for 24 h. The nanocrystalline mackinawite persisted up to 8 h of heating time. Thereafter, pyrite and greigite instead of the nanocrystalline mackinawite appeared. Finally pyrite became dominant. The d_{001} and lattice parameters of nanocrystalline mackinawite varied significantly compared with those heated under the absence of elemental sulfur. The pre-edge peak energy indicated that the Fe^{2+} was oxidized to Fe^{3+} by elemental sulfur acting as the oxidant during the phase transformation from nanocrystalline mackinawite to greigite. In the phase transformation to pyrite, on the other hand, the Fe^{3+} was reduced to Fe^{2+} by sulfur in mackinawite and greigite acting as the reductant. The EXAFS analysis revealed that the second peak from the Fe-Fe interaction appeared at the heating time of 2 h, implying the formation of sheet structure consisting of edge-sharing FeS_4 tetrahedra. Intensity of the second shell peak from the Fe-Fe interaction reduced after the heating time of 8 h. Instead, new peaks corresponding to the Fe-S and Fe-Fe interaction appeared after the heating time of 12 h. This result was strongly associated with formation of the disulfide bonds (S–S bonds) in pyrite. The third hydrothermal ageing experiment was performed by heating the nanocrystalline mackinawite at 140 ˚C. The nanocrystalline mackinawite persisted up to 2 h of heating time. After the heating for 4 h, greigite became dominant. The pre-edge peak energy indicated that the about 60% of Fe^{2+}/ Σ Fe was oxidized to Fe^{3+}. The EXAFS analysis suggested the shrinkage of FeS_4 tetrahedra. These results could be clearly explained by the phase transformation from the nanocrystalline mackinawite to greigite. Consequently, the elemental sulfur can be recognized as one of the most important factors to promote the phase transformation from mackinawite to pyrite in the reducing lake and marine sediments.

Keywords: iron sulfide nanoparticle, mackinawite, greigite, pyrite, elemental sulfur

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Crystal structure of nesquehonite, $MgCO_3 \cdot 3(H,D)_2O$ by neutron diffraction, Raman spectroscopy, and thermal analysis

*Gen-ichiro Yamamoto[1], Atsushi Kyono[1], Jun Abe[2], Asami Sano-Furukawa[3], Takanori Hattori[3]

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Neutron diffraction, Raman spectroscopy, and thermal analysis were performed to investigate the composition, structure, and formation conditions of magnesium carbonate hydrate, nesquehonite. Nesquehonite was prepared from a mixture of $MgCl_2$ and Na_2CO_3 solution at pH 10.9. The crystal structure of deuterated nesquehonite was analyzed by Rietveld refinement of the time-of-flight neutron powder diffraction pattern. The crystal structure possessed monoclinic space group $P2_1/n$ with lattice parameters of a = 7.72100(12), b = 5.37518(7), c = 12.1430(3) Å, β = 90.165(4) °, and V = 503.956(13) Å^3. The refinement with a final crystal structure model of deuterated nesquehonite converged to wRp = 4.22 % and Rp = 3.50 % (Fig. 1). The positions of six deuterium (D) atoms were successfully determined. The result indicated that the D atoms were coordinated to O1, O2, and O6 atoms as water molecules in nesquehonite. It can be therefore considered that nesquehonite obtained in the study had the chemical formula of $MgCO_3 \cdot 3D_2O$. The Raman bands corresponding to the CO_3 bending and stretching vibrations and the OH(OD) stretching vibration agreed substantially with those given by previous studies. The OH stretching vibration at 3555 cm^{-1} was also well consistent with those reported in the literature. It was experimentally impossible to distinguish the difference in chemical formula between $MgCO_3 \cdot 3H_2O$ and $Mg(HCO_3)(OH) \cdot 2H_2O$ by using the powder XRD pattern and the Raman bands of the OH stretching vibrations. The differential thermal analysis (DTA) curve showed three endothermic peaks corresponding to three dehydration reactions, which indicated that three water molecules were released step by step from the $MgCO_3 \cdot 3H_2O$ nesquehonite. There is a distinct difference in dehydration behavior between $MgCO_3 \cdot 3H_2O$ and $Mg(HCO_3)(OH) \cdot 2H_2O$. Therefore, the thermal analysis would be a most useful tool to distinguish the difference in chemical formula of nesquehonite.

Keywords: Nesquehonite, Magnesium carbonate hydrate, Neutron diffraction, Raman spectroscopy, Thermal analysis, Hydrogen bonding network

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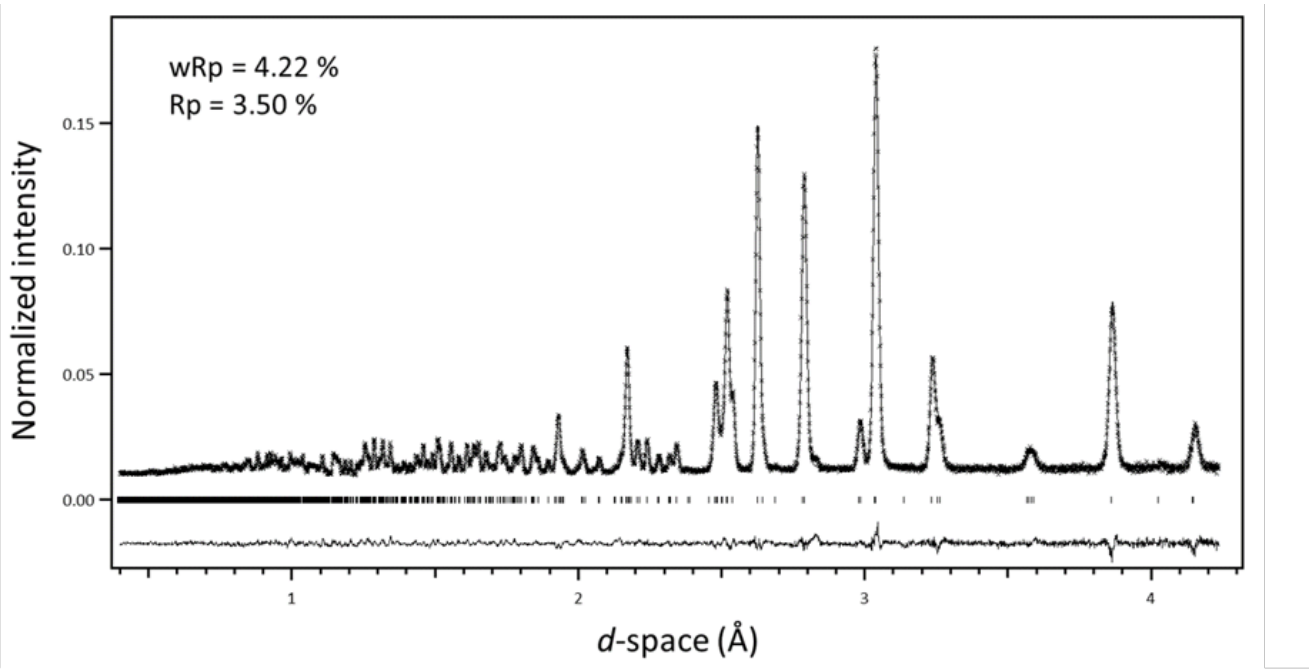

Figure 1 Neutron powder diffraction pattern and the result of fitting by Rietveld refinement for nesquehonite.

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High-*PT* neutron diffraction experiments on guyanaite: Pressure-temperature dependence of hydrogen bonding in hydrous minerals

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Water is transported to the deep mantle by hydrous minerals in a subduction zone. Hydrogen bonding in hydrous minerals greatly affects their elastic properties such as compressibility, seismic velocity, and so on [e.g., 1,2]; it is important for us to clarify the effects of water into the properties of deep-mantle minerals. Under high-pressure conditions, a lot of hydrous minerals have a distorted rutile-type structure such as δ-AlOOH and ε-FeOOH. Recently, pressure-induced hydrogen bond (H-bond) symmetrization was experimentally observed in δ-AlOOH at ~18 GPa and room temperature [3]. However, the behavior of hydrogen in distorted rutile-type hydrous minerals at high temperature has not been clarified. Guyanaite (β-CrOOH) has also a distorted rutile-type structure and its H-bonds are significantly shorter than that of δ-AlOOH and other distorted rutile-type hydrous phases at ambient condition [e.g., 3,4]. Thus, H-bond symmetrization in guyanaite is expected to occur at relatively low pressure. Guyanaite can serve as an analogue material for predicting H-bond symmetrization in distorted rutile-type hydrous minerals. In this study, we conducted high-*PT* neutron diffraction measurements on guyanaite and investigated *P*-*T* dependence of hydrogen bonding in guyanaite.

Deuterated guyanaite (β-CrOOD) was used as a sample to reduce incoherent scattering from hydrogen. The sample was hydrothermally synthesized from the mixture of CrO_2, D_2O and a reducing agent $(COOD)_2 \cdot 2D_2O$. Formation of the deuterated sample was confirmed from infrared absorption spectra and powder XRD. Neutron diffraction measurements at high-*PT* conditions up to 11 GPa and 1000 K were performed using a six-axis multi-anvil press installed at BL11, MLF, J-PARC. The structure of β-CrOOD was refined by every *P*-*T* condition using Rietveld method. High-*PT* XRD measurements up to 7.6 GPa and 900 K were also performed at NE7A, PF-AR, KEK. *P*-*V*-*T* data were fitted to high-temperature Birch–Murnaghan equation of state.

Thermoelastic parameters of β-CrOOD were determined to be K_{300} = 204(4) GPa (K_p = 4), dK/dT = −0.033(9) GPa/K, and α = 3.05(17) $\times 10^{-5}$ /K, where α is expressed as $V_T = V_{300} \times \exp\{\alpha \times (T-300)\}$. These values were comparable to those of β-CrOOH [5]. At 300 K, the axal ratio a/b increased with pressure up to ~4 GPa, but it became constant above ~4 GPa. This behavior was found in the process of H-bond symmetrization in δ-AlOOH [3]. At higher temperature, the change in the gradient of a/b shifted to higher pressure. The O···O and D···O distances elongated with increasing temperature, whereas the O-D bond distance shortened with increasing temperature. It means that the D···D distance gets longer with increasing temperature. This result suggests that the pressure of H-bond symmetrization under mantle conditions would be higher than that under high-*P* and room-*T* conditions. When we consider the effect of the H-bond symmetrization on seismic observation, we would need to carefully take the temperature dependence into account.

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Keywords: guyanaite, neutron diffraction, high-pressure, hydrogen bond

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[E] Oral | S (Solid Earth Sciences)：S-MP Mineralogy & Petrology

[S-MP36] Physics and Chemistry of Minerals

convener:Seiji Kamada(Frontier Research Institute for Interdisciplinary Sciences, Tohoku University), Masahiro KAYAMA(Department of General Systems Studies, Graduate School of Arts and Sciences, The University of Tokyo)

In this session, we will discuss the physics and chemistry of the Earth and planetary materials (including amorphous and melts) based on the results obtained from various experimental methods such as X-ray diffraction, FT-IR, Rman spectroscopy, electron microscopic observations, and computer simulations.

[SMP36-07] Single crystal elasticity of minerals under high-pressure conditions determined by inelastic x-ray scattering

★Invited Papers

*Hiroshi Fukui[1], Akira Yoneda[2], Seiji Kamada[3], Alfred Baron[4] (1.University of Hyogo, 2.Osaka University, 3.Tohoku University, 4.RIKEN)

[SMP36-08] Redetermination of enthalpy and reassessment of thermodynamic data set for SiO_2 stishovite

*Hiroshi Kojitani[1], Masaki Akaogi[1] (1.Department of Chemistry, Faculty of Science, Gakushuin University)

[SMP36-09] Generalized Theory of Brillouin Scattering Toward Multi-Grain Analyses

*Miaki Ishii[1], Raymond Jeanloz[2] (1.Department of Earth & Planetary Sciences, Harvard University, 2.Department of Earth & Planetary Science, University of California, Berkeley)

[SMP36-10] GHz ultrasonic velocity measurements of iron beyond the bcc-hcp transition

*Akira Yoneda[1], Ryo Tsuruoka[2], Seiji Kamada[3], Hidenori Terasaki[2] (1.Institute for Planetary Materials, Okayama University, 2.Graduate school of Science, Osaka Univ., 3.Frontier Research Institute for Interdisciplinary Sciences, Tohoku Univ.)

[SMP36-11] Density measurements of Fe up to 25 GPa based on X-ray absorption

*Seiji Kamada[1,2], Fumiya Maeda[2], Hidenori Terasaki[3,4], Ryo Tsuruoka[3], Yusaku Takubo[3], Saori I Kawaguchi[5], Naohisa Hirao[5], Akihiko Machida[6] (1.Frontier Research Institute for Interdisciplinary Sciences, Tohoku University, 2.Dept. Earth Science, Tohoku University, 3.Osaka University, 4.Okayama University, 5.JASRI, 6.QST)

Single crystal elasticity of minerals under high-pressure conditions determined by inelastic x-ray scattering

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Elasticity is one of the most basic properties of materials and one of the most important ones for high-pressure minerals to understand the earth's interior as elastic-wave velocities of the earth's interior are the most measured properties of the earth's interior. The understanding of the earth's interior is progressing with accumulation of seismic velocity data and experimentally measured elastic data. Single crystal elasticity is required to understand the relationship between anisotropic minerals and earth's interior. We have developed a technique to determine single crystal elasticity of minerals under high pressure conditions using inelastic x-ray scattering. We will introduce some recent results by means of this technique.

Keywords: single crystal elasticity, high pressure , inelastic x-ray scattering

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Redetermination of enthalpy and reassessment of thermodynamic data set for SiO_2 stishovite

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SiO_2 stishovite (St) is a high pressure polymorph of SiO_2 and believed to be one of major constituent minerals of the subducted slab. Thermodynamic parameters of SiO_2 St used for thermodynamic examination of the stability field of SiO_2 St or a phase assemblage containing it have not yet been constrained well. In particular, standard enthalpy of formation largely affects a position of a calculated phase boundary. Since previous enthalpy measurement of SiO_2 St by Akaogi et al. (1995) was performed using the differential drop-solution calorimetry, measured enthalpy included heat effect from not only SiO_2 St sample but also silica capillary tubes as a container and Pt chips as a weight. In this study, heat effect of only SiO_2 St was measured by the drop-solution calorimetry. Furthermore, to give an internally-consistent thermodynamic data set, high temperature heat capacity of SiO_2 St was reassessed based on an equation of state (EoS).

SiO_2 St samples for the drop-solution calorimetry were synthesized by heating reagent grade SiO_2 quartz (Qz) at 15 GPa and 1673 K using a Kawai-type high-pressure apparatus at Gakushuin University. It was confirmed that synthesized samples were single phase of SiO_2 St by micro-focused X-ray diffraction method. The drop-solution calorimetry was performed using a Calvet-type high-temperature calorimeter (SETARAM, HT-1000). A sintered SiO_2 St sample with weight of 3-6 mg was dropped directly into lead borate solvent ($2PbO{\cdot}B_2O_3$) placed in the calorimeter at 978 K. Drop-solution enthalpy ($\Delta H_{d\text{-}s}$), which is the summation of heat content from room temperature to 978 K and solution enthalpy at 978 K was measured. To hasten the solution of the samples, the solvent was stirred by bubbles of Ar gas.

In the reassessment of isobaric heat capacity (Cp) of SiO_2 St, isochoric heat capacity (Cv) was calculated using the Kieffer model with adjusting a VDoS model to reproduce low-temperature Cp data measured by Akaogi et al. (2011) and Yong et al. (2012). The anharmonic effect was calculated using isothermal bulk modulus, its temperature derivative and thermal expantivity derived from the EoS of Wang et al. (2012). From the average of six data, $\Delta H_{d\text{-}s}$ (SiO_2 St) was determined to be 3.8±0.4 kJ/mol. This value is slightly larger than 3.0±0.9 kJ/mol measured by Akaogi et al. (1995), though within the experimental errors. The difference between $\Delta H_{d\text{-}s}$ (SiO_2 Qz) [40.1±0.4 kJ/mol, Akaogi et al. (1995)] and the present $\Delta H_{d\text{-}s}$ (SiO_2 St) gives the phase transition enthalpy from Qz to St of 36.2±0.5 kJ/mol which provides the standard enthalpy of formation from elements of -874.5±0.5 kJ/mol. The calculated Cp of SiO_2 St agrees well with high-temperature Cp data measured by Akaogi et al. (1995). However, our Cp extrapolated to higher temperature region than 700 K shows slightly larger value (5% at 2000 K) than that by Cp equation of Akaogi et al. (2011). Thermodynamically calculated coesite-stishovite phase equilibrium boundary using the reassessed thermodynamic data set for SiO_2 St is consistent with the experimentally determined phase boundaries by Zhang et al. (1996) and Ono et al. (2017a). When the new thermodynamic data set for SiO_2 St is applied to thermodynamic calculation of the Mg_2SiO_4 ringwoodite (Rw) + SiO_2 St = $2MgSiO_3$ akimotoite boundary, the phase transition pressure at 1000 K is obtained to be 18 GPa and it is about 3 GPa lower than experimentally determined boundaries (e.g., Ono et al., 2017b), implying that the meta-stable region of Rw + St assembly is relatively extensive.

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Keywords: SiO2 stishovite, thermodynamics, enthalpy, heat capacity, equation of state, phase equilibrium boundary

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Generalized Theory of Brillouin Scattering Toward Multi-Grain Analyses

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Quantitative Brillouin scattering requires single crystals, which restricts the types of samples and conditions under which experiments can be performed. If the single-crystal requirement can be removed, we can obtain acoustic properties of a greater variety of minerals and over much wider ranges of pressures and temperatures than now possible, including for samples and conditions relevant to Earth's deep interior.

The restriction to single-crystal samples arises from the limited polarization and experimental geometry considered in the theory of Brillouin scattering. In particular, the fourth-order Pockel's tensor that describes elasto-optic interaction, i.e., interaction of phonons with the probing light, is examined only under specific circumstances such as horizontal and vertical polarizations with respect to the plane defined by the experiment. In order to avoid this limitation, we have derived a generalized Brillouin scattering intensity equation that includes the effects of two 4th order tensors, the elasticity tensor and Pockel's tensor. In addition to the tensors, the equation depends upon polarization of the incident and scattered light, geometry of the experiment (the orientation of the sample crystal with respect to the directions of incident and scattered light), acoustic wavevector, indices of reflection for incident and scattered light, optical dielectric tensor, and frequency of the scattered light. This generalization of the theory provides a means of predicting results for multi-grain and powdered samples for comparison with experimental results.

For optically and elastically isotropic materials, we obtain a relatively simple analytical expression of scattered light intensity as a function of frequency. Using this expression, as well as the scattered light frequency that depends upon the experiment geometry, we demonstrate how the theory can be taken from single crystal analysis to multi-grain analysis. For the single crystal case, we confirm that the intensity calculated from our analysis is consistent with previous results, such as those of Born & Huang (1954) and Cummins & Schoen (1972). In particular, the Brillouin spectrum peaks at a frequency related to the experimental geometry and the acoustic wave speed of the sample. Our analytical expression also shows how intensity changes with experimental geometry and polarization, a dependence that is key toward considering multi-grain or powder samples. We assume that elastic scattering from grain boundaries alters the polarization and geometry of the probe beam in a multi-grain sample, and that inelastic scattering occurs only once before reaching the observer. Given the distribution of polarization and geometry (e.g., randomized geometry for powder samples), the intensity and scattering frequency can be integrated over that distribution to predict the peak shape and position for a multi-grain relative to a single-crystal spectrum.

Keywords: Brillouin scattering, theory, multigrain samples

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GHz ultrasonic velocity measurements of iron beyond the bcc-hcp transition

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We have been developing GHz ultrasonic measurement in DAC up to ~15 GP both for P and S waves. This project of measuring iron was started after the achievements of preliminary work on KCl and natural olivine up to ~15 GPa (Yoneda et al., JpGU2019). We would like to present (1) additional technical improvements recently, and (2) preliminary experimental results at around 1GPa.

Keywords: CHz ultrasonic measurement, iron, high pressure

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Density measurements of Fe up to 25 GPa based on X-ray absorption

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Terrestrial planets, such as Earth, Venus, Mars, and Mercury, have metallic liquid and/or solid cores. The cores consist of mainly Fe and Ni with small amounts of light elements. Chemical compositions of solid state cores have been estimated by density measurements of crystalline core materials in a number of previous studies. On the other hand, there are a few previous studies on density measurements of liquid samples because of technical difficulties. Although Morard et al. (2008, 2013) obtained densities of liquid Fe with light elements by structure analyses from XRD patterns, accuracy of the densities was under debate because they used XRD patterns with narrow reciprocal lattice spaces. In this study, we have measured densities of crystalline Fe and amorphous materials using an X-ray absorption method in order to avoid problems of small diffraction angles due to a diamond anvil cell (DAC).
High pressures measurements were performed using DAC with gaskets having 3 sample chambers. Fe or amorphous samples were loaded in a sample chamber for density measurements. Powders of KCl, KBr, or RbBr as references for thickness were also loaded in another sample chambers. After XRD patterns were taken from all samples and references, absorption profiles were also measured. Experimental pressures were determined using pressure averages between KCl, KBr, or RbBr. Densities based on the X-ray absorption method were obtained using the Lambert Beer law with mass absorption coefficients from NIST data base. Densities of crystalline Fe were obtained up to 25 GPa and densities obtained based on X-ray absorption method were consistent with those by XRD.

Keywords: Diamond anvil cell, X-ray absorption method, Earth core

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[E] Oral | S (Solid Earth Sciences)：S-MP Mineralogy & Petrology

[S-MP37] Supercontinents and crustal evolution

convener:Madhusoodhan Satish-Kumar(Department of Geology, Faculty of Science, Niigata University), Krishnan Sajeev(Centre for Earth Sciences, Indian Institute of Science), Tomokazu Hokada(National Institute of Polar Research), Yasuhito Osanai(Division of Evolution of Earth Environments, Faculty of Social and Cultural Studies, Kyushu University)

Supercontinent formation and dispersion has been enigmatic in the Earth's history. Eurasia is one such current supercontinent and incredible progress in the understanding of its geological evolution has been achieved in the past decades. Earlier supercontinents in
the Earth's history such as Gondwana (0.5 Ga), Rodinia (1.0 Ga), Columbia/Nuna (2.0 Ga), Kenorland (2.5 Ga) and Vaalbara (3.1 Ga), have been the focus of several studies, however limited information on older supercontinents has restricted in understanding their tectonic evolution. Several important unsolved issues remain, such as how, when and where these supercontinents formed and how long they remained as such before breaking apart. Additional questions arise on the processes that triggered the fragmentation and unification of continents. In this session, we invite authors around the world to present original new
data as well as review results on the continental scale crustal processes and tectonic evolution that are associated with supercontinent formation events in Earth's history. The well-studied Eurasia and Gondwana supercontinents are of particular focus. Topics of interest include, but not restricted to, extremes in metamorphism, P-T-d-t evolution, magmatism, and the role of fluids. We hope to provide a platform for scientific discussions that will enlighten our understanding of the physical and chemical processes in the continental crust that records episodes of orogenesis that contributed to the formation and evolution of supercontinents.

[SMP37-01] Magma activities in Sør Rondane, eastern Dronning Maud Land, East Antarctica: Implications for amalgamation of the Gondwana supercontinent

★Invited Papers

*Masaaki Owada[1], Atsushi Kamei[2], Yasuhito Osanai[3], Nobuhiko Nakano[3], Ippei Kitano[3] (1.Yamaguchi University, 2.Shimane University, 3.Kyushu University)

[SMP37-02] Thermal gap between UH *T* granulite and surrounding pelitic gneiss from Rundvågshetta in the Lützow-Holm Complex, East Antarctica

*Kota Suzuki[1], Tetsuo Kawakami[1] (1.Department of Geology and Mineralogy, Graduate School of Science, Kyoto University)

[SMP37-03] Spinel+quartz assemblage in granulites from the Southeastern Madurai Block-Southern Granulite Terrain, India: Implications for ultrahigh-temperature Metamorphism

*Rajkumar Perumal[1], Krishnan Sajeev[1], KUMAR R. S.[2], Vinod Samuel[3], Kim S. W.[3], Justin K Antony[2] (1.Indian Institute of Science, Bangalore India, 2.Department of earth sciences, Annamalai University, Annamalai nagar, India, 3.Yonsei University, Department of Earth Sciences, South Korea)

[SMP37-04] Neoproterozoic fayalite-bearing charnockite from south-eastern India—its genesis and metamorphism

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[SMP37-05] C-O-Sr-Nd-Pb isotope geochemistry of metacarbonate rocks in continental collision zones as proxies for estimating the sedimentation age and understanding the tectonic setting of deposition

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Magma activities in Sør Rondane, eastern Dronning Maud Land, East Antarctica: Implications for amalgamation of the Gondwana supercontinent

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The formation of the Gondwana supercontinent resulted from the collision of the East- and West-Gondwana continents. The time of collisional event is regarded as geological time scale from the late Neoproterozoic to early Cambrian. The Sør Rondane Mountains (SRM), eastern Dronning Maud Land, East Antarctica, are situated within the Pan-African suture zone related to the formation of Gondwana supercontinent. The geology of SRM is divided into the northeast terrane (NE terrane) and the southwest terrane (SW terrane) in terms of lithology and metamorphic processes. These two terranes were welled during the Late Proterozoic (640 to 600 Ma). The NE terrane is composed mainly of metamorphic rocks, whereas the SW terrane consists of metamorphic rocks (Layered gneiss complex) and the tonalite (Tonalite complex). Post-kinematic intrusive rocks, granitoids, syenite, lamprophyres, and dolerites intruded into the both of SW and NE terranes.

The Layered gneiss complex in the SW terrane ubiquitously bears metamorphosed igneous rocks with various compositions. These igneous activities started at c. 1100 Ma and ceased at c. 650 Ma having two pulses with 1000 to 900 Ma and 770 to 630 Ma. The Tonalite complex consists mainly of the tonalite associated with the microgabbro occurring as magmatic enclaves and dikes. Although the Tonalite complex underwent low-grade metamorphism, zircon U–Pb dating indicate that the main igneous activities occurred during 1000 to 930 Ma.

Granitoid magmas are generally produced by partial melting of middle and lower crusts. The Nd isotopic data of granitoids, therefore, give important information for evolution of continental crust. The metamorphosed granitoids from the SW terrane show positive epsiolon-Nd values corrected to each intrusive age. Therefore, the SW terrane as a whole was derived from a juvenile crust during Neoproterozoic time from 1100 Ma to 650 Ma. The plausible tectonic setting for the formation of the SW terrane would be an oceanic arc. The SW terrane was situated at plate convergent boundaries for almost 450 million years. On the other hand, the epsilon-Nd values of post-kinematic granitoids, ranging from 620 to 500 Ma, possess almost zero to less than zero. It means that the old continental materials contributed to the formation of the post-kinematic granitoid magmas.

The syenite formed the magmatic activities from 560 to 550 Ma. At that time, SRM was situated at the extensional setting after the compressional event in the eastern Dronning Maud Land. The syenite also appears in the Yamato Mountains (YM), 300 km east of the SRM. The magmatic ages of the Yamato syenite are almost similar to those of the syenite from SRM. In addition, both syenites are geochemically originated from high-K basaltic magmas produced by partial melting of lithospheric mantle. In this scenario, the syenite magmatism of SRM and YM would be caused by up-welling of mantle asthenosphere as an acting heat source, probably accompanying lithospheric thinning. The region covering SRM and YM would, therefore, record an extensional collapse after amalgamation of the Gondwana supercontinent.

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Keywords: Gondwana supercontinent, East Antarctica, Sor Ronda Mountains, Magmatic history

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Thermal gap between UH*T* granulite and surrounding pelitic gneiss from Rundvågshetta in the Lützow-Holm Complex, East Antarctica

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Revealing the formation mechanisms of ultrahigh-temperature (UH*T*) metamorphic rocks is essential to understand the deep crustal processes associated with supercontinent formation events [e.g., 1]. The peak UH*T* metamorphic conditions and subsequent near-isothermal decompressional *P-T* paths of UH*T* granulites from Rundvågshetta (Lützow-Holm Complex, East Antarctica) have been well constrained by several previous studies [e.g., 2]. On the other hand, only a few studies have constrained the *P-T* conditions of other lithologies occurring in Rundvågshetta, which lack diagnostic mineral assemblages for UH*T* [e.g., 3]. The *P-T* evolutions of other lithologies, especially those of pelitic gneisses surrounding the UH*T* granulite layers or lenses, are indispensable to understand the formation mechanisms of UH*T* metamorphic rocks.

Recently, a number of trace element geothermometers have been proposed [e.g., 4] and applied to UH*T* metamorphic rocks [e.g., 5]. The trace element geothermometers have potentials to newly detect UH*T* metamorphic rocks that do not contain diagnostic mineral assemblages for UH*T* [6].

By applying the Zr-in-rutile geothermometer [4] to rutile inclusions in garnet enclosing Al_2SiO_5 minerals and nanogranite inclusions (NIs) [7], this study revealed the detailed *P-T*-melting histories involving early high-*P* stages of a UH*T* granulite and a surrounding pelitic gneiss from Rundvågshetta. Chemical zoning of garnet in terms of P was utilized to indicate isochronous surface. As a result, thermal gap of ~ 100 °C was detected between these two lithologies.

In the case of the pelitic gneiss without diagnostic mineral assemblages for UH*T*, the P-poor cores of garnet include NIs, as well as sillimanite and biotite. Biotite commonly occurs as inclusion minerals in the P-poor cores of garnet and rarely occurs as matrix minerals. This mode of occurrence of biotite can be interpreted as almost complete consumption of pre-existed matrix biotite during the prograde to peak metamorphism [e.g., 8]. The pre-existed granitic melt, which is now preserved as NIs in the P-poor cores of garnet, was probably produced through dehydration melting reaction consuming biotite under the sillimanite stability field. The estimated *P-T* condition of the P-poor cores of garnet spans the boundary of granulite/UH*T* metamorphism (~ 850 °C/0.1 kbar to ~ 930 °C/12.5 kbar).

On the other hand, in the case of the UH*T* granulite, no evidence of partial melting (i.e., NI) was found in garnet (5 thin sections from single sample). However, melt was probably present during or after the growth of P-poor rims of garnet, because the margins of garnet is partly replaced by the intergrowth of biotite + plagioclase [e.g., 9]. Extremely high-*T* under high-*P* condition was obtained from rutile inclusion in the P-rich mantles of garnet enclosing kyanite and sillimanite (~ 1026 °C at 14.6 kbar). Taking the occurrence of orthopyroxene + sillimanite in the rock matrix into account, this UH*T* granulite experienced the high-*P* granulite facies metamorphic condition (~ 1026 °C at 14.6 kbar) before the formation of diagnostic mineral assemblage for UH*T* under the sillimanite stability field.

Since partial melting is an endothermic process that absorbs heat energy to proceed [10], it must have buffered the temperature increase of the pelitic gneiss during the prograde to peak metamorphism in this

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studied case. On the other hand, if partial melting was suppressed in the case of UH*T* granulite until peak metamorphism, extremely high-*T* condition can be attained more readily [10]. The possible differences of timing of partial melting between these two lithologies might cause the thermal gap of ~ 100 °C in this studied case.

[1] Kelsey (2008); [2] Hiroi et al. (2019); [3] Tsunogae et al. (2014); [4] Tomkins et al. (2007); [5] Hart et al. (2018); [6] Kelsey and Hand (2015); [7] Cesare et al. (2009); [8] Kawakami and Hokada (2010); [9] Holness et al. (2011); [10] Clark et al. (2011)

Keywords: ultrahigh-temperature metamorphism, partial melting, nanogranite inclusion, Zr-in-rutile geothermometer, chemical zoning, phosphorus

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Spinel+quartz assemblage in granulites from the Southeastern Madurai Block- Southern Granulite Terrain, India: Implications for ultrahigh-temperature Metamorphism

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Evolution of the ultrahigh-temperature Mg-Al granulites of southeastern Madurai Block serves as a window to mid- deep crustal processes and metamorphism. Spinel bearing khondalites are collected from southeastern part of Madurai Block that fall outside the Kambam UHT belt. Spinel+quartz assemblage enclosed within garnet in garnet orthopyroxene–cordierite granulites from keelaparapatti within the southeastern Madurai Block. Garnet contains numerous inclusions along sillimanite and biotite as well as spinel and quartz. The spinel in direct contact with quartz has moderate X_{Mg} (= Mg/ (Fe^{2+} + Mg) = 0.44–0.47), and is Zn and Fe^{3+} poor (X^{Zn} = Zn/ (Fe_{2+} + Mg + Zn) = 0.027–0.036, Fe_{3+}/(Fe_{2+} + Fe_{3+}) = 0.12–0.17). Spinel is also present in the matrix surrounded by magnetite, but the matrix spinel contains more Zn (X^{Zn} = 0.067–0.072) and does not show any contact relationship with quartz. Such Zn- and Fe3+-poor spinel in direct contact with quartz has been regarded as a diagnostic evidence of ultrahigh-temperature (UHT) metamorphism. The diagnostic mineral assemblages, reaction textures and mineral chemical data obtained from the studied samples revealed ultrahigh temperature conditions. This implies that the Madurai Block has undergone peak metamorphic conditions at a temperature above 900˚ C. Phase diagrams provide further evidence for UHT conditions, which demonstrate a temperature above 950˚C at a pressure range of 5 -12 kbar. The U-Pb zircon ages indicate that the area was metamorphosed at 550 Ma during final stages of Gondwana amalgamation. These ages, petrological characteristics and PT conditions are in accordance with data documented from previous studies within these UHT localities of the southeastern Madurai Block. Also, spinel + quartz assemblage enclosed in poikiloblastic texture garnet has also been reported from the southeastern part of Madurai Block trace of a major suture zone within the Gondwana amalgam with evidence for prograde high-pressure metamorphism followed by UHT event. The spinel + quartz may consequently indicate decompression from higher pressure conditions which accompanied the final collision and amalgamation of the Gondwana supercontinent during the latest Neoproterozoic.

Keywords: South-eastern Madurai block, ultra-high temperature, spinal-quartz

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Neoproterozoic fayalite-bearing charnockite from south-eastern India—its genesis and metamorphism

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Rare fayalite-bearing charnockite (orthopyroxene-bearing granitoid) has been identified at the south-eastern edge of the Madurai Block, a little-studied remnant of the south-eastern part of the Southern Granulite Terrane, India. The major rock type in the region is hornblende-rich charnockite, intercalated with thin disrupted layers of pyroxenite and garnet-rich felsic rocks. Fayalite-bearing charnockite is exposed in a rock quarry and nearby regions, hosted within hornblende-rich charnockite. The major reaction texture present is coarse-grained fayalite and clinopyroxene rimmed by orthopyroxene coronas. The clinopyroxene grains have criss-crossing exsolution lamellae of orthopyroxene oriented in at least three directions, a texture indicating that the primary clinopyroxene was pigeonite. In a few domains fayalite is associated with magnetite and minor quartz. The matrix assemblage is mostly plagioclase, mesoperthite and minor quartz. Zircon is associated with both the mafic and felsic matrix mineral assemblages. Zircon grains associated with olivine or clinopyroxene are rounded, with a concentrically zoned CL-bright core rimmed by a CL-dark mantle overprinted by a thin grey rim. Zircon grains associated with mesoperthite and plagioclase are more elongate, with a similar zoning pattern but a thick outer rim. Temperature estimates based on the composition of clinopyroxene and integrated mesoperthite are *ca.* 850–890˚C. The *P-T* estimates based on an isochemical phase diagram show that the primary minerals were formed at high temperature (*ca.* 850˚C) at a pressure of *ca.* 7.5 kbar. These mineral assemblages were later overprinted by orthopyroxene at a similar temperature (*ca.* 800˚C) but lower pressure (*ca.* 6 kbar). The U-Pb zircon dating gave a mean core age of *ca.* 800 Ma and rim age of *ca.* 520 Ma. There is a small cluster of analyses (n = 4) at *ca.* 670 Ma. Based on the textural relations and dating, the primary magma was emplaced at *ca.* 800 Ma, possibly in connection with the break-up of the Rodinia supercontinent. Primary zircon was later overgrown by *ca.* 520 Ma rims during metamorphism and orthopyroxene formation associated with the amalgamation of Gondwana. The primary crystallization of fayalite along with clinopyroxene falls below the fayalite-magnetite-quartz buffer, indicating low activity of oxygen and volatiles such as H_2O. This conclusion is supported by the absence of hydrous phases such as hornblende or biotite in any of the observed fayalite-bearing charnockite samples. These results indicate that during Rodinia break-up the lower crust of south-eastern India was subject to a high-temperature heat pulse under highly reducing conditions.

Keywords: Fayalite-bearing charnockite , Southeastern India, Neoproterozoic

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C-O-Sr-Nd-Pb isotope geochemistry of metacarbonate rocks in continental collision zones as proxies for estimating the sedimentation age and understanding the tectonic setting of deposition

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Carbonate rocks is a rare rock type that preserve extinct oceanic signatures. They helpd in the determination of depositional ages and tectonic environment of metasedimentary sequences in orogenic belts as well as in understanding the formation and evolution of supercontinents. Here we present a detailed study on carbon, oxygen, strontium, neodymium and lead isotope geochemistry of metacarbonate rocks from different East Gondwana continents. In particular, metacarbonate rocks from East Antarctica and Sri Lanka were studied in detail. The isotopic systems studied have distinct residence and mixing time in seawater, and are also controlled by the input from surrounding continents. We present here a model on the closure of the “Mozambique Ocean” prior to the final amalgamation of the Gondwana supercontinent purely based on the isotope geochemistry of metacarbonate rocks.

In order to obtain primary sedimentary geochemical information for the study area an extensive geochemical screening protocol for identifying post-depositional alterations, using oxygen isotopes, trace elements and REE + Y patterns was followed. In general, the metacarbonate rocks have positive oxygen isotopic composition, suggesting that these rocks were not affected by external infiltration of fluids during digenesis, dolomitization or metamorphism. Strontium isotope chemostratigraphy was applied for the selected samples. Depositional ages were estimated using established strontium isotope evolution curves. By using the ε Sr vs. ε Nd cross-plots it was possible to distinguish the typical seawater-rock mixing relationship in metacarbonate rocks associated with continents and oceanic crusts. Pb isotope analysis was carried out for the first time for the metacarbonate rocks in the EAAO belt. The results indicate that Pb isotopic composition showed significant difference within a single terrane. This might be due to the difference of initial composition, as well as the relationship to depositional basin and seawater composition.

Our results confirm the evidence of an oceanic island arc system and peripheral oceans to continents before the formation of the Gondwana supercontinent in the Neoproterozoic. By applying a multi-element isotope geochemical approach on chemostratigraphically well constrained metacarbonate rocks collected from continental collisional zones, and comparing the data with basement rocks from various neighbouring Gondwana continents, regional affinities could be established. Sr, Nd and Pb isotopic compositions provide important information about the depositional settings of sedimentary rocks and provide key information about the surrounding terrains of oceanic and continental affinities during the time of deposition. This can lead to a better understanding of paleo-tectonic settings of crustal fragments that assemble to form supercontinents.

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Keywords: Metacarbonate rocks, Carbon and oxygen isotopes, Lead isotopes

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[E] Oral | S (Solid Earth Sciences)：S-MP Mineralogy & Petrology

[S-MP37] Supercontinents and crustal evolution

convener:Madhusoodhan Satish-Kumar(Department of Geology, Faculty of Science, Niigata University), Krishnan Sajeev(Centre for Earth Sciences, Indian Institute of Science), Tomokazu Hokada(National Institute of Polar Research), Yasuhito Osanai(Division of Evolution of Earth Environments, Faculty of Social and Cultural Studies, Kyushu University)

[SMP37-06] **Bulk rock Nd-Sr and multiple-sulfur isotope compositions of carbonatites from the Phalaborwa complex, South Africa**

★Invited Papers

*Anupam Banerjee[1], Madhusoodhan Satish-Kumar[1] (1.Niigata University)

[SMP37-07] Circum-Indian ca. 800 Ma tectonothermal activities: A review of imprints of Rodinia growth and dispersal at Indian Archean cratonic margin

*Kaushik Das[1] (1.Hiroshima University)

[SMP37-08] **Tectonics and crustal evolution of Shevaroy Block, Southern India: Insights from petrology, geochemistry and U-Pb zircon geochronology**

*Sam Uthup[1], Tsunogae Toshiaki[1,2], Rajesh VJ[3], Tsutsumi Yukiyasu[4] (1.Graduate School of Life and Environmental Sciences, University of Tsukuba, Japan, 2.Department of Geology, University of Johannesburg, Auckland Park 2006, South Africa, 3.Department of Earth and Space Sciences, Indian Institute of Space Science and Technology, Trivandrum, India, 4.Department of Geology and Paleontology, National Museum of Nature and Science, Ibaraki 305-0005, Japan.)

[SMP37-09] Multiple sulfur isotope characteristics of felsic-mafic-ultramafic granulites from the Nilgiri Block, southern India

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Discussion

Discussion

Bulk rock Nd-Sr and multiple-sulfur isotope compositions of carbonatites from the Phalaborwa complex, South Africa

*Anupam Banerjee[1], Madhusoodhan Satish-Kumar[1]

1. Niigata University

Carbonatites are unique mantle-derived rocks with more than 50% modal abundance of igneous carbonates and they mostly occur in association with alkaline silicate rocks. Since carbonatites and alkaline silicate rocks are highly enriched in Sr, Nd and S concentrations than any other terrestrial igneous rocks, they are less susceptible to crustal contamination. Therefore, such igneous rock suites provide an ideal opportunity to trace crust-mantle interaction through recycling and mantle heterogeneity. While $^{143}Nd/^{144}Nd$ and $^{87}Sr/^{86}Sr$ of any magmatic rocks are suitable tracers for distinguishing depleted versus enriched mantle source regions, sulfur isotopic compositions of these rocks are also useful in delineating crustal recycling owing to the higher $\delta^{34}S$ of crustal sediments than primitive and/or depleted mantle[1]. Additionally, $\Delta^{33}S$ of these rock samples would indicate the relative timing of crustal sources since only Archean sediments could possess a non-zero $\Delta^{33}S$ value[2]. A recent study, based on the combined S and Pb isotopic compositions of bulk rock carbonatites and in-situ measurements of sulfide minerals, from the ~2.06 Ga Phalaborwa complex of South Africa suggests a possible role of Archean sediments in their mantle source regions[3]. However, this study is limited to only three carbonatites and their constituent sulfur-bearing minerals. Thorough multiple isotopic investigations are required on multiple samples from this peculiar carbonatite occurrence to characterize the mantle source region of this igneous suite and its interaction with recycled components.

Here we report multiple-sulfur isotopic compositions of whole-rock carbonatites and associated alkaline silicate rocks along with their $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ from the Phalaborwa carbonatite complex of South Africa. Whole-rock sulfur isotopic compositions of these rocks have been measured with SF_6 method using Thermo Scientific MAT 253 gas source Ion Ratio Mass Spectrometer at Niigata University. The analytical uncertainty of $\delta^{34}S$, based on long-term measurements of sulfur isotope standards S-1 and S-2, is better than 0.5‰. Radiogenic Nd and Sr isotopic compositions of the carbonatites and the associated silicate rocks have been measured using MAT 251 Thermal Ionization Mass Spectrometer at Niigata University. Preliminary results obtained from these samples show a wide range in $\delta^{34}S$ for carbonatites and alkaline silicate rocks (-0.8 to 4.2‰ and -4.0 to 12‰, respectively). Mass independent fractionation (MIF) of sulfur isotopes is observed for most of the samples, as revealed by their positive $\Delta^{33}S$ values. On the contrary, two silicate rocks show no significant MIF S isotopes. The initial (calculated at 2.06 Ga) $^{87}Sr/^{86}Sr_{(t)}$ and $\varepsilon_{Nd(t)}$ of carbonatites and some silicate rocks show overlapping values, ranging from 0.703665 to 0.707879 and -6.6 to -8.3, respectively. Two silicate rocks, those showing mass-dependent fractionation of S isotopes, have extremely non-radiogenic $^{87}Sr/^{86}Sr_{(t)}$ (0.693161 and 0.698217) and CHUR like $\varepsilon_{Nd(t)}$ (-0.3 and 0.4) isotopic compositions. Based on the radiogenic Sr and Nd isotopic compositions of these rocks, we suggest that parent magma for this carbonatite complex is derived from an enriched mantle reservoir. Such enrichment of the mantle source region is perhaps the result of recycling of crustal sediments. This result is also consistent with the $\delta^{44/40}Ca$ of a different set of carbonatite samples from this location suggesting a possible role of crustal recycling process[4]. Since most of the rock samples used in this study show a large range in $\delta^{34}S$ and MIF $\Delta^{33}S$ isotopic composition, we suggest that such enrichment of mantle source must have happened prior to the global oxidation event at ~2.45 Ga.

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Keywords: Recycling, Carbonatites and alkaline silicate rocks, Mass independant fractionation of sulfur isotopes

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Circum-Indian ca. 800 Ma tectonothermal activities: A review of imprints of Rodinia growth and dispersal at Indian Archean cratonic margin

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Indian continent preserves rock records of small- to large-scale magmatic and metamorphic events related to plate tectonics from early Archean till recent geological past. Records of such events on the global level are quite plenty in the Phanerozoic era, but scarce in the Precambrian era. However, a recent surge in geochronological data, particularly of Proterozoic time in other old continental blocks helps to have a better understanding of global tectonism related to assembly, growth, and dispersal of several Proterozoic supercontinents, particularly Rodinia. Data from Indian continents are also coming up in recent years related to this supercontinent. The present study is mainly based on our data on rock records of tectonothermal events and their geochronological data (U-Pb zircon and U-total Pb-Th monazite age data) on orogenic belts in and around the present-day Indian landmass highlighting the events occurring at ca. 800 Ma.

The northern part of the Eastern Ghats Granulite belt (EGB), i.e. Chilka Lake province south of the Archean Singhbhum craton shows major zircon growth in aluminous granulite at ~800 Ma (777 ±5 Ma, 785 ±14 Ma, 780 ±9 Ma, 786 ±21 Ma depending on the rock types). This rock also preserves the textural evidence of strong isothermal decompression M_3-D_3 event from peak conditions of 9 Kbar, ~900 ˚C to 5-6 Kbar (cordierite-bearing assemblages), possibly during ca. 800 Ma. The matrix monazite grains yield a slightly lower age value of 760 ±21 Ma. Carbonic fluid ingression possibly occurred syn- to post ITD event affecting both zircon and monazite grains. Large-scale shear zone in the orogenic interior of the EGB, called Nagavalli Shear Zone contains the evidence of decompression and shear zone formation in orthopyroxene-bearing granitoids ranges between ca. 840 Ma to 780 Ma. Our ongoing study in this shear zone-bound megacrystic granitic-granodioritic gneiss yields a possible syn-tectonic granitic magmatism ~ 800 Ma (zircon U-Pb SHRIMP ages at 780 ±11 Ma; 816 ±17 Ma, lowest spot age; 823 ±42 Ma with inherited EGP orogenic event ages in between 1000 Ma and 900 Ma). Whereas, orogenic upheaval at the southern part of the Western Dharwad craton-margin occurred at the same time, where Paleo- to Mesoarchean sedimentary protolith (~3.0 Ga to ~3.6 Ga) suffered deep crustal metamorphism in between ~ 2.4-2.2 Ga. Thereafter, this deep crustal section was cratonized for nearly 1200 m.y. before it was reactivated and upheaved to shallow crustal depth in between 817 ±23 Ma (from granulite assemblage) and 814 ±18 Ma (from associated amphibolites). This reactivation has been petrologically imprinted in the metapelitic granulite through the reaction textures caused by isothermal decompression from peak conditions of ~10 Kbar and 850-800 ˚C. On the north-west side of the Indian continent, Aravalli-Delhi orogenic belt occurs in between two Archean cratonic blocks, namely Marwar Craton and Bundelkhand Craton. The Soth Delhi Fold belt, dominated by calc-silicate gneiss and some siliciclastic metasediments, is sandwiched between these two. This belt is dominantly showing the structural imprint of a transpressive orogeny and pre- to syn-to-post-tectonic granitoids which fix the age of transpression between 850 Ma and 820 Ma.
Hence, it seems that there was a possible orogenic pulse affecting the Archean craton-margin granulites from east India (south of the Archean Singbhum craton and northern part of EGB) to south India (south-western margin of the Dharwad craton) up to north-west India (South Delhi Fold Belt in

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Aravalli-Delhi Orogenic belt) at ca. 800 Ma. All these imply the presence of a tectonothermally active belt surrounding the preexisting Indian cratons ca. 800 Ma (similar to Knoydartian orogeny in Laurentia) along which the deep continental crustal materials were exhumed and grown, while the shallow crust was tectonically activated along narrow zones in the cratonic parts.

Keywords: Indian continent, 800 Ma, Circum-Indian peripheral tectonothermal events

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Tectonics and crustal evolution of Shevaroy Block, Southern India: Insights from petrology, geochemistry and U-Pb zircon geochronology

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The amalgamation of arcs through parallel collision and subduction, and subsequent vertical growth and lateral accretion led to the episodic continental crustal growth on the planet Earth. The Southern Granulite Terrane (SGT) in peninsular India is composed of various crustal blocks ranging in age from Paleoarchean to late Neoproterozoic which are dissected by transcrustal suture zones (e.g., Drury et al., 1984; Santosh et al., 2013, 2015; Uthup et al., 2019). These crustal blocks inherit signatures of crustal growth processes which operated during Archean. The Shevaroy Block (SB) is bounded by the NE trending Mettur Suture Zone in the west, in the east by the NNE trending Nallamalai Suture Zone, and in the south by the E-W trending Salem-Attur Suture Zone. The Shevaroy Block is dominantly composed of charnockite and felsic orthogneiss, along with mafic granulite, metapyroxenite, syenite, and younger pegmatite intrusions. The SB is characterized by NNE-trending structures. The dominant mafic-ultramafic lithologies present in the SB are meta-pyroxenite (clinopyroxene + orthopyroxene + calcic amphibole + ilmenite + magnetite), garnet-bearing mafic granulite (garnet + clinopyroxene + orthopyroxene + quartz + actinolite + cummingtonite + ilmenite), and amphibolite (calcic amphibole + plagioclase ±clinopyroxene + ilmenite ±magnetite).

A garnet-bearing mafic granulite sample examined is composed of porphyritic garnet with clinopyroxene, plagioclase, ilmenite, and quartz inclusions. These inclusions within the porphyroblastic garnet are regarded as relicts of the prograde mineral assemblage (clinopyroxene + $plagioclase_0$ + ilmenite + quartz). While, the medium- to coarse-grained clinopyroxene + $garnet_1$ + $plagioclase_1$ + $orthopyroxene_1$ + quartz present in the matrix represents the peak metamorphic mineral assemblage. Application of conventional geothermobarometers on the peak assemblages yielded metamorphic temperatures and pressures of 840-910˚C and 10-11.5 kbar. Similar peak metamorphic conditions are reported from the adjacent crustal blocks as well as from adjacent suture zones. An early retrograde stage is marked by the $orthopyroxene_2$ + $plagioclase_2$ corona texture formed around the $garnet_1$, as the result of a reaction: $garnet_1$ + $clinopyroxene_1$ + quartz →$orthopyroxene_2$ + $plagioclase_2$. Subsequently, these $orthopyroxene_2$ and $plagioclase_2$ underwent retrograde hydration to form cummingtonite and actinolite. The peak metamorphic minerals are also mostly overprinted by the late-stage actinolite along their grain boundaries.

All the studied mafic-ultramafic rocks from the SB are basaltic in the total alkali vs SiO_2 diagram. In the primitive-mantle normalized trace elements diagram, all the mafic-ultramafic rocks show negative Nb, Ta, P, and Ti anomalies and relatively constant high field strength elements (e.g, Zr, Hf) except for the garnet-bearing mafic granulite. The metapyroxenites and amphibolites are also characterized by enrichment of large ion lithophile elements (LILE) (e.g., Ba, K) suggesting fractional crystallization. In the chondrite normalized REE diagram, metapyroxenites and amphibolites show enrichment of light rare earth elements (LREE) over heavy rare earth elements (HREE). However, the garnet-bearing mafic granulite display slightly depleted LREE pattern over HREE. These REE patterns and normalized trace element

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diagram displayed by the garnet-bearing mafic granulite suggest a MORB source for its origin, while an arc-related origin for metapyroxenites and amphibolites. Different tectonic discrimination diagrams suggest volcanic arc setting for all the mafic rocks from the Shevaroy Block. The garnet-bearing mafic granulite, metapyroxenite, and amphibolite might have formed from an underplated mantle-derived magma. The geochemistry of these rocks from the SB suggests that the SB was formed dominantly by the arc magmatism in a convergent margin setting. The zircons from amphibolite displayed oscillatory zoned cores with thin bright CL rims. The magmatic core yielded U-Pb age of ca. 2.50-2.58 Ga, while the metamorphic overgrowth rims yielded an age of ca. 2.46 Ga. These magmatic ages also confirmed the crustal growth related to arc magmatism in a convergent tectonic setting, while the overgrowth ages are related to the high-grade granulite-facies metamorphism. Hence, the Shevaroy Block provides one of the best examples for understanding the continental growth and tectono-thermal history of southern India.

Keywords: Shevaroy Block, Geochemistry, Geothermobarometry, Crustal growth

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Multiple sulfur isotope characteristics of felsic-mafic-ultramafic granulites from the Nilgiri Block, southern India

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The Nilgiri Block belongs to granulite belt in the southern part of Dharwar Craton, India. Co-genetic (~2500 Ma) suite of pyroxenite, mafic granulite, two-pyroxene granulite and charnockite are exposed from North to South in this region. All these rock types are metamorphosed under granulite facies conditions at P-T conditions at around 600 to 1500 MPa and 650 to 900˚C {1,2,3]. Based on a detailed mineralogical and textural characterization of sulfide minerals, Samuel et al. [3] observed that, two-pyroxene granulite and metagabbro consist of pyrite +/- minor pyrrhotite and charnockite has mostly pyrrhotite, with minor chalcopyrite. In this study we report preliminary multiple sulfur isotopic composition of a suite of Neoarchean granulite facies metamorphic rocks from the Nilgiri Block, southern India.

Our δ34S results fall in a narrow range, representing typical magmatic sulfur isotopic compositions, with pyroxenites having slightly positive values compared to near zero values for charnockites. The relationship between δ33S, δ34S and δ36S are generally close to the theoretical relationship for mass-depended fractionation. A general trend shows that heavier isotopes are fractionated and enriched in ultramafic-mafic rocks compared to felsic two-pyroxene granulite and charnockite. However, Δ33S and Δ36S values indicate minor, but systematic variations with respect to δ34S values.

The trend observed in sulfur isotopes can well be explained a mass depended fractionation, that could be correlated to differentiation of primary mafic magma to ultramafic-mafic cumulates and a felsic melt. Such process is mostly happening during arc magmatism, were basaltic magma produced during partial melting of mantle wedge, further differentiated to form ultramafic-mafic-felsic rock suites. Compared to a more prominent mass-independent fractionation of S isotopes in the Paleoarchean Dharwar craton [4], the dominant mass dependent fractionation towards south during Neoarchean could be related to a major shift in the tectonic style, with nominal contribution of sulfur from subducting components.

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[E] Oral | S (Solid Earth Sciences)：S-MP Mineralogy & Petrology

[S-MP38] Deformed rocks, Metamorphic rocks and Tectonics

convener:Yoshihiro Nakamura(Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology), Yumiko Harigane(Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (AIST))

We invite all researchers who aim to understand the dynamics of the earth's crust and mantle at the plate boundaries, to discuss the latest results from various viewpoints. The scope will include contributions through petrology and structural geology as well as various techniques including rheology and transformation of heat and mass.

Introduction

Introduction

Introduction

[SMP38-01] Pure shear deformation experiments of polycrystalline olivine : Relationship between grain shape and crystallographic preferred orientation during diffusion creep

*AKIHIRO ANDO[1], Takehiko Hiraga[1], Kosuke Yabe[1] (1.Earthquake Research Institute, University of Tokyo)

[SMP38-02] Olivine-plagioclase assemblage in orogenic peridotites: Proxy for the extent of lithosphere thinning and asthenosphere shallowing

*Kazuhito Ozawa[1], Carlos J. Garrido[2], Karoly Hidas[3], Jean-Louis Bodinier[4], Tomo Aoki[1], Françoise Boudier[5] (1.Department of Earth and Planetary Science, Graduate School of Science, University of Tokyo, 2.Instituto Andaluz de Ciencias de la Tierra (IACT), CSIC – UGR, Armilla, Granada, Spain, 3.Instituto Geológico y Minero de España (IGME), Tres Cantos, Madrid, Spain, 4.Geosciences Montpellier, Montpellier, France, 5.University of Montpellier, Faculté des Sciences de Montpellier, Place E. Bataillon, 34095 Montpellier, France)

[SMP38-03] Early subduction processes recorded by the metamorphic sole of the Palawan Ophiolite, Philippines

*Gabriel Theophilus Vinalay Valera[1], Tetsuo Kawakami[1], Betchaida Duetes Payot[2] (1.Department of Geology and Mineralogy, Graduate School of Science, Kyoto University, 2.National Institute of Geological Sciences, University of the Philippines)

[SMP38-04] **Transition of melt-fluid infiltration along detachment fault sampled from deformed gabbroic rocks and amphibolites of initial and final stages on the Godzilla Megamullion, Parece Vela Basin, Philippine Sea**

*Yumiko Harigane[1], Jonathan Snow[2], Yasuhiko Ohara[3,4,5] (1.Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (AIST), 2.Louisiana State University, 3.Hydrographic and Oceanographic Department of Japan, 4.JAMSTEC, 5.Nagoya University)

Pure shear deformation experiments of polycrystalline olivine : Relationship between grain shape and crystallographic preferred orientation during diffusion creep

*AKIHIRO ANDO[1], Takehiko Hiraga[1], Kosuke Yabe[1]

1. Earthquake Research Institute, University of Tokyo

The CPO has long been considered to result uniquely from dislocation processes, while recently, olivine CPO has been found to develop during diffusion creep. Mechanism of the CPO development during diffusion creep has been experimentally explored, which found the ubiquitous occurrence of rigid-body-like grain (lattice) rotation induced by grain-boundary sliding (GBS) during diffusion creep. Preferential GBS on crystallographically controlled low-index-plane grain boundaries promotes the rotation of low-index grain boundaries toward the shear direction, resulting in CPO. In the previous studies, the type of CPO pattern under shear was estimated based on the CPO developed under uniaxial compression and tension where the former and latter could characterize preferential slip (GBS) plane and direction, respectively. Obviously, such results only allow quantitative estimations of the CPO pattern and seismic anisotropy in the upper mantle. Pure shear diffusion experiments were conducted on polycrystalline olivine in this study. Three dimensional olivine grains shapes in the deformed samples are determined and explained based on grain boundary structures, which should allow me to examine the relationship between the grain boundary structures and the observed CPO patterns.

To deform olivine aggregate in pure shear at high temperature, a specially designed carbon die was used. Geometry of the die allowed the square prism shaped specimen with its long dimension in the Z direction, where the specimen was compressed from, to deform only in the X and Z directions. The die with the specimen was installed in the high temperature furnace which was attached to the Instron-type deformation apparatus. We performed experiments at 6 different temperatures (i.e., 1240℃, 1250℃, 1260℃, 1270℃, 1320℃ and 1350℃). I analyzed microstructures of the deformed samples by scanning electron microscopy (SEM), finding the concentration of olivine [100] in the X direction and [010] concentration in the Z direction in the high temperature (1350 and 1320℃) samples. Such CPO pattern corresponds to A-type olivine fabric. In the intermediate temperature (1270 and 1260℃) samples, the olivine [010] concentrates in the Z direction and the [100] and [001] distribute almost uniformly in X-Y plane (i.e., girdle distribution). In the low-temperature (1250 and 1240℃) samples, random CPO or very weak [001] and [100] concentrations in the Z and X directions, respectively, develop. The three-dimensional olivine grain shape was analyzed in the sample XY, YZ and XZ cross sections. I found systematic grain shape changes from prolate-type to oblate-type with decreasing temperature at the intermediate to high temperature conditions. In the low temperature samples, olivine grains have the expected shape of the pure shear geometry. Based on the observed grain shapes, I estimated development of low-index-plane grain boundaries parallel to (010) of olivine with the grain-boundary plane extended in the [100] direction at the high temperature. At the intermediate temperature, (010) grain boundaries with the similar extensions to the [100] and [001] directions develop. The low-index-plane grain boundaries little develop at the low temperature. Such grain boundary structures predict preferential GBS at [100](010) and [*h*0*l*](010) at the high and intermediate temperatures, respectively, while GBS occurs evenly among grain boundaries at the low temperature. The grain rotations due to such GBS result in A-type, AG-type and random CPO at the high, intermediate and low temperatures, respectively, during diffusion creep.

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I considered the appearance of CPO types based on the temperature normalized by peridotite solidus in the oceanic upper mantle. At the shallow depth, A-type CPO develops, while AG-type develops at the medium depth. Random CPO develops at the deeper portion of the mantle.

Keywords: Olivine, diffusion creep, grain shape, crystallographic preferred orientation, pure shear

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Olivine-plagioclase assemblage in orogenic peridotites: Proxy for the extent of lithosphere thinning and asthenosphere shallowing

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The lithosphere and asthenosphere boundary zones (LABZ), where the transfer mechanisms of heat, material, and momentum from the Earth’ s interior to the surface drastically change, played an important role in plate tectonics. Deepening or shallowing of LABZ is intimately related to the transient and dynamic aspects of the plate tectonics, the time and spatial scales of which are important to understand the heat and material transfer across LABZ through the Earth’ s history. In this regard, orogenic peridotites are excellent research target. They provide direct information with high spatial resolution for a better understanding of the processes taking place in LABZ.

Plagioclase peridotite or olivine-plagioclase assemblage reported from some orogenic peridotites is a record of dynamic LABZ because of the following reasons. The olivine-plagioclase assemblage in fertile systems is in principle not stable even at the depth of the upper most subcontinental lithospheric mantle (SCLM) at steady thermal state because (1) the common crustal thickness in normal non-cratonic SCLM is ~35km, (2) the Moho temperature for the mean steady-state continental geotherm is much lower than 600˚C, (3) the upper stability limit of plagioclase (plagioclase to spinel facies transition) becomes shallower with decrease in temperature, and (4) kinetic barrier for subsolidus reactions in the peridotite system becomes enormous at temperatures below 600˚C. Oceanic lithospheric mantle could have plagioclase-bearing peridotites just beneath the Moho, but they are records of magmatism took place beneath mid ocean ridges, the most extensive lithosphere thinning on the Earth.

The occurrence of olivine-plagioclase assemblage in some orogenic peridotite bodies, therefore, implies transient and dynamic high-temperature (>800˚C) processing at depth shallower than 20km (plagioclase-spinel facies boundary at ~800˚C), i.e., high-temperature decompression of LABZ up to the depth closer to the Moho. Adiabatic decompression of high-temperature LABZ leading to decompressional melting with inefficient melt segregation may give rise to plagioclase peridotite. Decompression along moderately high temperature adiabatic path or heating to allow subsolidus reactions leading to transformation of either spinel peridotites or garnet peridotites may give rise to plagioclase peridotite. However, decompression of LABZ associated with efficient cooling does not produce any olivine-plagioclase assemblage. Plagioclase peridotites thus could provide precious information on the dynamics of shallowing LABZ and underlying asthenosphere.

We have examined several orogenic peridotite complexes, Ronda, Pyrenees, Lanzo, and Horoman, to clarify the extent of shallow thermal processing based on olivine-plagioclase assemblage. The key approach of this study is searching olivine-plagioclase assemblage not only in various lithologies but also in microstructures, whose scale and mode of occurrence provide extent and strength of thermal processing in the shallow upper mantle. The wide-spread occurrence of plagioclase peridotites and localized partial melting in Lanzo suggest exhumation along high temperature adiabatic paths from the

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thermally structured LABZ in the Seiland subfacies; the predominance of plagioclase peridotites and its localized partial melting in Horoman suggest exhumation along variously heated paths from the garnet stability field; the moderate development of plagioclase peridotites without partial melting in Ronda suggest exhumation along variously but weekly heated paths from the spinel-garnet stability field, and the occurrence of minor plagioclase peridotites in Pyrenees suggest exhumation along cold path from the garnet-spinel facies boundaries except for localized thermal anomaly induced by shear heating. The extent of shallower thermal processing decreases, and thus lithosphere thinning becomes less extensive in this order.

Keywords: lithosphere-asthensphere boundary, subcontinental mantle, temperature-pressure history, plagioclase peridotite, orogenic peridotites

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Early subduction processes recorded by the metamorphic sole of the Palawan Ophiolite, Philippines

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Metamorphic soles are slivers of the subducted oceanic lithosphere which were welded at the base of ophiolite sequences during the early stages of subduction. They are composed primarily of metamafic rocks and record inverse *P-T* gradients (Soret et al., 2017). In this work, the petrological signatures of the Dalrympole amphibolites underlying the Late Eocene Palawan Ophiolite is investigated. Earlier works suggest that this ophiolite represents the obducted forearc region of a nascent arc formed following the subduction of the proto-South China Sea (e.g. Encarnacion et al., 1995).

The metamorphic sole consists from structurally lower sections of epidote amphibolites, amphibolite pods surrounded by epidote amphibolites and garnet amphibolites near the contact with basal peridotites. Synmetamorphic fluid movement is signified by foliation-parallel quartz veins. Raman spectrometry and preliminary microthermometry of primary fluid inclusions in one deformed quartz vein revealed that they are aqueuous with salinity of 3.3 –6.9 wt.% NaCl equivalent.

The epidote amphibolites are generally composed of hornblende, epidote, quartz and sodic plagioclase (An_{2-18}) with minor chlorite, sphene and rutile. The amphibolites are composed almost exclusively (~90%) of coarse hornblende and some sphene, rutile and albite. The garnet amphibolites are composed of garnet porphyroblasts set in a matrix of hornblende, epidote, oligoclase (An_{10-26}) and rutile. Inclusions of quartz, amphibole, epidote, albite and muscovite were also found in some garnets.

Hornblendes in the epidote amphibolite and amphibolite are mostly magnesiohornblende and edenite. They show prograde zonation marked by higher concentrations of Na, Al and Ti and lower Si at the rim relative to the core. Hornblende in the garnet amphibolites mostly classify as pargasite to tschermakite. Hornblende in garnet amphibolite have higher total Al (= 1.97-2.98 a.p.f.u) compared to other lithologies (= 0.20-2.73 a.p.f.u). Garnets in the garnet amphibolites also show prograde growth marked by decreasing Mn and increasing Mg content towards the rim. These garnet grains have high Fe (X_{Mg} =0.15-0.40) and Ca content (= Grs_{15-23}).

Pressure-temperature estimates calculated for the Dalrympole amphibolites suggest high-*P* amphibolite facies metamorphism consistent with their mineralogy and mineral chemistry (Wei and Duan, 2019). *T* was estimated using Zr-in-rutile thermometry (Tomkins et al., 2007) of rutile grains which occur in the matrix and as inclusions in amphibole and garnet. The epidote amphibolites and amphibolites generally have lower *T* values (=616-680 ˚C) compared with garnet amphibolites (=698-710 ˚C). *T* estimates using pairs of garnet and hornblende rims (Ravna, 2000) in the same samples are slightly lower (=659-704˚C). Only garnet-hornblende thermometry was applied to a garnet amphibolite (=727 ˚C) which lacks rutile. *P* was estimated for the epidote amphibolites (=10.3-12.9 kbars) and amphibolites (=10.4-12.6 kbars) by calculating the TZARS equilibria using the rim composition of the matrix assemblage following Kapp et al. (2009). The GHPQ barometer (Kohn and Spear, 1990) was applied to the garnet amphibolites using the garnet rims and matrix assemblage. Average *P* values for the garnet amphibolites (=12.7-13.2 kbars) are slightly higher but within the range of those obtained for the other lithologies.

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The *T* values obtained for the Dalrympole amphibolites are lower compared to other ophiolites (e.g. Semail) while the *P* values are significantly higher. Although high-*P* can be attributed to low-crossing angle of Zr-in-rutile thermometer and TZARS equilibria, the apparent paleogeothermal gradient preserved in the Dalrympole amphibolites (~16 ˚C/km) are comparable to hot subduction zones (e.g. Penniston-Dorland et al., 2015). These suggest that in Palawan, subduction might have been initiated by forcing a young oceanic lithosphere to subduct beneath a relatively colder and thicker oceanic crust.

Keywords: Metamorphic sole, Dalrympole amphibolites, Palawan ophiolite

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Transition of melt-fluid infiltration along detachment fault sampled from deformed gabbroic rocks and amphibolites of initial and final stages on the Godzilla Megamullion, Parece Vela Basin, Philippine Sea

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Detachment faults within oceanic core complexes interprets to act as conduits for fluid migration into deeper parts of the oceanic lithosphere. Thus, such detachment faults may influence underlying magmatism, hydrothermal activity and the rheology of oceanic lithosphere. In this study, to investigate the relationship of melt-fluid infiltration along detachment faults, we focused on the amphiboles in gabbroic rock and amphibolite because amphiboles are common hydrous minerals within oceanic gabbroic rocks and are generated by magmatic and metamorphic processes. We represent the results of microstructural and major- and trace-element analyses of amphiboles in the deformed gabbroic rocks and amphibolites sampled from two dredge sites (KR03-01-D6 and -D10) on the Godzilla Megamullion, and these two sites correspond respectively to the initial (i.e., breakaway area) and final (i.e., termination area) stages of development of the Godzilla Megamullion. Furthermore, we also compare the melt-fluid infiltration along the detachment fault between each dredge site. Amphiboles are classified into four distinct groups (Bleb, Coronitic, Matrix in brown amphiboles and Green amphibole) based on the microstructural and compositional classifications from Harigane et al., (2019, Lithos). We believe that these results at each stage might have been linked to entirely understand magmatic and hydrothermal circulation processes during detachment faulting of the Godzilla Megamullion.

Keywords: amphibole, gabbroic rock, amphibolite, detachment falut, Godzilla Megamullion, oceanic core complex

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[E] Oral | S (Solid Earth Sciences)：S-MP Mineralogy & Petrology

[S-MP38] Deformed rocks, Metamorphic rocks and Tectonics

convener:Yoshihiro Nakamura(Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology), Yumiko Harigane(Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (AIST))

We invite all researchers who aim to understand the dynamics of the earth's crust and mantle at the plate boundaries, to discuss the latest results from various viewpoints. The scope will include contributions through petrology and structural geology as well as various techniques including rheology and transformation of heat and mass.

[SMP38-06] **Fault zone structure and deformation in pelagic sedimentary rocks in the Jurassic chert-clastic complex, Central Japan**

*Wang Ding[1], Kohtaro Ujiie[1] (1.University of Tsukuba)

[SMP38-07] Energy based normalized brittleness index and its relationship with mineralogical composition of shale rock

*Nikita Dubinya[1,2], Kirill Ezhov[3], Aleksander Kolomytsev[3], Daria Petrova[3] (1.Moscow Institute of Physics and Technology, 2.Schmidt Institute of Physics of the Earth of the Russian Academy of Sciences, 3.Center of integrated engineering for e&p of unconventional resources, Gazprom neft)

[SMP38-08] Banded marbles and pseudotachylyte-like veins from the Higo Metamorphic Rocks:Indication of deep earthquake?

*Tadao Nishiyama[1], Ryuraro Nishida[1] (1.Department of Earth and Environmental Sciences, School of Science, Graduate School of Science and Technology, Kumamoto University)

[SMP38-09] Estimating volume change in metamorphic rocks using deformed vein sets example of the Del Puerto canyon region, in the Franciscan belt, W USA

*Shogo Soejima[1], Simon Richard Wallis[1] (1.Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo)

[SMP38-10] Petrologic evidence for ultrahigh-temperature metamorphism in lower crustal granulite xenoliths from Siberian kimberlite pipes

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[SMP38-11] Petrology and metamorphism of pelitic rocks from the internal zone of the Pan-African Lufilian belt, Copperbelt, Zambia

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Fault zone structure and deformation in pelagic sedimentary rocks in the Jurassic chert-clastic complex, Central Japan

*Wang Ding[1], Kohtaro Ujiie[1]

1. University of Tsukuba

At shallow depths in subduction zones, plate-boundary faulting is highly localized along weak layer such as smectite-rich pelagic clay. However, it remains poorly understood whether localization of plate-boundary slip also occurs at deeper portions of subduction zones. We examined the ~60 m-thick fault zone developed in pelagic sedimentary rocks of the Jurassic chert-clastic complex, Central Japan. The fault zone was developed along the imbricate thrust branched from the plate-boundary fault. In the fault zone, deformation was partitioned into folding in siliceous claystone, shearing along black carbonaceous mudstone layers, and localized slip along discrete slip surfaces. The orientation and geometry of asymmetric, tight to isoclinal folds in siliceous claystone is consistent with top-to-the-south sense of shear during subduction, while intense scaly fabric showing the composite planar fabric in carbonaceous mudstone layers represent shear concentration. Localized slip is represented by polished surfaces with slickenlines, showing a left-lateral shear sense. The Raman spectra of carbonaceous materials in the localized slip surface and scaly carbonaceous mudstone indicate that the intensity ratio of D1 and D2 Raman bands is markedly increased in localized slip surface relative to surrounding scaly carbonaceous mudstone, suggesting an increase in temperature during localized slip. Our results indicate that plate-boundary faulting was highly localized along carbonaceous mudstone, and that the increased heating during left-lateral faulting along discrete slip surfaces may represent seismic slip accommodating strike-slip component during oblique subduction.

Keywords: pelagic sedimentary rocks, fault zone structure, Raman Spectra, plate boundary faulting

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Energy based normalized brittleness index and its relationship with mineralogical composition of shale rock

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The study is focused on mechanical properties of shale rocks involved into hydrocarbon development and interrelations between these properties and rocks' mineralogical composition. Rocks' brittleness, which is one of the key factors for problems of hydrocarbon development, is the main focus of the research.

There are many different ways to introduce brittleness index as a factor determining whether a rock is ductile or brittle in terms of its mechanical behavior while being subjected to high external stresses. In the current study we consider an energy-based brittleness index. This index is mostly based on energy balance law. According to this law, the changes in total energy of a rock sample are related to changes in elastic energy, plastic energy, and (for post-peak) rupture energy. Whenever changes in microstructure of the rock appear, it may result into ductile deformation of grains or emergence and development of microcracks. As both processes may be clearly related to changes in mechanical energy, one is capable to distinguish them after analyzing enough data.

In the current study we carried out a series of triaxial loading test on shale rock samples extracted from a particular oil field. We carefully studied the obtained stress-strain curves in terms of energy-based brittleness-index. In order to compare different samples we modified the existing brittleness index definition by introducing its normalization. We proposed two concepts of "ideally ductile rock" and "ideally brittle rock" as examples of hypothetical rocks distinguished by their inelastic behavior. The introduced "ideally brittle rock" is a rock which shows perfectly elastic behavior similar to behavior of the considered sample until the stresses achieve a certain maximum when one major fracture emerges leading to brittle failure of the sample. On the contrary, "ideally ductile rock" is characterized by infinite plastic deformation without any fractures emergence. These concepts were used to establish a mathematical definition for mechanical behavior of rock samples subjected to triaxial loading in terms of brittleness. As a result, brittleness index was strictly normalized so that brittleness index of zero was related to "ideally ductile rock" and brittleness index of one was related to "ideally brittle rock".

Such normalization made it possible to compare the studied samples. Approximately thirty samples extracted from a particular wellbore from a depth interval of fifty meters were analyzed in terms of brittleness. At the same time, borehole and core data regarding mineral composition were studied. All the samples were divided into three groups characterized by low, average and high brittleness. According to obtained results, ductile behavior is positively connected with clay minerals content and presence of kerogen. The most brittle rocks have small amount of clay and organic material, and high values of quartz-feldspar-mica and carbonate minerals. It was also clear just from the sight of the samples, that higher value of brittleness reveal more fractures after failure. Samples with low brittleness have smaller and discrete fractures.
We believe that the obtained results on shale rock samples alongside with the approach to normalize brittleness index following the basic laws of solid mechanics will make it possible to deepen the understanding of relationship between rock mechanical properties and mineralogical composition. It

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should also be noted that precise information about brittleness profile along the wellbore will significantly increase the efficiency of multi-stage hydraulic fracturing in unconventional shale reservoirs, especially in horizontal wells.

Keywords: Brittleness index, Shale formation, Mineralogy

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Banded marbles and pseudotachylyte-like veins from the Higo Metamorphic Rocks: Indication of deep earthquake?

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We have reported the occurrence of the ultrahigh-pressure pseudotachylyte in a marble from the Higo Metamorphic Rocks, central Kyushu, Japan, in the 2019 Annual Meeting of JpGU (Nishiyama and Fujimoto, 2019). This finding will be important, because this UHP-pseudotachylyte may represent a signature of deep earthquake within a subducting crustal material. During the course of our survey for clarifying the regional distribution of the pseudotachylyte, we newly found some peculiar rocks such as banded marbles and pseudotachylyte-like fault rocks in the same marble layer with a thickness of 20 meters. Because these rocks have some similarity to the pseudotachylyte we have described, we studied the petrological characteristics of these rocks to clarify whether they have formed by frictional melting or by water infiltration.

Petrography of banded marble

Banded marbles occur within a massive marble layer close to the contact with pelitic gneiss. They can be categorized into two types: white-colored and black-colored ones. Both types have a common mineral assemblage of calcite + quartz + wollastonite + diopside + titanite with secondary datolite and prehnite, and graphite occurs only in the black-colored type as inclusions in diopside or as independent platy grains. Wollastonite shows a breakdown texture surrounded by calcite, and calcite is directly in contact with quartz. Banding consists of alternation of calcite-rich, diopside-rich, and quartz-rich layers. In some layers in the black-colored type, fractured grains of titanite and diopside are embedded in quartz and calcite, indicating hydrofracturing caused by fluid or melt (fluid or melt infiltrated into this rock, fractured titanite and diopside, and then precipitated calcite and quartz).

Petrography of pseudotachylyte-like fault rocks

The pseudotachylyte-like fault rocks occur along faults within a massive marble. The rocks consist of rounded fragments of marble embedded in a black matrix, in which network-veined quartz occurs in calcite, sometimes showing microfoldings. Quartz occasionally includes tiny calcite grains. Peculiar veins occur, consisting of quartz, caclcite and Al-Si clay mineral (unidentified) with a small amount of K-spar, which is very similar to the silicate domain (quartz + Al-Si clay mineral + dolomite) in the UHP-pseudotachylyte we have described. The Al-Si clay mineral is an alteration product of K-spar. The difference with the silicate domain in the UHP pseudotachylyte is that the carbonate species is not dolomite but calcite in these fault rocks.

Discussion

Hydrofracturing observed in the banded marble can be caused by infiltration of calcite + quartz melt. The presence of a peculiar vein in the fault rocks similar to the silicate domain in the UHP pseudotachylyte suggest the melting of these rocks. Quartz and K-spar components are incorporated into the fractured zone from the exterior (surrounding pelitic gneiss). In the CaO-SiO_2-CO_2 system, melting of calcite and

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quartz occur at temperatures higher than 1300 ^{o}C and pressures higher than 1.8 GPa (Huang et al., 1980). At lower temperatures and pressures, calcite and quartz will react to form wollastonite. The melting temperature will be drastically decreased by addition of water, although it is not determined experimentally yet. So, the question is whether the melting is caused by frictional heating associated with the fault movement or by water infiltration. The wollatonite stability field will increase as water is added at low pressures. The decomposition of wollastonite observed in the banded marbles precludes water infiltration at low pressures. Therefore, these rocks indicate either melting owing to frictional heating or by melting owing to water infiltration along the fault plane, both at pressures higher than 1.8 GPa. In either case, these rocks with a signature of melting represents faulting in subducting crustal materials at high pressures, possibly related to the deep earthquake.

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Keywords: pseudotachylyte, deep earthquake, water infiltration

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Estimating volume change in metamorphic rocks using deformed vein sets example of the Del Puerto canyon region, in the Franciscan belt, W USA

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Three independent components of finite rock deformation can be defined: strain, rotation and volume change. Studies in structural geology since the 1960s have helped develop many different methods for estimating finite strain. Since the 1990s new methods have been developed to estimate the rotational component of deformation. However, in most studies the third component of deformation is unknown or only poorly constrained. Developing methods to estimate volume change is needed to investigate the importance of mass transfer and fluid transport within the deeper, metamorphic domains of accretionary complexes. One of the few approaches used to estimate volume change in rocks is the Isocon method (Grant, 1986). The Isocon method is a chemical approach that uses the bulk rock composition to discuss changes in element concentrations of the rock. Knowledge of the original rock composition combined with assumptions about immobile elements can be used to estimate those elements that have been added or removed and hence the volume change. However, the need to know the original composition introduces major uncertainties and in the estimates. These uncertainties are compounded by possibility of major differences in the mobility of different elements in different chemical environments. Another method based on identifying microstructural domains of dissolution and reprecipitation have been proposed but their effectiveness has not been assessed (Ring & Brandon 1999).

The potential for deformed vein sets to be used to determine all three components of finite deformation was recognized in the 1990s (Passchier 1990, Wallis 1992) but has not been developed and applied to regional studies. This method is geometric and uses orientation and deformation style (shortened, extended or shortened and then extended) of deformed veins to define a Mohr diagram for finite deformation and hence derive the three deformation parameters. This method does not require information on the composition of the original rock. By combining the vein-set method with other deformation analyses such as strain analysis can help constrain the deformation parameters more accurately.

Deformation analysis of metagraywacke in the Del Puerto canyon in the Franciscan belt was performed using this method, and finite strain, vorticity and volume change were estimated. Pressure solution of quartz particles in the metagraywacke was observed, and deformed quartz veins were observed in outcrops in this study area. Finite strain was estimated from the shape of quartz particles by the Rf / Φ method, and deformed vein analysis was performed on quartz veins. The results of these analyses indicate volume change of the rock between 8 and 60 %. This contradicts previous estimates based on microstructural studies of about -30% (Ring and Brandon 1999).

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Keywords: Volume change, Deformation analysis, Accuretionary wedges, Deformed vein sets, Franciscan belt

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Petrologic evidence for ultrahigh-temperature metamorphism in lower crustal granulite xenoliths from Siberian kimberlite pipes

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Paleoproterozoic high-pressure mafic granulites have been known as lower crustal lithology of the Siberian Craton. Those lower crustal granulites were brought to the surface in some kimberlite pipes, and they have been petrologically studied (e.g., Koreshkova et al., 2011). These xenoliths allow to understand a thermal history of lower continental crust with extremely low heat flow. The investigated lower crustal xenoliths were collected from the Udachnaya kimberlite pipe. The xenoliths are characterized by the granulite-facies mineral assemblage of garnet + clinopyroxene ±F-rich pargasite + plagioclase + K-feldspars ±quartz ±F-rich biotite + ilmenite; they are subdivided into clinopyroxene-rich and pargasite-rich granulites. Although mineral assemblages are similar to some previous studies, the investigated samples contain characteristically various exsolution textures in clinopyroxene, feldspars and ilmenite. All these textures might imply slow cooling of granulites. In particular, orthopyroxene lamellae in clinopyroxene vary in thicknesses, lengths, and directions. It indicates that the granulite cooled in comparatively fast.

Solvus geothermometers to the integrated mode composition of exsolved pyroxenes and feldspars suggest that granulites have experienced a high-temperature metamorphism of at least 900°C, which is higher than previous temperature estimations. Pyroxene geothermometer also suggests that granulites have cooled to 600°C. Garnet contains abundant inclusions of Fe-Ti oxides and/or Ti-rich oxide minerals. It is noteworthy that our study newly discovered the occurrence of Fe-rich armalcolite. In pargasite-rich granulites, F contents of pargasite reach up to 0.8 wt% and ones of biotite reach up to 1.6 wt%, resembling to those minerals in some ultrahigh-temperature (UHT) metamorphic rocks in collisional orogenic belts. Applying *in-situ* petrographic thin-section U-Pb dating technique, we could confirm Paleoproterozoic age (1830 ±18 Ma) for metamorphic zircon, textually in equilibrium with garnet and pargasite. Considering the exsolution features and the occurrence of Fe-rich armalcolite, the lower crust would have undergone a Proterozoic UHT metamorphism. Subsequently, it has cooled relatively fast and had stayed under the condition of amphibolite-facies for a considerable time until the Early Paleozoic kimberlite eruption.

Keywords: Siberian craton, high-pressure granulite, ultrahigh-temperature metamorphism, xenolith, armalcolite

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Petrology and metamorphism of pelitic rocks from the internal zone of the Pan-African Lufilian belt, Copperbelt, Zambia

*Kabangu Grace Sakuwaha[1], Toru Takeshita[1]

1. Hokkaido Univ.

The Luswishi Dome located in the Domes region of the Central African Lufilian Copperbelt belt consists of Neoproterozoic metasedimentary rocks explored for their potential to host copper sulphide minerals (Turlin et al., 2016). The region has undergone Pan-African metamorphism interpreted to be associated with late stages of Gondwana assembly during the late Proterozoic to Cambrian (Eglinger et al., 2016). This study examines the conditions of metamorphism in this area based on drill core logging and thermobarometry to help better resolve their P-T-d history in order to contribute to an improved understanding of the tectonothermal evolution of the Domes region. We present new petrologic and geothermobarometric data as well as phase equilibria models constructed for garnet-bearing pelitic schists from the Dome’ s region (Luswishi, Zambia). The studied samples consist of garnet-plagioclase-kyanite or garnet-amphibole porphyroblasts in a foliated matrix of biotite-muscovite-plagioclase-quartz-ilmenite. Amphibole compositions lie in the field of pargasite and plagioclase is mainly andesine with X_{An}=30-50 (in amphibole-absent schists), or oligoclase with X_{An} =10-30 (in amphibole-rich schists). Garnets are chemically zoned with almandine and pyrope increasing from core to rim whereas sperssartine and grossular decrease from core to rim with an upturn at the rim suggesting that the zoning is as a result of growth processes which, have been slightly affected by subsequent diffusion on the rims where the zoning is reversed. A decrease of the Fe/(Fe+Mg) from core to rim in garnet zoning also indicates an increase in the temperature during the garnet growth for the modelled samples. P-T calculations were conducted by inverse modelling using mineral compositions obtained by EPMA and application of the garnet-plagioclase-biotite-muscovite thermometer and GASP barometers. Pseudosections have been constructed in the MnNCKFMASHTO system with SiO2 and H2O saturation using Perple_x 6.8.6 (Connolly, 2005), updated March, 2019 and the updated 2011 version of internally-consistent thermodynamic database (Holland & Powell, 2011). The results from the two methods are consistent with each other, with peak conditions at 500-600˚C and 5.5-9 Kbar. Textural relationships from thin section analysis also suggest a prograde metamorphic path accompanied by at least 3 distinct deformation phases with episodes of crystallization and deformation as determined from the porphyroblast-matrix microstructural relationships. Features of both ductile and brittle deformation are preserved in some samples, some of which also show overprinting by an episode of metasomatism and retrograde metamorphism.

Keywords: Copperbelt, Metamorphism, Thermobarometry, Pseudosections

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[E] Oral | S (Solid Earth Sciences)：S-MP Mineralogy & Petrology

[S-MP38] Deformed rocks, Metamorphic rocks and Tectonics

convener:Yoshihiro Nakamura(Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology), Yumiko Harigane(Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (AIST))

We invite all researchers who aim to understand the dynamics of the earth's crust and mantle at the plate boundaries, to discuss the latest results from various viewpoints. The scope will include contributions through petrology and structural geology as well as various techniques including rheology and transformation of heat and mass.

[SMP38-13] Single-shot laser ablation ICP-MS U-Pb dating of invisible outer-rim of zircon

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[SMP38-14] **Detection of zircon growth pulses and thermal evolution of Ryoke complex**

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[SMP38-15] Dating ductile deformation in a high-temperature/low-pressure type metamorphic terrane (Ryoke belt, Japan)

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[SMP38-16] **Does the Median Tectonic Line in the Chubu district, Japan preserve a subduction interface?**
Implication for a paired metamorphism in subduction zone

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Single-shot laser ablation ICP-MS U-Pb dating of invisible outer-rim of zircon

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In U-Pb dating, cathodoluminescence (CL) imaging is an important tool for revealing the internal structure of zircon. It is important to distinguish between the outer (overgrowth) rim and an inner (inherited) core, in particular for zircons from granitic and metamorphic rocks. For spot analysis, the rim and core need to be thicker than the minimum spot diameter. This presents a limitation of conventional U-Pb dating techniques. A newly-developed multiple collector (MC) ICP-MS is capable to provide U-Pb ages with 1-μm depth resolution by a very short laser ablation (LA) of 1 second (Hattori et al., 2017). Furthermore, the combination of multiple Daly detectors with the above LA-MC-ICP-MS system improves the in situ U-Pb geochronology for small sample size (Obayashi et al., 2017).

U-Pb dating using the above techniques was performed on the natural external surfaces of zircon crystals. Because the laser pit depth from a single shot is approximately 0.2 μm, depth profiles with five ages can be obtained over a thickness of 1 μm. Results are presented for zircons from mylonitic granite and metamorphic rocks in the Mount Everest region. The U-Pb age profiles of most of the zircons allow to distinguish a ~ 0.5 μm outer rim of 15 Ma and an inner rim of 19 Ma. The outer rims are not distinguishable in CL images of an internal cross section of the crystal. The single-shot LA technique is a major improvement for dating the metamorphic rims of zircon.

Hattori et al. (2017) JAAS 32, 88-95.
Obayashi et al. (2017) JAAS 32, 686-691.

Keywords: LA-ICPMS, U-Pb age, zircon, outer-rim

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Detection of zircon growth pulses and thermal evolution of Ryoke complex

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Zircon growth pulses in high-temperature metamorphic rocks and coeval plutonic rocks of the Ryoke complex were detected by a statistical model for multiple discrete growths. The model assumes rapid growth of zircon in comparison with analytical errors. Zircon U-Pb ages x_j (j = 1, 2, 3, ,,, n; n is number of data) and their analytical errors s_j were used as input data for the numerical simulation of the model. The numerical simulations of the statistical model were performed by Hamiltonian Monte Carlo (HMC) sampling, and yielded optimized values of ages of growth pulses m_i (i = 1, 2, 3, ,,, k; k is number of growth pulses) and their proportions p_i. The adequate k was evaluated by information criterions, such as Akaike's Information Criterion (AIC), Bayesian Information Criterion (BIC) or etc.

Two pelitic migmatites and three gneissose tonalites from the Mikawa Ryoke, central Japan, and one pelitic migmatite from the Yanai Ryoke, southwest Japan, were used for the detection of zircon growth pulses. The pelitic migmatites were collected from the lower and middle units. Their *P-T* conditions are 5.7 kbar and 801 deg C (the lower unit) and 4.3 kbar and 715 deg C (the middle unit), respectively (Miyazaki, 2010). Three gneissose tonalites from the Mikawa area intruded into lower unit. One pelitic migmatite (6.4 kbar and 850 deg C) from the Yanai area was collected from the highest metamorphic pressure and temperature area forming dome-like structure (Ikeda et al., in preparation).
Diffusion-controlled growth kinetics of metamorphic zircon were determined by the method proposed by Miyazaki et al. (2018). High-pressure and high-temperature experiments of diffusion-controlled zircon dissolution show that dissolution of 50 micron zircon in hydrous felsic melt requires only 100 year at 750 deg C (Harrsion and Watson, 1983). Reversely, growth of 50 micron zircon also requires only 100 year at the same conditions other than positive supersaturation S =1.We estimate upper bound of duration of zircon growth in hydrous melt using formulation of diffusion-controlled Ostwald ripening (Miyazaki et al., 2019). The supersaturation of Ostwald ripening with 10 micron critical size is $S = 2 \times 10^{-4}$, 10 micron overgrowth on 50 micron core requires about 2×10^5 year. Even if effective diffusion coefficient in pelitic migmatite is 10 times smaller than that in melt, the growth duration is short time similar to U-Pb analytical error.

Our results show that two pelitic migmatites in the Mikawa area have three growth pulses, such as ca. 100 Ma, ca 90 Ma, and ca 75 Ma. Conventional U-Pb spot analysis of the pelitic migmatite of the upper part yielded only ca. 100 Ma and ca. 90 Ma pulses. However, single-shot laser ablation ICP-MS U-Pb dating of invisible outer-rim of zircon (Iwano et al., 2020) revealed ca. 75 Ma growth pulse. U-Pb zircon ages from three gneissose tonalites show two or three pulses around ca. 75 Ma. Interval of growth pulses in gneissose tonalites (3-7 Myr) is shorter than those of metamorphic growth (10-15 Myr). One pelitic migmatite from the Yanai area yielded five zircon growth pulses, such as ca. 107 Ma, 103 Ma, 99 Ma, 97 Ma, and 93 Ma. Number of pulses and interval of pulses in the Yanai migmatites are larger (five pulses) and shorter (2-4 Myr) than those in the Mikawa migmatites. Our statistical model revealed that multiple growth pulses of zircon occurred in the Ryoke complex in the Mikawa and Yanai areas. Field observations suggest that zircon growth associated with developments of migmatites and/or coeval intrusions of gneissose tonalites. It is suggested that generation of growth pulses may related to advection of melt and

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releasing latent heat during solidification of melt. The melt advection and solidification may control thermal evolution of the high-*T* Ryoke complex.

Keywords: metamorphic reaction, zircon, metamorphic age, growth model, U-Pb dating, Ryoke

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Dating ductile deformation in a high-temperature/low-pressure type metamorphic terrane (Ryoke belt, Japan)

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High-temperature/low-pressure (high-T/low-P) type metamorphic belts are often considered to have formed below the volcanic arc in the subduction zone setting, and to represent a cross-section of ancient active continental crust. Detailed study on the evolution of high-T/low-P type metamorphic belts thus provides information on how continental crust replied to the abundant magmatic intrusions into the middle to lower crust. In this study, timing of ductile deformation that formed gneissosity of the migmatites in the high-temperature metamorphic terrane (Mikawa area, Ryoke belt, Japan) was dated utilizing pegmatite veins that crosscut the gneissosity and affected/not-affected by the gneissosity-forming ductile deformation.

Based on Takatsuka et al. (2018), three plutono-metamorphic stages are recognized in the Mikawa area: (1) 99-84 Ma: intrusion of granitoids (99-95 Ma pulse) into the upper crust and high-temperature regional metamorphism reaching sillimanite-grade (97.0 ±4.4 Ma to 88.5 ±2.5 Ma) in the middle crust, (2) 81-75 Ma: intrusion of gneissose granitoids (81-75 Ma pulse) into the middle crust at ~19-24 km depth, and (3) 75-69 Ma: voluminous intrusions of massive to weakly-foliated granitoids (75-69 Ma pulse) at ~9-13 km depth and formation of contact metamorphic aureoles (Takatsuka et al., 2018). Kazuratachi et al. (2019) obtained several zircon rims of metamorphic origin (Th/U<0.03) with ~81 Ma age from the vicinity of the 81-75 Ma pulse granitoids. They considered that this could represent the recrystallization of zircon during contact metamorphism by the 81-75 Ma pulse granitoids (Kazuratachi et al., 2019).

In this study, three pegmatite veins from northern part of the Mikawa area (Dando-san area) and one pegmatite vein from southern part of the Mikawa area (Hongu-san area) were dated. Zircon grains were extracted from the pegmatite veins and utilized in U-Pb dating performed by LA-ICPMS. In the Dando-san area, zircon from one pegmatite vein that crosscuts the gneissosity and shows a pinch-and-swell structure gave weighted average age of 70.0 ±1.8 Ma (2σ, MSWD = 2.0). Sillimanite and biotite define the gneissosity. Zircon from two non-deformed pegmatite veins that crosscut the gneissosity showed weighted average age of 70.5 ±2.3 Ma (2σ, MSWD = 1.0) and 70.2 ±2.3 Ma (2σ, MSWD = 1.2). The vein nearest to the Inagawa granite (~75-69 Ma) alone showed syn-kinematic nature. In the Hongu-san area, zircon from one pegmatite vein that shows gneissosity-oblique boudin trains gave weighted average age of 78.5 ±1.9 Ma (2σ, MSWD = 0.4). The gneissosity of this sample is also defined by the arrangement of sillimanite and biotite. Based on these data, we consider that final stage of ductile deformation that formed the penetrative gneissosity took place at ~70 Ma in the Dando-san area (corresponding to the ~70 Ma upper crust), whereas it was ~79 Ma in the Hongu-san area (corresponding to the ~80 Ma middle crust). Thermal input into the host metamorphic rocks by granitoid intrusions helped ductile deformation to take place at least locally in the vicinity of the intrusions utilizing the penetrative gneissosity even after the peak regional metamorphism (~97-89 Ma in the middle crust).

Kazuratachi, K., Kawakami, T., Skrzypek, E., Sakata, S., Hirata, T. (2019) JpGU meeting abstract. SMP32-P05.
Takatsuka, K., Kawakami, T., Skrzypek, E., Sakata, S., Obayashi, H., Hirata, T. (2018) *Lithos,* 308–309, 428–445.

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Keywords: U-Pb zircon age, gneissose structure, metamorphism, pegmatite vein, ductile deformation

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Does the Median Tectonic Line in the Chubu district, Japan preserve a subduction interface?
Implication for a paired metamorphism in subduction zone

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The Juxtaposition of Sanbagawa (High-P/T type) and Ryoke (Low-P/T type) metamorphic belts is classically called as a “paired metamorphic belt”. The two belts formed at a different part of a single convergent margin with different types of ridge interaction were amalgamated by Median Tectonic Line (MTL) along the arc-parallel tectonic boundary during late Cretaceous age. Therefore, the detailed *P-T-D* estimations of MTL lead to a further understanding of the formation tectonics of a paired tectonic belt in the Circum-Pacific region.

We here present detailed petrographic and microstructural studies using the Kashio mylonite and ultramylonite derived from the Ryoke metamorphic rocks along the MTL. Located in the Kashio area, Chubu district, Japan, the Kashio mylonite is a good example for investigating the detailed *P-T-D* conditions during mylonitization. A minor amount of mylonitic metasediments occurs as a small block in the gneissose Hiji tonalite. The peak *P–T* conditions of the metasediments were estimated at 750–800 ℃ and 4.5–5.5 kbar combined with the biotite-garnet thermometry and the garnet-biotite-plagioclase-quartz barometry. The gneissose Hiji tonalite, which is a candidate for the protolith of Kashio mylonite, was intruded as sheet-like bodies, and its granitic magma was emplaced at around 680–720 ℃ under pressures of 4.6–5.8 kbar based on the Al in the hornblende barometry and hornblende-plagioclase thermometry.

After peak metamorphism with magmatic intrusions, the estimated temperatures inferred from the rim of zoned garnet and mylonite foliations (e.g., muscovite and chlorite) exhibit the sigmoidal decrease from 700 to 400 ℃ with increasing deformation. On the other hand, the estimated pressure conditions show roughly the same at around 3.8–5.1 kbar from protolith to ultramylonite zone. Our pressure estimations indicate the Kashio mylonite was deformed at the depth of 14–19 km, applying an average crustal density of 2700 kg / m^3. In particular, a part of ultramylonite records P ~ 7.5 kbar at T ~ 400℃, suggesting the subsidence of mylonitic metasediments before exhumation.

Previous studies argued that MTL was one of the most prominent "intraplate" fault boundaries in Japan and thought to be results of rapid cooling of Ryoke granitoids by exhumation. However, our detailed *P-T* estimations demonstrated that the Kashio mylonite was formed by isobaric cooling at the middle crust (14–19 km), and a part of mylonite was also recorded by further ductile deformation with Sanbagawa metamorphic rocks at the subduction zone. Thus, these data imply that the thick mylonite zone along the MTL was formed by rapid cooling due to the underplating of high-P/T metamorphic rocks. The amalgamation of high-P/T and low-P/T type metamorphic belts might result in the large-scale ductile shear zone, which serves as a subduction interface.

Keywords: Median Tectonic Line, Kashio mylonite, P-T-t-D path

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[E] Oral | S (Solid Earth Sciences)：S-MP Mineralogy & Petrology

[S-MP38] Deformed rocks, Metamorphic rocks and Tectonics

convener:Yoshihiro Nakamura(Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology), Yumiko Harigane(Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (AIST))

We invite all researchers who aim to understand the dynamics of the earth's crust and mantle at the plate boundaries, to discuss the latest results from various viewpoints. The scope will include contributions through petrology and structural geology as well as various techniques including rheology and transformation of heat and mass.

[SMP38-18] Hydrologic properties evolution during magmatic fluid activity in the middle-crustal conditions estimated from metamorphic fluid-rock reaction zones, Sør Rondane Mountains, East Antarctica.

*Diana Mindaleva[1], Masaoki Uno[1], Atsushi Okamoto[1], Noriyoshi Tsuchiya[1] (1.Graduate school of environmental studies, Tohoku University)

[SMP38-19] Mass transport during carbonate–silicate rock interaction in a collisional orogen: C-O-Sr isotope study of drill core samples from the Hida Belt, Japan.

*Hironobu Harada[1], Tatsuki Tsujimori[1], Keitaro Kunugiza[2], Katsuyuki Yamashita[3], Hideko Takayanagi[1], Yasufumi Iryu[1] (1.Tohoku Univesity, 2.Toyama University, 3.Okayama University)

[SMP38-20] **The formation of micro- to nano-pores in feldspars induced by fluid infiltration within the crust**

*Astin Nurdiana[1], Atsushi Okamoto[1], Masaoki Uno[1], Kenta Yoshida[2], Takayoshi Nagaya[3], Noriyoshi Tsuchiya[1] (1.Tohoku University, 2.Japan Agency for Marine-earth Science and Technology (JAMSTEC), 3.The University of Tokyo)

[SMP38-21] An integrated study of prograde-zoned garnets in low-temperature eclogites: Reappraisal of omphacite antiphase domain geospeedometry and new insights in fluid-induced metamorphic crystal growths

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[SMP38-22] Migration of Albite and Chlorite Rhythmic Bands with Temperature and Pressure Change in the Metamorphic Rocks.

*mitsuhiro toriumi[1] (1.Japan agency of marine science and technology)

Discussion

Discussion

Discussion

Hydrologic properties evolution during magmatic fluid activity in the middle-crustal conditions estimated from metamorphic fluid-rock reaction zones, Sør Rondane Mountains, East Antarctica.

*Diana Mindaleva[1], Masaoki Uno[1], Atsushi Okamoto[1], Noriyoshi Tsuchiya[1]

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Aqueous fluids flow could be responsible for changing hydrologic and thermodynamic properties of rocks. It is generally accepted that fluids play a key role in the earthquake’s generation and crustal evolution. Fractures created by rapid fluid pressure rise providing fluids pathways and provide hydration reactions. The extent, chemistry, time of infiltration, distribution and flow mechanisms of such hydration reactions are controlled by fluid flow rate and hydrologic and chemical properties of rocks where reactions have happened. However, fluid pressure gradients and permeability within the crust remain poorly constrained due to their heterogeneity. Therefore, it is important to constrain fluid flow rate and hydrological properties to understand fluid pressure gradient and permeability. We applied new methodology connecting fluid infiltration timescales and fluid pressure gradients to estimate permeability from fluid-rock reaction zones by reactive-transport modeling of trace element profiles.

This study aims to investigate fluid-rock reaction zones with relation to pegmatite melt in amp-opx gneiss samples (~0.55 GPa, 750˚C) from Brattnipene, Sør Rondane Mountains (SRM), East Antarctica, and constrained pressure gradient and permeability. Previous studies (e.g., Higashino et al., 2013; Higashino et al., 2019; Uno et al., 2017) suggested Cl-bearing fluid infiltration in the SRM from melt and aqueous fluids. Samples are partially hydrated along fractures associated with mm-scale hydration reaction zones. Pegmatite intrusions are crosscutting the schistosity.

We divide samples into several reaction zones from the fracture by modal amount of minerals, reaction textures, and trace elements (Cl and F) concentrations distributions profiles. The host rock is dominated by clinopyroxene, orthopyroxene, plagioclase, with minor amount of ilmenite, magnetite, biotite, and apatite. In the reaction zone, pargasite, tschermakite, plagioclase, with minor amount of quartz, biotite, and apatite were observed. Pegmatite consists of quartz and pyroxene with pargasite and biotite inclusions. Also, replacement textures of orthopyroxene and clinopyroxene by pargasite and biotite in the reaction zones are observed. CaO and Al_2O_3 are depleted in the host rock, whereas Na_2O, K_2O, and H_2O are enriched in the reaction zone. Cl concentration in apatite, biotite and pargasite grains were gradually decreasing with distance from the fracture, the highest concentrations were observed next to partial melt. Cl distributions profiles in pargasite were analyzed by a reactive-transport model to define transport mechanism and timescales of fluid infiltration. Duration of fluid infiltration was estimated to be 1-46 h depending on partition coefficient. Based on these result we will estimate fluid pressure gradient and permeability during magmatic fluid activity in the SRM. Estimated timescales represent process starting from fluid pressure rise, fractures propagation, and further fluid infiltration, which caused hydration reactions and reaction zone formation.

Higashino F. et al. Precambrian Research, 234 (2013) 229-246.
Higashino F. et al. Journal of Petrology, 60.2 (2019) 329–358.
Uno M. et al. Lithos 284–285 (2017) 625–641.

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Keywords: Permeability , Hydration, Fluids activity, Magmatic activity, Fluid pressure

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Mass transport during carbonate–silicate rock interaction in a collisional orogen: C-O-Sr isotope study of drill core samples from the Hida Belt, Japan.

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During orogenic process in convergent plate margin, supracrustal carbonate rocks often mingle with silicate-dominant rocks at deep crustal and/or mantle depth, and the process causes a variety of CO_2 -involved reactions. In order to understand the general rule of regional scale carbonate–silicate interaction on large-scale mass-circulation and mass-transports, we conducted an integrated study on impure marble and calcareous gneiss from the Hida Belt, which had formed during a Permo-Triassic suturing between North China and South China Blocks.

The impure marbles of the Hida Belt commonly contain subordinate amount of diopside–hedenbergite series clinopyroxene, grossular-rich garnet, rare wollastonite, vesuvianite, titanite, and quartz; the mineral assemblage suggests a high-temperature metamorphism of upper amphibolite-facies condition. Over 217 C–O stable isotope analyses of calcite from the selected nine drill-core and surface samples of clinopyroxene- and grossular-bearing calculous gneiss and impure marble found a large variation of $\delta^{18}O_{VSMOW}$ values (from +1.6 to +21‰). Overall, marble with less amount of silicate minerals have relatively constant $\delta^{13}C_{VPDB}$ values (from +1.6 to +4.2‰; mostly > +2.5‰) with a wide range of $\delta^{18}O$ (from +8.7 to +21‰). A narrow reaction zone between marble and syenitic intrusion shows a moderate variation of $\delta^{13}C$ (from −0.1 to +4.2‰) with a small variation of $\delta^{18}O$ (from +13 to +19‰). Notably, well-decarbonated samples formed by a carbonate–silicate rock interaction are characterized by a negative $\delta^{13}C$ (from −4.4 to −2.9‰). No correlation among C–O isotope data and $^{87}Sr/^{86}Sr$ ratio (0.707255–0.708220).

Considering applicable isotope fractionation modelling for our data (Hida Belt) and further comparisons with data from LT–HP marble in Syros (own data) and from HT–UHP marble in Kokchetav (literatures), very low $\delta^{13}C$ signature in orogenic impure marble can be formed via significant decarbonation at high-temperature condition during regional metamorphism. In essence, carbon isotope compositions of orogenic marble can be significantly modified by tectonic mingling by high-temperature carbonate–silicate rock interaction at continental collision zone. The high-temperaturecarbonate–silicate rock interaction can form 'hybrid' rock and enhance regional-scale lithological change. Although the process does not affect original $^{87}Sr/^{86}Sr$ ratio, decarbonation can decrease carbon isotope to the value similar to upper mantle value (~−5‰). Throughout the deep continent subduction, high-temperature carbonate–silicate rock interaction in a slab might play an important role to control carbon isotope signature of downgoing calcarious materials into Earth's interior.

Keywords: Hida Belt, marble, stable isotope, strontium isotope ratio

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The formation of micro- to nano-pores in feldspars induced by fluid infiltration within the crust

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Micro- to nano-pores are commonly formed during feldspar replacement and potentially act as fluid pathways within the crusts. However, there is a large variety of textures and conditions of pores, thus the effects of host minerals and fluid compositions on pore generation are poorly understood. This study reports novel occurrences of pores within altered plagioclase grains in the mafic schists around the pegmatite-bearing quartz diorite body in the Kinkazan Island, NE Japan. We reveal the temporal relationship of metamorphism, fluid infiltration, and pore generation. In addition, we conducted hydrothermal experiments on plagioclase replacement to examine the effects of fluids and host minerals.

Analyses of three mafic schists in the Kinkazan Island reveal the multiple stages of fluid infiltrations during cooling after the intrusion of quartz diorite. The quartz diorite is mainly composed of hornblende and plagioclase and the P-T conditions were estimated to be 710-760˚C and 0.3 –0.45 GPa. The first stage of fluid infiltration into the surrounding mafic schists was characterized by pegmatitic veins with reaction zone in which replacement of clinopyroxene by hornblende and Ca-rich plagioclase I (An80-90) by plagioclase II (An40-60). Assuming the similar pressure to quartz diorite, the temperature was estimated to be ~545˚C and the sodium-rich fluid infiltration was inferred. The second stage is the infiltration of potassium-rich fluid at 430-490˚C. In this stage, plagioclase III (An4Ab94Or2) and K-feldspar (An0Ab1Or99) were formed as the replacement products of plagioclase II. This stage of alteration is characterized by ubiquitous occurrences of the micro- to nano-scale pores. The mass balance analyses indicate the feldspar replacement is characterized by the gain of SiO_2 and K_2O and the losses of Al_2O_3 and CaO, with almost constant Na_2O. Furthermore, the later potassium-rich fluid propagated subsequently to form a K-feldspar vein which coexists with the lower-Al hornblende and the other micro-scale pores, then actinolite composition replaced the hornblende at the following stage. The profound diversity of replacement presents the change of fluid composition from the sodium-rich to the potassium-rich fluid as a decreasing temperature. Those fluids may emerge different pores properties according to certain host mineral compositions.
In order to understand the feldspar replacement and pore generation, we have started hydrothermal experiments of feldspar replacement. As the preliminary results, we found the development of micro-size pores at the reaction front of albite replacement by K-feldspar in an aqueous 2 M KCl under 600˚C & 150 MPa for 4 days. We will evaluate the effects of the composition of host plagioclase (An content) on the progress of replacement and resulting pore generation.

Keywords: micro-nano pores, feldspar replacement, potassium-rich fluid, fluid infiltration, hydrothermal experiment

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An integrated study of prograde-zoned garnets in low-temperature eclogites: Reappraisal of omphacite antiphase domain geospeedometry and new insights in fluid-induced metamorphic crystal growths

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Omphacite with compositions close to $Ca_{0.5}Na_{0.5}(Mg, Fe^{2+})_{0.5}Al_{0.5}Si_2O_6$ and garnet occur ubiquitously in high-pressure and ultrahigh-pressure (H*P*–UH*P*) eclogites. In order to understand growth kinetics of garnets in progressive eclogitization of subducting oceanic crust, we zeroed in on antiphase domains (APDs) of omphacite inclusions in prograde-zoned garnets in glaucophane-bearing L*T* eclogites. Two garnet crystals, which were extracted from Syros (Greece) and the South Motagua Mélange (SMM) eclogites, show a rhombic dodecahedral crystal habit. The center-cut garnets exhibit concentric zoning, in which Mg/(Mg+Fe) atomic ratio increases rimward, and contains abundant mineral inclusions. TEM observations on the omphacite inclusions found a few pristine APDs, which are devoid of significant deformation; but also various types of APDs, which had undergone subtle deformation. The average sizes of equiaxed APDs were: ~54 nm (from the core of the SMM garnet); ~26 nm (from the rim of the SMM garnet); and ~32 nm (from the rim of the Syros garnet). Rim-to-rim trace-element zoning in the SMM garnets are characterized by both 'A'-shaped (Tb, Dy, Ho, Y, Er, Tm, Yb, Lu) and 'M'-shaped (Sm, Eu, Gd) profiles. In contrast, the Syros garnet showed only 'M'-shaped REE profiles, which was attributed to change of REE partitioning due to transition from titanite to rutile during the prograde metamorphism. Application of Carpenter (1981)'s APD geospeedometry for 'non-deformed' omphacite inclusions suggests that the Syros garnet had grown ~1–2 orders of magnitude faster than the SMM garnet. Moreover, our new diffusion-limited REE-uptake modeling scheme (Fukushima and Tsujimori, in this conference) for the analysed trace-element line profile infers that the Syros garnet had grown ~2–3 orders of magnitude faster than the SMM garnet.

Our TEM study of omphacite inclusions also confirmed: (1) the presence of elongated APDs near the boundary between omphacite and host garnet in the SMM sample; and (2) the presence of nano-size fracture-like pore between omphacite and host garnet in the Syros sample. Assuming that the pore was filled with aqueous fluid, we postulate a hypothesis that growth of such elongated APDs or cation ordering in omphacite near such boundaries was controlled by fluid transportation. Petrographic observations on two eclogite samples suggest different metamorphic fluid compositions between Syros and the SMM. Probably they led to difference in physical mechanisms of fluid transportation, consequently the shape diversity of APDs near such grain boundaries.

Keywords: omphacite, antiphase domain, garnet, diffusion-limited REE-uptake model, eclogite

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Migration of Albite and Chlorite Rhythmic Bands with Temperature and Pressure Change in the Metamorphic Rocks.

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1. Japan agency of marine science and technology

The rhythmic bands of albite and chlorite together with epidote and actinolite are very common in low grade basic schists in the plate boundary metamorphic belts. These bands are very important for investigation of the mechano-petrological process in the plate boundary mechanics because these are formed by the transition from uniform basic schist to bifurcated banded one with chemical differentiation incorporated by high pressure aqueous solution during metamorphism in the plate boundary.

The author discussed in the previous talk in JpGU and GSJ meetings that the bands are probably derived from pore banding with negative slope of yield surface and their time scale are possibly inferred by means of band width and waveform of the band boundary surface. At this time, the constant temperature and pressure condition is assumed in the formation of bands. Thus, in the present discussion the author will intend to propose the change in pressure and temperature during the formation of bands.

Toriumi and Inui (2001) clarified that the garnet growth in the progressive metamorphism of the Sanbagawa metamorphic belt is associated with heterogeneous fluid outflow from the pelitic schists. They measured quantitative outflow of water using exact P-T paths from garnet zoning and grain size frequency distribution of peliltic schists and obtained the results that the peak of outflow rates are at pressures of 0.7 and 8.5 GPa during the subduction. Thus, the banding formation should be considered under the pressure and temperature increase in the large outflow of water together with retrograde hydration process.

Dissolution and precipitation equilibrium relations of albite and chlorite should shift at the band boundaries with grain boundary pore fluid. The relations of them are controlled by Gibbs free energy difference between albite and chlorite with water and ionic species. In the simple case of chlorite and albite bands, the Gibbs free energy of general exchange reaction of them with ionic species in fluid can be obtained easily and then it results that the albite band becomes widen by resorption of chlorite band in the pressure and temperature increase. Thus, the waveform of the band boundary formed by MS instability should give the band boundary migration velocity synchronous with pressure increase.

Reference

Toriumi M., and Inui, M., 2001, Bull. Earthq.Res.Inst., Univ. Torkyo, 76, 367-376.

Keywords: albite - chlorite band, boundary migration by temperature and pressure change, dissolution and precipitation process

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[E] Oral | S (Solid Earth Sciences)：S-MP Mineralogy & Petrology

[S-MP39] Oceanic and Continental Subduction Processes

convener:REHMAN Hafiz Ur(Department of Earth and Environmental Sciences, Graduate School of Science and Engineering, Kagoshima University), Tatsuki Tsujimori(Tohoku University), Kazuaki Okamoto(Faculty of Education, Saitama University)

This session aims at bringing earth scientists from Japan and overseas to present their research related to the processes of oceanic and continent subduction, continent-continent collisions, metamorphism of crustal rocks, formation of the oceanic/continental arcs, and accretion/ tectonic erosion of material along subduction boundaries.

Topics such as role of the fore- and back-arcs in the subduction zones, process of accretion of volcaniclastic and terrigenous sediments along the subduction/collision boundaries, deformation and metamorphism of subducted crust, and exhumation will be the main focus of the session.

Exchange of ideas among geoscientists applying different approaches on problems related to the theme of the session are most welcome.

[SMP39-01] **Models for Seismic slip and Fluid Flow along the Subduction Interface**

*Donald M Fisher[1], John N Hooker[1] (1.Pennsylvania State University)

[SMP39-02] Geological records related to ridge subduction in the back-arc basin: a case study from East China Sea Shelf Basin

*Shunli Gao[1], Jun Zhao[1], Senqing Hu[1], Xiaowei Fu[2] (1.China National Offshore Oil Corporation (CNOOC), China Limited-Shanghai, 2.State Key Laboratory of Marine Geology, Tongji University)

[SMP39-03] Slab breakoff tectonics: constraints from temporal changes of melting conditions recorded in geochemical stratigraphy of the Cumulate Member and ultramafic dikes of the Hayachine-Miyamori ophiolite, northeast Japan

*Takafumi Kimura[1], Kazuhito Ozawa[1] (1.Department of Earth and Planetary Science, The University of Tokyo)

[SMP39-04] **Boninites and related tholeiites from the southernmost of West Mariana Arc: geochemical evidence for subduction initiation**

*Ji Zhang[1,2], Guoliang Zhang[1] (1.Institute of Oceanology, Chinese Academy of Sciences, 2.University of Chinese Academy of Sciences)

[SMP39-06] A new scheme of diffusion-limited REE-uptake model for prograde-zoned garnets in low-temperature eclogites: Principle and application

*Ryo Fukushima[1], Tatsuki Tsujimori[1] (1.Tohoku University)

Models for Seismic slip and Fluid Flow along the Subduction Interface

*Donald M Fisher[1], John N Hooker[1]

1. Pennsylvania State University

A numerical model for slip along the subduction interface shows that coupling between fluid flow and fault healing is important for the spatial, temporal and size distribution of slip events. Field observations of exposed plate boundary fault zones from ancient subduction zones such as the Shimanto belt and the Kodiak accretionary complex have several first-order features that must be accounted for in models for the slip behavior during subduction. 1) Subduction fault zones record stratal disruption along a compactive strain path in the form of wide zones of mélange. 2) The slip occurs through development of a scaly fabric in mudstones and hydrofracturing of stronger blocks. 3) At depths and temperatures associated with the seismogenic zone, deformation is characterized by dissolution and continuous metamorphic reactions in the scaly fabric and diffusion to cracks in the blocks, with veins that have evidence for crack seal deformation, and 4) veins record evidence for both local and external fluids, suggesting events of fluid infiltration. We interpret these features as a record of plate boundary deformation at rates too slow to accommodate plate motions that occurs in the interseismic period between earthquakes. Importantly, this interseismic deformation, marked by pressure solution and a linear viscous rheology, is capable of healing the subduction interface through development of increased contact area and reduction in crack porosity. To investigate this process, we develop a 2-D block-slider cellular automaton that allows for temperature dependent fault zone strengthening. The same cellular automaton grid also functions as a darcian flow model that includes fluid production at depth and venting at the trench. The two models are coupled through (1) a failure law based on effective stresses that account for fluid pressures, and (2) the process of mineral redistribution, by which healing and increase in contact area coincide with reduction in permeability, whereas failure of the interface leads to restoration of greater permeability. These models show that the slip behavior of the plate interface and the time evolution of the fluid flow system are controlled by the balance between fluid production, fluid flow, and the rate law for fault strengthening.

Keywords: subduction, seismogenic zone, mélange, cellular automaton, scaly fabric, permeability

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Geological records related to ridge subduction in the back-arc basin: a case study from East China Sea Shelf Basin

*Shunli Gao[1], Jun Zhao[1], Senqing Hu[1], Xiaowei Fu[2]

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The consequences resulting from the ridge subduction have been widely observed. However, the according changes in the back-arc region are poorly known. During 60-50 Ma, the Izanagi-Pacific ridge subducted beneath the Eurasia roughly parallel to the trench (Müller et al., 2008;). This event has been recognized in the accretionary prism of Shimanto Belt (Raimbourg et al., 2014) and magmatic belt as the transition of geochemical composition (Imaoka et al., 2011) in the SW Japan. The performance related to this phase of ridge subduction is not clear in back-arc realm. The Cenozoic East China Shelf Basin (ECB) was suggested to be a back-arc basin, which formed by the subduction of Izanagi Plate, Pacific Plate and Philippine Plate, respectively. In this study, we firstly observed a strong magmatic event in the northern ECB at ~53 Ma, based on zircon U-Pb dating of granite samples which selected from the bottom of Well HZ8 located in Jinshan Sag of Changjiang depression. According to the seismic sections, this granite intrude into the Paleocene strata which was dated by microfossils and zircon U-Pb dating of the volcanic interbred. Furthermore, the high magnetic anomalies related to this magmatism show that the anomalies zone tends NE-SW and connected with the Yushan Uplift and Haijiao Uplift. Thus, we infer this magmatism belt may distribute in a large region. Moreover, a regional uplift event was observed in the east of Changjiang Sag resulted in the obvious truncation of the older layers (Paleocene and lower Eocene) and a large alluvial fan in the west of this uplifted zone. Because the absence of the thrust faults in the seismic sections, we proposed that this uplifted zone could result from the intrusion of the magmatism. This scenario means the magmatic belt jumped inland and into the back-arc basin (Changjiang Sag). The further geochemical composition of volcanic or intrusive rocks in other industrial wells in Xihu Sag or Fujiang Sag will give more details about this ridge subduction event.

Keywords: East China Shelf Basin, ridge subduction , zircon U-Pb dating, high magnetic anomalies, regional uplift event

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Slab breakoff tectonics: constraints from temporal changes of melting conditions recorded in geochemical stratigraphy of the Cumulate Member and ultramafic dikes of the Hayachine-Miyamori ophiolite, northeast Japan

*Takafumi Kimura[1], Kazuhito Ozawa[1]

1. Department of Earth and Planetary Science, The University of Tokyo

Slab breakoff models have been applied to explain thermal perturbations in asthenosphere inducing various geological events, such as, extensive alkali basaltic magmatism ([1]), bimodal basaltic and rhyolitic magmatism ([2]), and rapid exhumations of high-pressure metamorphic belts ([3]). These records, however, do not necessarily require the slab breakoff tectonics as a casual mechanism. [4] and [5] warned that the slab breakoff models are invoked mostly for a pure convenience without any compelling factual evidence in the literatures.

When a slab detachment and sinking occur as a terminal event of a steady-state subduction during continent/arc collision events, passive upwellings of the wedge and/or sub-slab asthenosphere are inevitably take place owing to the counter flow (e.g., [4], [6]). A numerical modeling suggests that the asthenosphere upwells from various depths ranging 100 - 600 km ([6]), which are distinctively deeper than those in other spreading tectonics. Such upwelling could cause decompressional melting if appropriate conditions for melting, such as thermal state and chemical compositions of the supra- or sub-slab mantle, are satisfied. [7] succeeded to show magma generation by passive upwelling of the sub-slab asthenosphere from at least ~160 km depth triggered by the slab breakoff in the Cambrian-Ordovician northeast Japan. In this study, we show an evolution of the slab breakoff tectonics estimated from the temporal change of the melting depth and fluid influx rate recorded as geochemical stratigraphic of the Cumulate Member and ultramafic dikes in the Hayachine-Miyamori ophiolite, northeast Japan.

The Cumulate Member has ~2 km in thickness and consists of dunite-dominant lower and upper horizons and a wehrlite-dominant middle horizon. We examined stratigraphic variation of rare earth element (REE) ratios of cumulus clinopyroxene to estimate those of parental magmas for the Cumulate Member by carefully evaluating effects of trapped melt crystallization and subsolidus elemental exchange. The mean values of (Ce/Sm)n of the parental magma in a layer for the lower, middle, and upper horizon range 0.65 –1.03, 1.02 –1.23 and 1.29 –1.59, respectively, and (Sm/Gd)n, 0.48 –1.10, 1.03 –1.17, and 1.28 –1.50, respectively, and (Dy/Yb)n, 0.63 –0.79, 1.10 –1.18, and 1.43 –1.55, respectively. Extensive examination of REE behavior in a fractional melting with material influx ([8]) shows that these elemental ratios provide useful proxies for melting conditions during open-system melting: degree of melting in the mantle ((Sm/Gd)n), percentage of melting in the garnet-stability field in total melting (PMGF; (Dy/Yb)n), and influx rate of fluid in the melting (β; (Ce/Sm)n). The degree of melting for the lower, middle, and upper horizon of the cumulates and the dikes range 6.4 –15.0, 7.8 –14.2, 8.6 -.12.4, and 16.6 in %, respectively, the PMGF, 76 –92, 76 –93, 85 –93, and 88.4 in %, respectively, the β, 0.00 –0.26, 0.00 –0.38, 0.01 –0.11, and 0.03, respectively.

The degree of melting with limited material influx ($\beta < 0.1$) is positively correlated with the PMGF, while that with significant influx ($\beta > 0.1$) is high with low PMGF. This indicates that the melting took place through two mechanisms: (1) decompressional melting of a depleted mantle with limited material influx at the depth > ~75 km and (2) fluxed melting at the depth < ~75 km. The PMGF and β for the lower horizons show wide variations from 76 to 93 % and 0.00 to 0.38, respectively. By contrast, those for the upper

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horizons tend to converge to 85 –93 % and 0.00 –0.11, which is the values for the ultramafic dikes occurring in the Cumulate Member. This temporal change in the conditions suggests decompressional melting of supra- and sub-slab mantle took place at various depths from ~75 km to ~160 km involving various amounts of fluid influx, which was followed by decompressional melting of sub-slab mantle under suppressed material influx with convergence of the depth of the melting to ~160 km. From this sequence of the melting, we propose that a slab breakoff in young oceanic lithosphere (< 30 Ma, [9]) was initiated at a depth shallower than ~75 km and its sinking continued up to the depth of ~160 km.

[1] Dal Piaz et al., 2003; [2] Sui et al., 2013; [3] Ernst et al., 1997 [4] Niu et al., 2017; [5] Garzanti et al., 2018; [6] Gerya et al, 2004 [7] Kimura et al., 2020 (under review for American Mineralogist); [8] Ozawa, 2001; [9] Duretz et al., 2011

Keywords: slab breakoff, Cumulate Member, Hayachine-Miyamori ophiolite

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Boninites and related tholeiites from the southernmost of West Mariana Arc: geochemical evidence for subduction initiation

*Ji Zhang[1,2], Guoliang Zhang[1]

1. Institute of Oceanology, Chinese Academy of Sciences, 2. University of Chinese Academy of Sciences

Subduction initiation is one of the essential outstanding problems of plate tectonics.The first lavas to erupt during subduction initiation are fore-arc basalts (FABs) and Boninites. Appearance of boninites marks the turning point from mantle decompression melting to fluid-assisted mantle melting, and therefore boninites preserve key information on the slab-mantle interaction during subduction initiation. In this study, we analysed major element, trace element and Sr-Nd-Pb-Hf isotope data for samples collected from the diving sites on the southernmost of West Mariana Arc. These samples can be geochemically classified into Low-Si Boninites (LSB) and tholeiites. We interpret these tholeiites to be transitional compositions between FAB and boninites. These boninites are depleted in HFSE and enriched in LILE, indicating that the mantle source was metasomatized by subducted slab-derived components. High contents in LILE and Ba/Th and Th/Yb suggest the mantle wedge have been metasomated by slab-derived fluids. However, unlike the Izu-Bonin boninites with U-shaped REE pattern, depleted LREE signature of these boninites rule out the contribution of slab melts that might account for the relatively high LREE. We further propose that that the FAB-LSB-HSB rock sequence record the increased contribution of subducting slab during subduction initiation.

Keywords: Boninite, Subduction initiation, Slab-mantle interaction

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A new scheme of diffusion-limited REE-uptake model for prograde-zoned garnets in low-temperature eclogites: Principle and application

*Ryo Fukushima[1], Tatsuki Tsujimori[1]

1. Tohoku University

Garnet has received considerable attention because of its common occurrence and its major element/REE zoning in rocks metamorphosed under various pressure–temperature (*P*–*T*) conditions . Because of the limited scale of cation diffusion at low-*T*, strong compositional zoning patterns are observed in garnet metamorphosed below ~600°C. This characteristic feature enables us to understand a snapshot of the metamorphic history. One of the most promising methods for unraveling metamorphic record is REE uptake modeling in low-*T* garnet, especially the diffusion-limited REE-uptake model proposed by Skora *et al.* (2006). Their model takes into consideration *T*-induced increase of REE diffusion coefficients around a given garnet porphyroblast. This model can reasonably explain 'secondary peaks' of REEs in the mantle of zoned garnets.

In this contribution, we will introduce a new scheme of diffusion-limited REE-uptake modeling for low-*T* prograde zoned garnet. Using this new model, we tried to reproduce REE profiles in garnets from Syros and South Motagua Mélange (SMM) eclogites (Fukushima *et al.*, in this conference). The rim-to-rim trace-element zoning in the SMM garnets are characterized by both 'A'-shaped (Tb, Dy, Ho, Y, Er, Tm, Yb, Lu) and 'M'-shaped (Sm, Eu, Gd) profiles, resembling the results of Skora *et al.* (2006). Our new model is designed to predict 'D_0/α' for each garnet, which means the ratio of the pre-exponential factor of REE diffusion coefficients around a garnet porphyroblast (D_0) to its growth rate (α). Although Skora *et al.*'s (2006) model regarded these two values as distinct parameters, we found that this ratio could be regarded as a single parameter only if a given garnet radius could be approximated by a linear function of time. The incorporation of the parameter 'D_0/α' enabled us to evaluate: (1) a possible range of REE diffusion parameters in the SMM eclogite, and (2) difference of growth rates between the Syros and the SMM garnet. Applying the new model to the quantitative core-to-rim profiles, we concluded that the Syros garnet had grown ~2–3 orders of magnitude faster than the SMM garnet. In essence, the new scheme of diffusion-limited REE-uptake model would be a useful predictive tool for comparing difference of garnet growth kinetics in low-*T* eclogites.

Keywords: diffusion-limited REE-uptake model, garnet, eclogite

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[E] Oral | S (Solid Earth Sciences)：S-MP Mineralogy & Petrology

[S-MP39] Oceanic and Continental Subduction Processes

convener:REHMAN Hafiz Ur(Department of Earth and Environmental Sciences, Graduate School of Science and Engineering, Kagoshima University), Tatsuki Tsujimori(Tohoku University), Kazuaki Okamoto(Faculty of Education, Saitama University)

This session aims at bringing earth scientists from Japan and overseas to present their research related to the processes of oceanic and continent subduction, continent-continent collisions, metamorphism of crustal rocks, formation of the oceanic/continental arcs, and accretion/ tectonic erosion of material along subduction boundaries.

Topics such as role of the fore- and back-arcs in the subduction zones, process of accretion of volcaniclastic and terrigenous sediments along the subduction/collision boundaries, deformation and metamorphism of subducted crust, and exhumation will be the main focus of the session.

Exchange of ideas among geoscientists applying different approaches on problems related to the theme of the session are most welcome.

[SMP39-07] Push out and Phase Transition of Mantle under the Izu Slab, recorded on CMT solutions of JMA

*Nobuaki Niitsuma[1] (1.Institute of Geosciences,Shizuoka University)

Discussion

[SMP39-08] **Variations in Frictional Properties Depending on Temperature in Tectonic Mélanges of Ancient Accretionary Prisms**

*Tsai-Wei Chen[1], Donald M Fisher[1], Andrew J Smye[1], Chris J Marone[1], Yoshitaka Hashimoto[2] (1.Pennsylvania State University , 2.Kochi University)

Discussion

Discussion

Discussion

Push out and Phase Transition of Mantle under the Izu Slab, recorded on CMT solutions of JMA

*Nobuaki Niitsuma[1]

1. Institute of Geosciences,Shizuoka University

1. Anomalous distribution in seismic intensity on M6.6 in 2019/7/28.

The epicenter of CMT was located on the axis of Nankai Trough off Mie Pref. of central Japan with depth 393km, however, the seismic intensities were less than 1 in Mie but the maximum 4 was recorded in Miyagi Pref. of northeast Japan, The anomalous distribution indicates the existence of less attenuate Slab, consistent with hypocenter distribution.

2. Polymorph of seismicity in the Izu, Ogasawara & Mariana Slab

The hypocenter distribution has polymorph with subduction types of low gradient Wing , vertical & recumbent. The earthquake with anomalous seismic intensity was happened on the base of the low gradient Wing.

3. Wing Subduction and Push out Mantle

The root of Wing is high seismicity with mainly reverse fault type and the tip of wing with strike slip fault type. The difference could be explained with pushing up strain to reduce the gradient of Slab. The hypocenters of low gradient Wings are concentrated above 410km in north and 550km in south of Hachijo Island.

4. Phase Transition of push out Mantle

The depths 410km and 550km of the Wings are well corresponding to α / β and β / γ phase transition in Mantle Transition Zone. The Wings should be related with the phase transition of the Mantle. The accompanied Mantle umder the ocean floor should be interrupted by descending Slab along trench axis and push out to continue the Plate Motion. The phase transitions of α / β and β / γ are progress more under higher pressure and lower temperature. Push out cool Mantle under the terminal of Slab could be transited than Slab for the depth. The terminal of Slab might be float on the transited Mantle with higher density and form Wings.

5. Changes in Push out Mantle recorded on Seismicity of Wing

The seismicity of the Wings have been observed for the last hundred years with seismometer of JMA. We can trace back the strength of the push out Mantle as the seismicity of the Wings. The time series of the seismicity are not in phase but reversed phase.. The phase should have influence on seismic and volcanic activities of Japanese Island Arcs.

Keywords: Izu Slab, Mantle Phase Transition, Wing Subduction, Push out Mantle, accompanied Mantle, Centrol Moment Tensor Solution of Japan Meteorological Agency

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Variations in Frictional Properties Depending on Temperature in Tectonic Mélanges of Ancient Accretionary Prisms

*Tsai-Wei Chen[1], Donald M Fisher[1], Andrew J Smye[1], Chris J Marone[1], Yoshitaka Hashimoto[2]

1. Pennsylvania State University , 2. Kochi University

Silica redistribution is an important process for fault healing likely to control the slip behavior of the subduction interface. The structure of tectonic mélanges in ancient accretionary prisms likely records the relative motion of tectonic plates and is typically marked by veined sandstone blocks within scaly mudstones, with silica diffusing from shearing mudstones and precipitating in fractures of sandstone blocks. This temperature-dependent process involves mineral precipitation and fracture healing and could strengthen subduction faults during the interseismic period by increasing the contact area across the fault zone in the time between slip instabilities. For mélanges that were accreted at different temperature, we suggest that the temperature variations are likely to result in different silica kinetics that are recorded in microstructural variations that may reflect different frictional properties along plate interfaces. The slip behavior of the plate interface depends on temperature as evidenced by down dip variations in slip mode and differences in earthquake size distributions for subduction zones with different age crust. Based on vitrinite reflectance and fluid inclusion analyses, there are two fossil accretionary prisms, the Kodiak accretionary complex and the Shimanto belt, that have undergone a range of temperatures that correspond to the full range of the seismogenic zone. Rocks from these complexes record variations in clay mineralogy with increasing temperature. Here, we present the results of a series of rock deformation experiments using mélange samples collected from the Kodiak accretionary complex and the Shimanto belt to evaluate how mineralogical changes within the seismogenic zone impact the frictional properties. The samples were powered, sieved to <125 μm grain size, and prepared to layers with area of 5 x 5 cm and proper thickness according to the content of clay minerals in the powers. The layers were then sheared under low normal stress to measure the frictional strength as a function of shear strain based on the assumption that the mélanges were under low effective stress. After steady-state sliding was achieved, multiple velocity steps were conducted. The velocity dependence of steady-state friction and the critical slip distance were determined by fitting the data with rate and state friction laws. The experiments serve as the first step to test the relationship between the paleotemperatures and friction properties.

Keywords: Silica Redistribution, Subduction Zone, Shimanto Belt, Kodiak Accretionary Complex, Slow Earthquake, Rock Deformation Experiment

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[E] Oral | S (Solid Earth Sciences)：S-MP Mineralogy & Petrology

[S-MP40] Thermal structure of subduction zones: modeling and the rock record

convener:Simon Richard Wallis(The University of Tokyo), Takayoshi Nagaya(Graduate School of Science, The University of Tokyo), Shoichi Yoshioka(Research Center for Urban Safety and Security, Kobe University)

The thermal structure of subduction zones is key to understanding the origin of magma,
the cycling of rocks and volatiles and the distribution of earthquakes in these regions. In recent years there have been many recent advances in thermal modeling of subduction zones and most are in broad general agreement. However, different approaches and different assumptions about boundary conditions mean that significant differences remain. The rock record of subduction-type metamorphism has the potential to provide useful additional constraints on the conditions of otherwise inaccessible regions. However, with few exceptions this record has not been closely considered in developing models. Recent studies have highlighted differences between the range of subduction conditions preserved in the rock record and those predicted for modeling of modern subduction zones. However, the reasons for such differences are unclear. Key remaining questions are how to improve the consistency between the modeling and rock record, and the most effective use of the rock record to constrain the boundary conditions for modeling. We invite contributions from subduction zone modelers and researchers of subduction-type metamorphic rocks. The aim of this session is to explore how best to combine these two approaches to estimate conditions along subduction zones and to improve our understanding of these geologically important regions.

[SMP40-01] Bayesian inference of model parameters controlling the thermal structure of subduction zones

*Manabu Morishige[1], Tatsu Kuwatani[1] (1.Japan Agency for Marine-Earth Science and Technology)

[SMP40-02] A holistic view of the thermal structure of subduction zones

★Invited Papers

*Peter E Van Keken[1], Geoff Abers[2], Cian Wilson[1] (1.Carnegie Institution for Science, Washington DC, USA, 2.Cornell University, Ithaca, NY, USA)

[SMP40-03] Subduction zone processes with fluid and melt: numerical model and observations

★Invited Papers

*Hikaru Iwamori[1] (1.Earthquake Research Institute, The University of Tokyo)

[SMP40-04] Low and high stress subduction zones recognized from metamorphic P-T paths

*Simon Richard Wallis[1], Kazuhiko Ishii[2] (1.The University of Tokyo, 2.Osaka Prefecture University)

[SMP40-05] Constraining the temperature conditions of paleo-subduction plate interfaces: Combining petrology and geodynamics

★Invited Papers

*Sarah Penniston-Dorland[1], Kayleigh Harvey[1], Xin Zhou[2], Ikuko Wada[2], Besim Dragovic[3], Peter E Van Keken[4] (1.University of Maryland College Park, 2.University of Minnesota, 3.University of South Carolina, 4.Carnegie Institution for Science)

[SMP40-06] Thermal structure near the continental Moho of subduction zone: Natural example of the Asemigawa region of the Sanbagawa metamorphic belt, SW Japan

*Yui Kouketsu[1], Kazushi Sadamoto[1], Hayato Umeda[2], Hirokazu Kawahara[3], Takayoshi Nagaya[4], Tomoki Taguchi[5], Hiroshi Mori[6], Simon Richard Wallis[4], Masaki Enami[7] (1.Department of Earth & Planetary Sciences, Graduate School of Environmental Studies, Nagoya University, 2.DOWA Metals & Mining Co., Ltd., 3.Japan Oil, Gas and Metals National Corporation (JOGMEC), 4.Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, 5.Department of Geology and Mineralogy, Graduate School of Science, Kyoto University, 6.Faculty of Science, Shinshu University, 7.Nagoya University)

Bayesian inference of model parameters controlling the thermal structure of subduction zones

*Manabu Morishige[1], Tatsu Kuwatani[1]

1. Japan Agency for Marine-Earth Science and Technology

It is critical to estimate the thermal structure of subduction zones to better understand the mechanisms of magma genesis and the range of observed earthquake types including megathrust earthquakes, slow earthquakes, and intraslab earthquakes. Material circulation at geological timescales may also be strongly affected by the thermal structure, because subduction zones are the only regions where surface materials are subducted deep into the Earth’ s interior. Geodynamic modeling has been widely used to compute the thermal structure and rock deformation. Surface heat flow observations have often been used to validate the predicted thermal structure. However, this type of approach has several limitations, including: (1) it is difficult to investigate the effects of a large number of model parameters in a systematic way, (2) uncertainties of model parameters are not obtained, (3) other sets of model parameters which better explain the observation might exist, and (4) information on the observation error cannot be considered. In this presentation, to overcome these difficulties in geodynamic modeling Bayesian inference is employed to simultaneously obtain five model parameters controlling the thermal structure of subduction zones based on surface heat flow observations.

The subduction zones at Tohoku in Japan and Cascadia are considered as the studied regions, because they are the representatives of cold and warm subduction zone, respectively. A 2D finite-element-based approach is used to solve the equations of mass conservation, momentum, and energy, to predict the surface heat flow. Metropolis algorithm, which is a Markov chain Monte Carlo method (MCMC), is used to sample the following model parameters: slab-mantle kinematically decoupling depth D_{dec}, the activation energy for shear viscosity E, the radiogenic heat production rate in the upper continental crust H_{UCC}, and the effective friction coefficient μ' controlling shear heating along the subducting plate interface. Preliminary results show that the obtained values of E are lower in both regions, and obtained values of H_{UCC} are lower in Cascadia, than the previously-reported values. This approach provides us a framework to validate and refine geodynamic models based on various types of observations.

Keywords: Bayesian inference, subduction zone, geodynamic modeling

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A holistic view of the thermal structure of subduction zones

*Peter E Van Keken[1], Geoff Abers[2], Cian Wilson[1]

1. Carnegie Institution for Science, Washington DC, USA, 2. Cornell University, Ithaca, NY, USA

Since the discovery of plate tectonics it has been puzzling that phenomena such as arc volcanism that require significant amounts of heat are located where cold oceanic lithosphere subducts. The apparent discrepancy between cold subduction and hot arc conditions has historically been explained by large arbitrary amounts of shear heating along the plate interface and viscous dissipation in the mantle. While it has become apparent that the arc conditions can be explained naturally by asthenospheric counterflow, there remains a puzzling discrepancy below the forearc. Exhumed blueschists and eclogites that are thought to have been part of the subducting oceanic crust tend to record maximum pressure-temperature conditions that tend to be, on average, significantly warmer than is predicted from the average thermal models of present-day subduction zones. It is reasonable to ask whether the thermal models are missing important heat sources (such as shear heating along the plate interface), whether the maximum rock conditions are overpredicted, or whether exhumation just occurs naturally under conditions that are warmer than the present-day average predicted conditions.

We provide a holistic view of subduction zone thermal structure that effectively puts the brakes on the importance of shear heating. Most important aspects include the important observation that forearc heatflow indicates that the underlying lithosphere is among the coldest on the planet, limitations of the shear heating effect past the brittle-ductile transition, the rather poor ability of shear heating to warm the subducting oceanic crust below the plate interface, as well as signficant dynamic limitations on the ability of the plate interface to create significant shear heating.

Keywords: exhumed oceanic crust, finite element modeling, model comparisons

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Subduction zone processes with fluid and melt: numerical model and observations

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Subduction zone processes involve various geodynamic aspects and the related structures. The thermal structure is one of the important constituents of the system, which affects and is affected by other structures/processes; for instance, the thermal structure controls dehydration of the subducted slab (locus and degree), which affects the viscosity structure of the convecting mantle wedge. In turn, the viscosity structure modifies the flow-thermal structure, which then affects the slab dehydration again to constitute a nonlinear feedback loop as a single geodynamic system. Therefore, these processes and structures have to be considered simultaneously to understand the actual processes in subduction zones.

In this presentation, such consistent models are introduced, including slab dehydration, water-rock interaction including melting, fluid migration-distribution, and viscosity-thermal-flow structure (Horiuchi and Iwamori, 2016, JGR; Nakao et al., 2016, EPSL; 2018, GRL). Then how these models are compared with the observations, such as occurrence of volcanic belt, surface heat flow, seismic velocity and attenuation structures, will be discussed, taking account of the recent knowledge on physical properties of fluid-melt-rock systems.

Keywords: subduction, fluid, melt, temperature, magmatism, seismic structure

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Low and high stress subduction zones recognized from metamorphic P-T paths

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It is generally accepted that the main strength of subduction boundaries occurs in the shallower region where frictional deformation is dominant. However, estimates of absolute values—commonly expressed as apparent coefficient of friction, μ'—show great variation. Frictional shear heating is closely related to μ', and estimates of the extra thermal energy supplied by shearing can in principle be used to estimate subduction zone strength. One such approach is based on surface heat flow measurements. However, heat flow in convergent margins shows large local scatter and even in the same area, different studies using this method show large variations in estimates of μ' indicating large uncertainties. The thermal record of subduction conditions preserved in subduction-type metamorphic rocks is developed over geological time scales that average out local complexities in heat flow and therefore has good potential as an alternative indicator of the amount of shear heating and, hence, shear strength along subduction boundaries. Thermal models that incorporate shear heating were developed for two contrasting and well-known subduction-type metamorphic belts: the relatively warm Sanbagawa belt of SW Japan and the relatively cold Franciscan belt of western USA. High-grade rocks of the Sanbagawa belt show strongly curved P–T paths that display increasing P/T to about 2 GPa. Information on the rate of plate movement and the age of the subducting slab at the time of metamorphism can be combined with modellingresults to show that relatively high shear stresses, equivalent to μ' ~ 013 are required to account for the observed curved P–T paths. In contrast, the high-grade rocks of the Franciscan belt show relatively cool P–T conditions that do not allow for strong shear heating with an appropriate upper bound for μ' of ~ 0.03. Modelling suggests subduction rate and lithology are potentially important controls on the development of high-versus low-stress subduction zones. High-stress subduction zones are likely to be associated with high aseismic/seismic slip ratios possibly related to slab roughness.

Keywords: Subduction, Sanbagawa metamorphism, Franciscan metamorphism, Stress, Thermal modelling, P–T paths

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Constraining the temperature conditions of paleo-subduction plate interfaces: Combining petrology and geodynamics

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Pressure-temperature (*P-T*) estimates from exhumed metamorphic rocks are often used to constrain the thermal conditions of paleo-subduction zone plate interfaces. However, the exhumed rock record on average indicates temperatures 200-300˚C warmer than those predicted by geodynamic models for modern subduction zones. To elucidate the difference in the paleo and modern subduction zone thermal structures, we investigate the role of regional tectonics at five selected paleo-subduction localities, including the Franciscan Complex in California, the Raspas Complex in Ecuador, the Rio San Juan Complex in the Dominican Republic, the Sanbagawa Belt in Japan, and the Pam Peninsula in New Caledonia. These terranes were chosen to represent a range of thermal conditions from hot to cold. We develop 2-D coupled kinematic-dynamic models for these localities, using the paleo-subduction parameters, such as convergence velocity and plate age, that are constrained by global plate reconstruction models and regional geological and petrological studies. For comparison with petrology, we supplement existing *P-T* estimates with quartz-in-garnet elastic thermobarometry combined with equilibrium thermodynamics to evaluate the *P-T* history of exhumed rocks from these localities. We compare the model-predicted subduction thermal structures with the *P-T* conditions that are estimated from exhumed rocks in the selected localities and assess the key factors that contributed to the petrologically constrained *P-T* conditions.

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Thermal structure near the continental Moho of subduction zone: Natural example of the Asemigawa region of the Sanbagawa metamorphic belt, SW Japan

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Metamorphic rocks in subduction-type metamorphic belts record the metamorphic history from subduction to exhumation in subduction zones. Temperature, which is one of the most important variables in controlling the dynamics of subduction zones, has traditionally been estimated from mineral assemblage and chemical compositions. However, the temperature information recorded in metamorphic rocks is usually overprinted by retrograde metamorphism during exhumation. Such issues with the preservation potential for this information may be important in understanding the commonly observed difference in the thermal structure predicted from model calculations and the metamorphic temperature obtained from natural rocks (e.g., Uehara & Aoya, 2005_Tectonics; Penniston-Dorland et al., 2015_EPSL). In this study, we focus on the Sanbagawa metamorphic belt, a well-known example of a subduction-type metamorphic belt, and discuss the meaning of the petrologically obtained temperatures.

The peak metamorphic temperatures of 126 samples of pelitic schists collected along three routes in an area with dimensions 11 km north-south and 7 km east-west in the Asemigawa region in central Shikoku were estimated by using the Raman carbonaceous material geothermometer. The obtained temperatures show an overall continuous increase from 288 to 553℃ from south to north in the study area. The temperature range is consistent with the thermal structure of the metamorphic zonation reported in previous studies. A temperature discontinuity is observed at all three studied routes, with a jump between about 380℃ to 440℃. Close to the boundary of this temperature discontinuity, several large recumbent folds are present that deform both the compositional layering and the metamorphic isograds.

The temperature of 400℃ coincides closely the area where the downgoing slab comes into contact with the continental Mohorovičić (Moho) discontinuity in warm subduction zones as shown by thermal modelling. This result suggests that the temperature discontinuity identified in the Asemigawa region corresponds to the Moho depth, and that the lower and higher temperature sides of the discontinuity were overlain by continental crust and wedge mantle, respectively. The difference in the coupling strength with the slab and contact materials (serpentinite or continental crust material) may create a contrast in the ease of exhumation, and as a result, the exhumation-related deformation may become concentrated in the lower part which then accumulates close to the depth of the continental Moho. This tectonic scenario can account for the development of the observed temperature discontinuity and large-scale foldings.

In this study, we clarified the relationship between the thermal structure and deformation structure in the Sanbagawa metamorphic belt during the exhumation period. The derived thermal structure will help refine thermal models for the Sanbagawa subduction. In addition, the depth corresponding to the continental Moho boundary coincides with the region where the slow earthquakes are occurring in

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present day SW Japan, and the temperature discontinuity proposed in this study has potential as a guide to trace the location of past slow earthquakes in the field.

Keywords: Thermal structure, Sanbagawa (Sambagawa) metamorphic belt, Raman carbonaceous material geothermometer, Mohorovičić discontinuity, Slow earthquake

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[E] Oral | S (Solid Earth Sciences)：S-VC Volcanology

[S-VC41] Timescales of magmatism: from genesis to eruption

convener:Chamberlain Katy Jane(University of Derby), Iona McIntosh(Japan Agency for Marine-Earth Science and Technology), Kenichiro Tani(Department of Geology and Paleontology, National Museum of Nature and Science), Akihiko Tomiya(Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology)

Magmatic processes are known to operate across a range of timescales: from thousands to millions of years' residence and evolution within a magmatic plumbing system, through to the hours to minutes prior to eruption. Understanding the timescales of these magmatic processes, including accumulation, ascent, eruption, and final cessation of activity is vital for interpreting and responding to future magmatic activity. Together with thorough dating of deposits that reveal timing and frequency of past eruptions, this knowledge provides the foundation for improved hazard management in volcanic regions. By using a range of petrological, geophysical, geochemical and geochronological tools, increasingly detailed timescale constraints can be placed on past eruptive episodes.

In this session we invite submissions that examine magmatism and volcanism across a variety of timescales; from residence and rejuvenation within the crustal column, to eruptive triggering mechanisms and syn-eruptive processes, and their relation to the long-term timing and frequency of repeated activity.

[SVC41-01] Degassing processes of silicic magma estimated from multivolatile analysis of obsidian pyroclast

★Invited Papers

*Shumpei Yoshimura[1] (1.Department of Earth and Planetary Sciences, Hokkaido University)

[SVC41-02] Decoding the pre-eruptive process by crystal clots: A case study of Unzen 1991-95 eruption

*Kurumi Iwahashi[1], ATSUSHI YASUDA[1], Hidemi Ishibashi[2] (1.Earthquake Research Institute,The University of Tokyo, 2.Shizuoka University)

[SVC41-03] *Crystal archives of the Havre 2012 submarine rhyolite eruption: Understanding the origin of crystal-poor rhyolites*

*Joseph Knafelc[1], Scott E. Bryan[1], Henrietta Cathey[1], David Gust[2] (1.School of Earth, Environmental and Biological Sciences, Queensland University of Technology, Brisbane, Australia, 2.Institute of Future Environments, Central Analytical Research Facility, Queensland University of Technology, Brisbane, Australia)

[SVC41-04] **Extent of late Holocene volcanic activity in Southern Patagonia**

*Maximillian Van Wyk de Vries[1], Emi Ito[1], Mark Shapley[1], Guido Brignone[2], Shanti Penprase[1], Alexander Schmies[1] (1.University of Minnesota, Twin Cities, 2.University of Cordoba)

[SVC41-05] **Time constraints on magma ascent from volatile element diffusion in apatite**

★Invited Papers

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[SVC41-06] Plagioclase and biotite in holocrystalline composite dike record pre-solidification chemical diffusion in melt

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Degassing processes of silicic magma estimated from multivolatile analysis of obsidian pyroclast

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The degassing of silicic magma during ascent is important in the control of final eruption style. However, what actually occurs in ascending magma has not been well constrained because of lack of clear evidence. One possible way to investigate this is to analyse obsidian pyroclasts, which are ejected together with pumice and ash during an explosive eruption, and have been considered as essential magma fragments that were quenched at various depths of the conduit (e.g., Newman et al., 1988). In this study, I analysed volatile contents of rhyolitic obsidian pyroclasts from AD 886 eruption of Mukaiyama volcano and discuss the degassing process.

The obsidian pyroclast from Mukaiyama volcano was dense glassy fragment containing a small number of bubbles (<0.1 vol%). The major composition of obsidian pyroclast was identical to that of pumice. FTIR analysis revealed that the H2O content of glass was 1.1–2.4 wt% and CO2 content was <2 ppm. Assuming gas-melt equilibrium, I estimated the gas-saturation pressure to be 9–36 MPa by using solubility law of Liu et al. (2005). The initial H2O content of the Mukaiyama magma was estimated to be ~4 wt% based on phenocryst assemblage. Therefore, the obsidian pyroclasts are considered to have experienced open-system gas loss, because they are almost bubble-free but have only a part of initial water.
The Cl-content mapping analysis revealed that all samples have high-Cl stripes running in one direction. The width of each stripe was ~10 microns. Bubbles were often aligned in the same direction, and they were connected through the high-Cl stripe. The Cl content was elevated near the bubble interface. These observations indicate that bubbles are resorbing (Yoshimura et al., in prep.), and that the high-Cl stripes are the welded interface of the resorbing bubbles. Number density of the stripes, which may be proxy for bubble number density before resorption, was higher for lower-H2O clasts (150 stripes/mm for 1.1 wt%) and lower for higher-H2O samples (25 stripes/mm for 2.4 wt%). This indicates that vesicularity of the obsidian pyroclast had been pressure-dependent before bubbles resorbed. Timescale of bubble resorption was estimated to be a few minutes based on Cl diffusion profiles across the high-Cl stripes. Such rapid bubble resorption may have been caused by repressurisation. Another possibility that bubbles resorbed because of water depletion, which was caused by continuing open-system gas loss (Yoshimura et al., in prep.), is unlikely, because this process occurs only locally near open channels. The reason why repressurisation occurred in ascending magma is currently under investigation.

Keywords: magma, degassing, volatile

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Decoding the pre-eruptive process by crystal clots: A case study of Unzen 1991-95 eruption

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1. Introduction

Magma mixing is one of the major triggers of volcanic eruption. So, mixing process of end member magmas can control magnitude and style of eruptive activities. There are some factors that control magma mixing processes. Among them, viscosities of mixing end member magmas are the most important one. It is well known that the viscosity of magma depends on crystal abundance, melt composition, and temperature of magma. Although we can determine the compositions of crystals and melt of erupted magma, it is not easy to know these properties before magma mixing because magma mixing causes temperature increase and results in changing to the composition and crystallinity of magma different from those of initial pre mixing magma.

In this study, we use crystal clots to reveal the conditions of magmas before magma mixing. Crystal clots are assemblage of crystals. Because mushy magma reservoir contains >50 vol. % crystals, crystals can be closely assembled in the reservoir. From this consideration, crystal clots can be part of the mushy magma reservoir. In addition, between crystals, there are interstitial melts. So, these crystal clots are likely to possess information about condition of magma before magma mixing.

We use samples of Unzen 1991-95 eruption to deal with these questions. Unzen 1991-95 eruption is characterized by the growth and collapse of lava domes, leading to repeated pyroclastic flows. Pre-eruptive magma mixing is thought to have occurred in the magma reservoir (e.g., Nakamura, 1995).

2. Samples and analytical methods

During the 1991–1995 eruption, two peaks were observed in the eruption rate. So, we used 13 samples erupted at different period of the 1991–1995 eruption in this study to cover the two peaks. We call an assemblage of multiple minerals as crystal clots in this study. Crystal clots in products of Unzen 1991-95 eruption are mainly composed of plagioclases, amphiboles, pyroxenes and Fe-Ti oxides. Between crystals, interstitial melts exist.

We analyzed the interstitial melts, amphiboles and plagioclases in crystal clots. We also analyzed the rims of plagioclases to apply a plagioclase-liquid hygrometer. Compositional analysis was performed by EPMA (JEOL JXA-8800R) at Earthquake Research Institute, University of Tokyo. For quantifying the modal abundances in crystal clots, we used X-ray mapping using above-mentioned EPMA.

3. Results

Two temperature conditions are identified based on amphibole composition; LT (low temperature, 770-830℃) and MT (middle temperature, 870-950℃). Amphiboles in crystal clots are classified into A-type, B-type, C-type and D-type. A-type is characterized by zonal texture, B-type has breakdown rim and C-type has both zonal texture and breakdown rim. D-type is almost homogenous. Modal abundance of each type of amphiboles in crystal clots had changed during the 1991-1995 eruption. Changes in the amount of B-type and C-type amphiboles are obviously related to the effusion rate. Growth conditions estimated by methods of Putirka (2016) show that almost all amphiboles are grown in condition of LT magma reservoir and only 3% of amphiboles show condition of MT magma. On the other hands, SiO_2 contents of interstitial melts show similar with that of LT end member melt. Water content of LT magma is estimated to be ~7-10 wt.% by means of plagioclase-liquid hygrometer (Waters and Lange, 2015).

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Accordingly, assembled depth of crystal clots are calculated as 6-9 km, provided that the magma was saturated in water.

4. Discussion
Assembled depth of crystal clots are similar to the depth of main magma reservoir of Unzen 1991-95 eruption estimated by geophysical observations. Occurrences of crystal clots imply that they were part of LT magma reservoir, and was caught by injected magma. So, we estimate crystal ratio of LT and MT magma from that of crystal clots and their mixing ratio. Moreover, we calculated viscosity of each endmember magma by using estimated crystal content to consider magma mixing process. We also constrained this process by considering the timescale of formation of reaction rims surrounding amphiboles. Finally, we propose model of pre-eruptive process of Unzen 1991-95 eruption based on these results and consideration.

Keywords: crystal clots, pre-eruptive process, mushy magma reservoir

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Crystal archives of the Havre 2012 submarine rhyolite eruption: Understanding the origin of crystal-poor rhyolites

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The Havre 2012 submarine eruption is the largest submarine eruption of rhyolite recorded in historical times. Eruptive products included a ~1.4 km^3 pumice raft and an additional ~0.1 km^3 of magma was emplaced as 12 distinct fissure-fed lava flows/domes across the summit with an associated field of giant seafloor pumice. In addition to the challenges in resolving the dominant eruptive mechanism that produced the pumice raft from such a deepwater setting, the Havre eruption also poses challenges in understanding how large volumes of rhyolite magma are generated in island arc settings. This is because the past eruptive history and previous eruption products that can be used to provide insights into the operation of the Havre magmatic plumbing system are poorly known due to its remote and deep-water (900 mbsl) location. General models for rhyolite magmatism have distinguished two end-member types: 1) crystal-rich rhyolites and dacites as the product of mush remobilisation, and 2) crystal-poor rhyolites that can reflect very efficient melt segregation from crystal mush. The 2012 Havre eruption evacuated a crystal-poor rhyolite (3-5%) to produce the volumetrically dominant pumice raft, while subtly higher phenocryst contents are observed in the seafloor Giant Pumice (5-8%) and lavas (8-12%). For crystal-poor rhyolites like the Havre pumice, it can often remain ambiguous as to whether the few phenocrysts present (in the case of Havre: plagioclase, orthopyroxene, clinopyroxene, titanomagnetite, ±accessory phases of ilmenite, pyrrhotite and quartz) truly represent autocrysts crystallising from the surrounding melt or are antecrysts due to mush remobilization, or possibly a combination of both. The few crystals present are then strongly relied upon to constrain magma timescales and pre-eruptive conditions such as magmatic temperatures, pressures, water content and fO_2 assuming all crystals are autocrystic. Here, we present the first detailed petrographic and chemical study of the crystal cargo of the Havre pumice raft (~93% of the eruptive material) and in comparison, the giant seafloor pumice. This coupled with thermobarometry calculations and MELTS models will constrain the origins of phenocrysts in this crystal-poor rhyolite. Consequently, identifying the proportions of autocrysts versus antecrysts in the Havre pumice is a first step in understanding petrogenetic processes in the Havre volcano. Each crystal population can provide valuable insight into the Havre magmatic system including: 1) the pre-eruptive conditions; 2) the conditions of a parental melt; and 3) mush zone(s). The combined information from each crystal population allows for a more complete understanding of the magmatic processes (i.e., crystal fractionation, magma recharge, mush remobilization) and the timescales needed to generate significant volumes of crystal-poor rhyolitic eruptions in island arc settings.

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Extent of late Holocene volcanic activity in Southern Patagonia

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Glaciated volcanoes may respond in several ways to changes in ice volume. For instance, the rate of magma influx, number of volcanic debris avalanches and quantity of eruptions may all be affected by thinning ice. However, the magnitude of these effect is highly variable, depending on the properties of both the volcano and local ice mass. Due to their remoteness and difficulty of access, ice covered volcanoes are also some of the least well studied. This is particularly relevant in areas such as southern Patagonia, where active volcanoes are adjacent to the southern hemisphere’ s largest non-polar ice cap. In this project we aim to determine the background frequency and magnitude of eruptions of the volcanically active portion of Southern Patagonia.

Previous work has identified a small number of Holocene eruptions, however the lack of an extensive and high preservation dataset limits our understanding of the volcanic sources. We collect a total of nearly 50 lacustrine sediment cores from a large proglacial lake, Lago Argentino, that is within 100 km of the three active volcanoes of the Southern Patagonian Icefield: Lautaro, Aguilera and Reclus. The location of this lake and the cores collected is shown in the associated figure. We use this over 100m of well laminated lake bottom sediment to identify tephras from local volcanic eruptions. Early analyses suggest that an order of magnitude more late Holocene tephra horizons can be identified than found in previous studies, including key regional marker horizons as well as more than 10 fine cm to mm scale tephra bands.

Our results suggest that the understudied volcanoes within the Southern Patagonian icefield, in particular Aguilera and Lautaro stratovolcanoes, may have a higher eruptive frequency than previously considered. This suggests that the magma plumbing system of these volcanoes is also more active, which increases the likelihood of ice thinning and depressurization triggered eruptions. In addition, our results have geohazard implications for a region with a rapidly growing tourist population. With much of the Southern Patagonian icefield thinning at rates of several metres a year, more detailed work is required to understand likely future volcanic influence on this region in the coming decades to centuries.

Keywords: Volcano, Eruption, Patagonia, Lake, Core, Tephra

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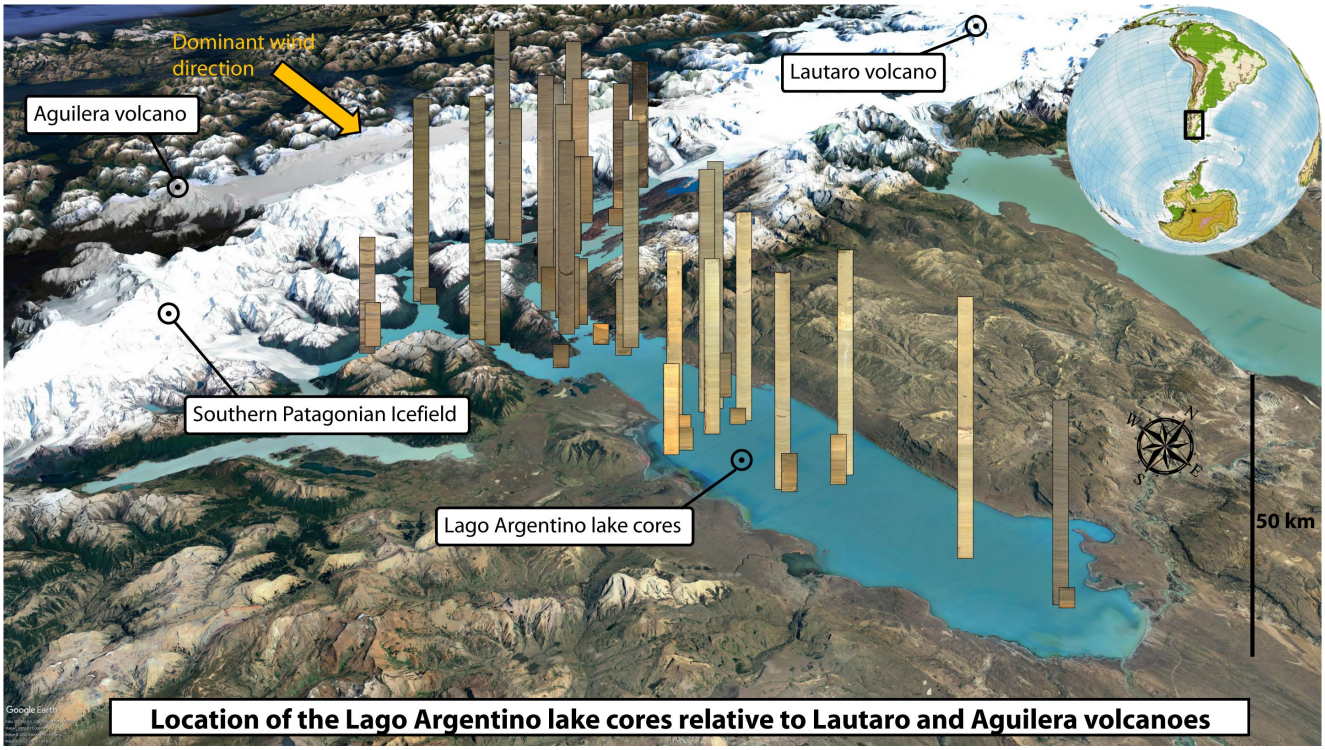

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Time constraints on magma ascent from volatile element diffusion in apatite

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Diffusion theories and models in crystals have been widely used for constraining the timescale of magmatic processes. A remaining challenge is to determine the timescale of relatively short magmatic processes that occur within hours to weeks, such as the ascent of magma towards the Earth’s surface, which can play a key role in controlling eruptive style. Our recent study has shown that chemical zoning of volatile elements, such as chlorine (Cl), in volcanic apatite is a promising new indicator of the times and rates of magma ascent. However, application of this new tool requires knowledge of the diffusion mechanism and rates of volatile elements/molecules in apatite. We have performed experiments at magmatic temperature (800–1100 ºC), 1-atm to determine the diffusivities of F-Cl-OH in apatite. We used gem-quality natural crystals with distinct compositions of F-Cl-OH, and made two types of diffusion couples by either embedding a single crystal into fine powders, or depositing nanoscale thin film over single crystal. Compositional profiles were obtained from the experimental products using multiple techniques, including secondary ion mass spectrometer (SIMS), electron microprobe (EPMA), and nuclear reaction analyses (NRA). A striking feature of the chemical profiles is the presence of uphill diffusion of Cl, which reflects a multi-component diffusion process of F, Cl and OH, whose anions are present at the same crystallographic site of apatite. Compositional profiles measured from the run products using SIMS and EPMA were fitted with those computed using a three-component diffusion model (based on a finite-difference algorithm) to extract the diffusivities of F, Cl and OH. We find that parallel to the c-axis, F diffuses faster than Cl which in turn diffuses faster than OH, and the difference in diffusivities between F and OH is more than one order of magnitude. The diffusion of Cl and OH is anisotropic, i.e. one to two orders of magnitude faster parallel to the c-axis than perpendicular to it. We have applied the new diffusion data and to natural apatite from two eruptions with distinct explosivities at Merapi volcano (Indonesia). We find that the Cl zoning in apatite from the dome-forming eruption in 2006 requires magma ascent to occur at least 12 to 14 days before eruption, whereas the absence of Cl zoning in apatite from the more explosive eruption in 2010 reflects a maximum time of magma ascent of about 5 days. The calculated timescales match with the duration of volcanic unrest before the two eruptions, and reflect more rapid magma ascent in 2010 than 2006. Our diffusion data and model based on apatite provide new constraints on the times and rates of magma ascent, which would contribute to a better understanding of the cause of different eruption activities, and to potentially more accurate eruption forecasting.

Keywords: Apatite, Multicomponent diffusion, Magma ascent, Timescale, Eruptive style

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Plagioclase and biotite in holocrystalline composite dike record pre-solidification chemical diffusion in melt

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Magma mixing plays important roles in forming magmas of various compositions as well as in triggering volcanic eruptions (Perugini & Poli, 2012). Magmatic enclave (ME) originally crystallized from a part of discrete magma which intruded into a host magma with a different composition (Perugini & Poli, 2012). Since they crystallized before mixing completely, ME/host boundary can retain information about the magma mixing. For example, compositional profiles with a distance from ME/host boundary in volcanic glasses are reported (e.g. Perugini et al., 2003; Schreiber et al., 1999). Such profiles are determined in μm to mm scale and enable us to estimate timescales of chemical diffusion in some cases (e.g. Petrelli et al., 2006). On the other hand, compositional gradients across the ME/host boundary in plutonic rocks are usually determined by bulk-rock analyses, resulting in relatively rough (cm to dm) scales (e.g. Zhu et al., 2018; Wiebe, 1973; Eberz & Nicholls, 1990).

Yamazaki et al. (2019) investigated a holocrystalline composite dike (Ryoke belt, Japan) focusing on the systematic chemical change of minerals at ME/host boundary. In this composite dike, felsic host has simple mineral assemblage (Plagioclase (Pl) + Quartz (Qtz) + Biotite (Bt) ±rare garnet (Grt)). The Pl shows compositional zoning with core (An35-60), mantle (An25-35) and rim (An35-45) within a single grain. In addition, mm-scale compositional profiles are observed as changes of mineral compositions in a felsic host with distance from the ME/host boundary. With distance from the boundary, concentrations of MgO in Bt and CaO in Pl-rim are well fitted (R^2>0.80) by the solution of diffusion equation and their diffusion distances are the same order of magnitude. Therefore, these profiles are considered to have resulted from chemical diffusion in melt during magma mixing. The timescale of the diffusion is estimated to be less than 10^4 years. However, the geological meaning of this timescale has not been understood. In this study, the chemical profiles recorded in Bt enclosed in Pl are newly determined and its significance is discussed.

In the felsic host, some of the coarse-grained Pl include Bt in the mantle, and such Bt (simply referred to as “inclusion-Bt” below) shows compositional variation with distance from the ME/host boundary. The profile that MgO in inclusion-Bt showed was fitted by the solution of diffusion equation (Crank, 1956) and gave a good fitting result (R^2>0.70). The CaO content of Pl-mantle in the felsic host also shows a diffusion profile well fitted by the solution of diffusion equation (R^2~0.80). These diffusion distances are in the same order of magnitude. This observation suggests that the chemical diffusion in melt formed these profiles, because diffusion coefficients of Ca and Mg are almost same in melts (Mungall et al., 1999), while Fe-Mg interdiffusion in Bt is much faster than NaSi-CaAl interdiffusion in Pl (Liu & Yund, 1992; Usuki, 2002).

The diffusion distance of MgO in matrix-Bt is similar to that of the inclusion-Bt. Similarly, the diffusion distance that the profile of CaO in Pl-rim showed and that the Pl-mantle showed were the same. Assuming that the formation of the above diffusion profiles had started on the intrusion of ME into the felsic host and continued until the complete crystallization of the felsic host, the diffusion distance recorded by inclusion-Bt and matrix-Bt should be different; the former should be shorter than the latter. However, our observation showed that they are the same. This suggests that the formation of the diffusion profiles in the melt almost stopped soon after the crystallization of Pl-mantle.

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Keywords: magma mixing, chemical diffusion, magmatic enclave

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[E] Oral | S (Solid Earth Sciences)：S-VC Volcanology

[S-VC42] Dynamics of volcanic eruptions and their physical and chemical processes

convener:Atsuko Namiki(Graduate School of Integrated Arts and Sciences, Hiroshima University), Christian Huber(Brown University), Michael Manga(University of California Berkeley), Yujiro Suzuki(Earthquake Research Institute, The University of Tokyo)

A Volcanic eruption is a hazardous phenomenon that results from a sequence of coupled processes, including storage in the subsurface and ascent to the surface. The volcanic gas exsolving from the ascending magma generates bubbles, which influence both the potential energy of the magma (density) and its resistance to flow (viscosity). Bubbles can sometimes deform and/or fragment the surrounding magma, leading up to explosive eruptions that develop volcanic plumes and/or pyroclastic flows. A broad range of approaches is required to tackle these processes and better understand the factors that govern the physics of explosive eruptions. We welcome contributions from interdisciplinary approaches, including, geophysical observations of active/quiet volcanoes, geochemical measurements of eruptive products, theoretical approaches, and numerical simulations, and laboratory experiments designed to explore the fundamental processes underlying explosive volcanism.

[SVC42-01] Magma flow style based on deformed bubble structure of pumice

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[SVC42-03] **The dynamics of buoyancy driven fragmentation in a deep subaqueous volcanic eruption, observations of the 2009 eruption of West Mata**

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[SVC42-04] Eruption mechanics of the 2012 eruption of Mount Tongariro, NZ: Revealed by temporal Magnetotellurics

*Graham Hill[1,2], Hugh Bibby[3], Jared Peacock[4], Erin Wallin[5], Yasuo Ogawa[6], Luca Caricchi[7], Harry Keys[8], Stewart Bennie[3], Yann Avram[9] (1.Institute of Geophysics, Czech Academy of Science, Prague, Czech Republic, 2.Gateway Antarctica, University of Canterbury, Christchurch, New Zealand, 3.GNS Science, Lower Hutt, New Zealand, 4.United States Geological Survey, Menlo Park CA, USA, 5.United States Army Corps of Engineers, Huntsville AL, USA, 6.Volcanic Fluid Research Centre, Tokyo Institute of Technology, Tokyo, Japan, 7.Department of Earth Sciences, University of Geneva, Geneva, Switzerland, 8.Department of Conservation, Turangi, New Zealand, 9.Phoenix Geophysics, Toronto, Canada)

[SVC42-05] Fluid ascent dynamics of the Onikobe geyser, NE Japan: Insight from the thermal infrared imagery

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Magma flow style based on deformed bubble structure of pumice

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Bubble textures in pumice have been thought to reflect the history of magma ascent. Thus, it is valuable to create a new analysis method based on the morphological variables, such as bubble size, bubble number density, and bubble shape. The purpose of this study is to develop a new scheme to connect bubble shapes with the dynamics of explosive eruptions. Pumice containing highly deformed bubbles like tubes is called as tube pumice, and it is thought to record the flow history of magma up to fragmentation surface. In order to extract shear deformation and magma flow style from such a deformed bubble structure, it is necessary to solve the following three problems: (1) Calculate transient bubble deformation, (2) Evaluate the effect of bubble interaction on its shape, and (3) Calculate bubble deformation in an arbitrary velocity field.

First, using the droplet deformation model of Jackson and Tucker (2003), we developed a model that can calculate the transient deformation of a single bubble in an arbitrary velocity field. Next, to evaluate the interaction between bubbles, we performed tensile experiments with a solidifying foam. By comparing the experimental results of bubble shape with the numerical simulations, we confirmed that the average shape of bubbles coincided with the theoretical deformation model of a single bubble. This result suggests that the average of bubbles in pumice can be compared with the numerical simulation of a bubble in a conduit flow.

Next, the bubble deformation model and the quasi-two-dimensional steady conduit flow model were combined to solve the bubble deformation in the conduit. The bubble shape at the fragmentation surface significantly depends on the velocity profile across the conduit. Flow with a constant viscosity had a parabolic velocity profile and produced highly elongated bubbles, which were deformed mainly by simple shear. On the other hand, viscous-heating with the temperature-dependent viscosity led to a plug-like velocity profile and produced less elongated bubbles, which were deformed primarily by pure shear.

Finally, we conducted a bubble structure analysis of pumice erupted at Taupo Volcano. It was found that the plinian eruption had a single peak in the bubble shape distribution, while the ignimbrite eruption had a broad distribution and contained highly elongated bubbles. The comparison of the natural bubble textures with the results of the combined simulation of conduit flow and bubble deformation suggested that the velocity profile of the plinian eruption was close to a plug-like shape. We propose the reason why the ignimbrite eruption produced a large amount of tube pumice that the widening of the conduit reduced the viscous heating effect, delayed the transition from parabolic flow to plug-like flow, and increased bubble deformation during the parabolic flow regime.

Acknowledgement: This paper integrates results of the studies collaborating with S. Takeda, K. Hirota, S. Sato, O. Kuwano, M. Kameda, A. Toramaru, D. Gravley, B. Kennedy, and F. Maeno.

Keywords: bubble deformation, tube pumice, bubble texture

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The dynamics of buoyancy driven fragmentation in a deep subaqueous volcanic eruption, observations of the 2009 eruption of West Mata

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All subaqueous eruptions interact with ambient water. Interaction occurs both through rapid heat transfer on direct contact between magma and water, and as a result of water's differing physical properties compared with air. The potential implications of these interactions are understood i.e. reduced degree of volatile exsolution due hydrostatic pressure, explosive boiling of water, rapid quenching of magma, etc. However due to the difficulty of studying such eruptions *in situ* the exact nature of the interaction processes, from effusive to pyroclastic, during deep subaqueous eruptions (>500 m below sea level (mbsl)) remain enigmatic.

In May 2009 a submarine eruption at West Mata volcano, located in the Northeast Lau Basin, was directly observed and sampled using remotely operated vehicle Jason2. The eruption occurred from vents Hades (1200 mbsl) and Prometheus (1175 mbsl). Pyroclastic activity occurred at both vents, but this study will focus on activity at Hades, which exhibited the discontinuous release of 0.6-2 m diameter volatile-filled magma-skinned bubbles that fragmented and quenched in the water column. In addition, pillow lava flows up to 350-500 m long were erupted from Hades vent. The 2009 West Mata eruption is one of only two deep submarine eruptions for which both syn-eruptive visual observations and seafloor samples have been collected. The wealth of syn-eruptive data for the 2009 West Mata eruption provides the ideal opportunity to develop an eruption model of small scale mafic pyroclastic deep submarine volcanism.

Here we present inferences on an eruptive style termed bubble blowing, defined by the irregular eruption of distinct volatile bubbles that ductily inflate the overlying magma and quench within 1 s. We combine detailed observations from frame by frame examination of eruption video with heat loss and volatile expansion modelling to give an integrated view on a range of eruption processes such as magma fragmentation and magma-water interaction processes at various stages during the eruption.

Bubble blowing eruptions can be broadly split into four stages based on changes in volatile and magma behavior. Those stages are 1. Buoyant ascent of a volatile bubble through the magma column causing inflation and deformation of the magma's surface into a magma-skinned volatile-filled bubble, 2. Ductile fragmentation and retraction of the magma-skin bringing the volatile bubble into direct contact with ambient water, 3. Rapid contraction of the volatiles due to cooling/condensation leading to implosion of the bubble, and 4. Formation of a turbulent plume of heated water and entrained particles.

The influence of the ambient water column plays a key role at all stages during bubble blowing eruptions. Volatile expansion, a key process in driving subaerial explosive volcanism, is highly restricted at pressures higher than that equivalent to water depths of ~ 100 m. At the depth of West Mata vents volatile expansion is negligible. Volcanism and fragmentation are therefore driven not by rapid volatile expansion, but by the buoyancy of the volatile bubble. The driving eruption force however switches to implosion following rapid cooling of the volatiles on contact with the ambient water. Therefore, we suggest bubble

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blowing is a buoyancy implosive eruption style.

Extensive evidence of ductile fragmentation in the products of bubble blowing eruptions and heat loss modeling also show that magma can behave in a ductile fashion on eruption timescales despite direct contact with the ambient water.

Observations of bubble blowing activity question several fundamental concepts in subaqueous volcanology including what we mean by “explosive” fragmentation, whether there is a single transition between deep and shallow eruptions, and the effect of quenching of eruption processes. However, detailed observations can also more widely inform discussion of magma fragmentation and magma-water interaction processes in all environments.

Keywords: Subaqueous, Fragmentation, Magma-water interaction, West Mata, Lau Basin, Pyroclastic

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Eruption mechanics of the 2012 eruption of Mount Tongariro, NZ: Revealed by temporal Magnetotellurics

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Monitoring dynamics of volcanic eruptions with geophysics is challenging. In August and November, 2012, two small eruptions from Mount Tongariro provided a unique opportunity to image subsurface changes caused by the eruptions. A detailed magnetotelluric survey of the Tongariro volcanic complex completed prior to the eruption (2008-2010) provides the pre-eruption structure of the magmatic system. A subset of the initial measurement locations was reoccupied in June 2013. Significant changes were observed in phase tensor response at sites close to the eruptive centre. Although, subsurface electrical resistivity changed, the geometry of the pre-eruptive magmatic system did not. These subsurface resistivity variations are interpreted as being predominantly caused by interaction of partial melt and the overlying brine layer causing volume reduction of the brine layer through phreatic eruption. The ability to detect significant changes within the magma system associated with eruptive activity suggests that magnetotellurics can be a valuable volcano monitoring tool.

Keywords: magnetotelluric, eruption dynamics, Taupo Volcanic Zone, Tongariro

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Fluid ascent dynamics of the Onikobe geyser, NE Japan: Insight from the thermal infrared imagery

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Geysers provide a natural laboratory of multiphase eruptive processes like volcanoes due to their advantages for observation, frequent eruptions, and simple material properties. Thus, by understanding the dynamics of geyser eruptions, we may provide potential insights not only into geysers themselves but also into volcanic eruptions. For understanding the eruption dynamics of volcanoes and geysers, thermal observations have been used. Harris et al. [2012], analyzing high frame rate (33 Hz) thermal video data, estimated the velocities of ejecta and described the plume ascent dynamics at Stromboli volcano, Italy. Karlstrom et al. [2013], using the visual and infrared video data, estimated the velocities of water effusions and defined four phases during an eruption cycle at Lone Star Geyser, Yellowstone National Park, USA. However, the details of fluid ascent process are still not fully understood in both volcanoes and geysers. In this study, using the thermal infrared imagery and acoustic signals, we examine the fluid ascent dynamics of geysers.

We conducted a field observation at Onikobe geyser, NE Japan, on 24 October, 2019. We observed the erupted fluid thermally using an infrared camera (InfReC G100, Nippon Avionics Co. Ltd.) and measured the acoustic emission using an acoustic sensor (SI102, Hakusan Corp.) deployed about 2 m distant from the vent. The thermal infrared data was collected at a sampling rate of 10 frame/s. The acoustic data was collected using a data logger (HKS-9700, Keisokugiken Corp.) with a sampling frequency of 100 Hz.

We analyze the obtained thermal infrared data using a software (InfReC Analyzer NS9500 Standard, Nippon Avionics Co. Ltd.). For investigating the evolution of fluid ascent from the vent, we make two kinds of time series of the thermal infrared data: (1) the raw temperature of the thermal plume along the vertical axis set at above the vent, and (2) the total temperature at each height integrated in the horizontal direction. In addition, to discriminate the behaviors of water and vapor with hotter and lower temperatures, we set a threshold of temperature at 30 degree and make the two kinds of time series for the hotter and lower temperature.

The time series (1) and (2) show many individual bursts from the vent for each effusion with a duration of about 40 s. Oscillatory signals with period of about 1 s are recognized especially in the latter period of effusion (about 15-40 s from the onset of effusion). The spectrogram of the infrared data is well matched with that of the acoustic signals. In the time-height evolution of hotter and lower temperature data, we can trace the trajectories of water and vapors. We find two characteristic ascent velocities: (1) relatively high velocity (about 10-20 m/s) and (2) low velocity (about 1-2 m/s). The higher velocity is explained by the theory of ballistic motion under the gravity and air resistance with viscous drag. We estimate the ejection velocity to be 5-25 m/s and a radius of each water droplet that forms water jets with about 0.1–0.3 mm. On the other hand, the water and vapors in the lower temperature image seem to vertically ascend with a slightly accelerated low velocity of 1-2 m/s. From this result and visual observations at the geyser, we infer that the other mechanisms such as buoyant thermal plume may explain this ascending water and vapors.

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Keywords: Geyser, Thermal infrared imagery, Acoustic emission, Ascent velocity

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[S-VC42] Dynamics of volcanic eruptions and their physical and chemical processes

convener:Atsuko Namiki(Graduate School of Integrated Arts and Sciences, Hiroshima University), Christian Huber(Brown University), Michael Manga(University of California Berkeley), Yujiro Suzuki(Earthquake Research Institute, The University of Tokyo)

A Volcanic eruption is a hazardous phenomenon that results from a sequence of coupled processes, including storage in the subsurface and ascent to the surface. The volcanic gas exsolving from the ascending magma generates bubbles, which influence both the potential energy of the magma (density) and its resistance to flow (viscosity). Bubbles can sometimes deform and/or fragment the surrounding magma, leading up to explosive eruptions that develop volcanic plumes and/or pyroclastic flows. A broad range of approaches is required to tackle these processes and better understand the factors that govern the physics of explosive eruptions. We welcome contributions from interdisciplinary approaches, including, geophysical observations of active/quiet volcanoes, geochemical measurements of eruptive products, theoretical approaches, and numerical simulations, and laboratory experiments designed to explore the fundamental processes underlying explosive volcanism.

[SVC42-07] An analysis of the relationship between mass eruption rate and runout distance of pyroclastic density currents

★Invited Papers

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[SVC42-08] 3D numerical simulations of volcanic jets inside a crater during explosive volcanic eruptions

*Fiodar Perakozhau[1], Takehiro Koyaguchi[1] (1.Earthquake Research Institute, the University of Tokyo)

[SVC42-09] Simulating tephra fall deposit from a bending eruption plume: development of a new code and its validation using inversion

*Kazutaka Mannen[1] (1.Hot Springs Research Institute of Kanagawa Prefecture)

[SVC42-10] Dynamics of ballistic projectiles based on Trashcano experiment

*Saruta Shusaku[1], Kae Tsunematsu[1], Isao Motoyama[1] (1.Yamagata University)

[SVC42-12] **ERUPTION DYNAMICS AND CONDUIT PROCESS OF THE 52-ka MANINJAU CALDERA FORMING ERUPTION, WEST SUMATRA, INDONESIA**

*Indranova Suhendro[1], Atsushi Toramaru[1], Agung Harijoko[2,3], Haryo Edi Wibowo[2,3] (1.Department of Earth and Planetary Sciences, Graduate School of Sciences, Kyushu University, 2.Department of Geological Engineering, Faculty of Engineering, Universitas Gadjah Mada, Jl. Grafika no. 2, Yogyakarta, 3.Center for Disaster Studies Universitas Gadjah Mada, Jl. Mahoni C-16 Bulaksumur, Yogyakarta)

An analysis of the relationship between mass eruption rate and runout distance of pyroclastic density currents

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Explosive volcanic eruptions generate buoyant plumes that rise into the atmosphere to form umbrella ash clouds. In many cases, variations in source parameters during eruptions cause the plumes to turn into collapsing fountains, which generate ground-hugging pyroclastic density currents. It is well known from previous work that the plume height increases with the mass eruption rate. A similar relationship for pyroclastic density currents, relating their runout distance to the eruption rate, has been suggested by some authors but remains to be quantified from a large dataset. In this context, we compiled the data of 39 well-documented eruptions of small (<0.01 km^3) to large (>1000 km^3) volumes, with eruption rates (Q) and flow runout distances varying by five and two orders of magnitude, respectively. The eruption rates given in literature are obtained by three different means. Most data are reported for the plume phase and are derived from the height of the column determined from isopleths of the fall deposits (Q_h). Eruption rates are also given for the current phase, either from the ratio of the volume to the duration of the flows (Q_v) or from models of the pyroclastic currents and their overriding ash clouds (Q_m). A first analysis of the cases for which different types of eruption rates were known showed that Q_m (cf. current phase) was one order of magnitude higher than Q_h (cf. plume phase). This is in agreement with previous work, and it may be interpreted in terms of conduit enlargement due to erosion and/or onset of caldera collapse with opening of multiple vents or ring-fractures. When only Q_h was known for a given eruption, we have therefore taken into account corrected (larger) values of Q_h in our database to quantify the relationship between the eruption rate and the runout distance of the currents. We found also that the values of Q_v (cf. current phase) were in general closer to those of Q_m than to those of Q_h. Then, based on authors interpretations of flow deposits and on recent quantitative advances, we considered end-member, dominant transport mechanisms of particles within the currents. We thus distinguished between fully dilute turbulent currents (at Q up to 10^{10} kg/s) and basal concentrated flows with an overriding ash cloud (at Q up to 10^{12} kg/s). The results highlight two distinct trends with coefficients of determination of 0.92-0.93: the runout of dilute and dense currents increases with $Q^{0.47}$ and $Q^{0.38}$, respectively. At given eruption rate, dilute currents have longer runouts than dense ones, but the longest runouts >100 km are those of dense flows driven by the highest eruption rates. Similar trends are found also for the runout as a function of the volume of the flow deposits, because the latter correlates positively with the eruption rate, but with lower coefficients of determination of ~0.80. Our analysis suggests that the mass eruption rate is the main control parameter on the runout of pyroclastic density currents. The trends identified for dilute and concentrated currents are robust and can be used to infer eruption rate from runout when the former is unknown. This is of particular interest when fall deposits are absent.

Keywords: explosive volcanism, eruption rate, pyroclastic density currents, runout distance

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3D numerical simulations of volcanic jets inside a crater during explosive volcanic eruptions

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During explosive volcanic eruptions an eruption column forms a buoyant plume or collapses to generate a pyroclastic flow. Since the impact and type of volcanic hazards are largely different between these two eruption styles, it is important to predict the condition where an eruption column collapses (i.e., the column collapse condition). One of the main quantities determining the column collapse condition is the initial upward momentum. The initial upward momentum depends on the mass flow rate at the crater base and the crater shape. The presence of a crater causes the formation of expansion and/or shock waves inside and/or just above the crater, which leads to a transition between supersonic and subsonic eruptions. The influence of crater shape on eruption column dynamics was recently investigated by Koyaguchi et al. (2018) on the basis of a quasi-1D steady model for the flow inside crater. Their model implicitly assumes that pressure is uniform in each horizontal slice along the flow inside the crater. However, Ogden (2011) showed that this assumption is valid only for small open angles. If $\theta > 30º$, the pressure distribution is distorted, because 2D waves are generated around convex corners (Prandtl-Meyer expansion). As a result, the quasi-1D approach is no longer valid. In this study, we investigate the whole range of possible crater open angles using 3D simulations inside the crater. We conducted 3D simulations of flow inside and just above the crater under uniform pressure distributions at the crater base for different open angles (θ = 15º, 30º, 45º, 55º, 75º) . The representative results are as follows.

For given mass flow rate at the crater base, the flow inside and just above the crater depends on ratio of cross-sectional area at the top and the base of crater (*At/Ab*) and open angle of the crater (θ). For all the investigated cases, when θ is sufficiently, the physical quantities at the crater top are approximately uniform. In this case, the 3D simulations are consistent with what are predicted by the quasi-1D approach. When *At/Ab* is small, an underexpanded flow occurs at the crater top. A jet from the underexpanded flow has a large momentum flux after the decompression processes just above the crater. As *At/Ab* increases, an overexpanded flow occurs. A jet from an overexpanded flow with relatively large *At/Ab* can have a small momentum flux due to the deceleration by shock waves just above the crater. As *At/Ab* further increases, a shock wave forms inside the crater. The flow strongly decelerates due to this shock wave so that it erupts as a subsonic jet from the crater top. As θ increases (the depth of the crater decreases for given *At/Ab*), a pressure bulge at the crater base caused by Prandtl-Meyer expansion starts affecting flow in the upper part of the crater. As a result, the physical quantities at the crater top substantially deviate from the quasi-1D results. Because of this deviation from the quasi-1D results, the momentum flux of jet after the decompression/compression processes just above the crater decreases with the increasing θ . As θ further increases and exceeds a certain value, a detachment of the flow from the crater wall occurs. This detachment leads to a qualitative change in flow structure inside and just above the crater; the flow erupts as an underexpanded flow directly from the crater base. The transition associated with the flow detachment results in a significant increase in momentum flux after the decompression/compression processes just above the crater particularly for overexpanded and subsonic flows with large *At/Ab*. It is suggested that the eruption style can change from a pyroclastic flow to a buoyant plume as θ increases for the explosive eruption from a crater with large *At/Ab*, and vice versa.

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Keywords: Explosive volcanic eruption, 3D numerical simulations, Compressible fluid dynamics

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Simulating tephra fall deposit from a bending eruption plume: development of a new code and its validation using inversion

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Most of the existing tephra fall simulations, such as Tephra2, assume a vertical plume as the particle source. However, such a source may not be applicable in many cases, because atmospheric wind easily bend the uprising plume and paricle fallout can take place from horizontally drifting plume far downwind from the source vent. In this study, we developed a new code named WT (= windy Tephra2). The prototype of this code is Tephra2 (Connor et al 2001; Bonadonna et al 2005) and include the trajectory and the diameter of the source, which are predicted by a recently developed 1D plume model in windy condition (Woodhouse et al 2013). To validate WT, we reconstructed tephra dispersal of the 2011 Shinmoe-dake eruption, in which extensive particle fallout from a horizontally drifting plume was observed.

This eruption was recorded in detail using various instrumental and fluctuation of plume height was observed. However, since the tephra fall simulation is in very primitive stage, such a time-dependent height change cannot be included in the simulation and only a single set of wind profile and plume height should be assigned to run a simulation. Also, particle segregation pattern along the plume is unknown but essential to reconstruct the tephra dispersal. We thus gave possible sets of wind profile and plume height that were observed during the eruption and calculated inversely the particle segregation pattern and misfit between observed and calculated mass loadings on the ground. Then, the set of wind profile and plume height that shows the lowest misfit was compared with observed time (=wind profile) and plume height.

The result shows misfit lowered at the timings of three main explosions during the eruption and the optimum plume height is calculated to be 4 km, which is slightly lower than horizontally drifting plume observed by a meteorological satellite (MTSAT). The particle segregation showed logarithimic decay of particle fallout as a function of distance from the source vent and this implies well mixed nature of the plume.

Keywords: tephra, eruption plume, particle segregation

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Dynamics of ballistic projectiles based on Trashcano experiment

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Ballistic projectiles ejected during explosive eruptions are centimeter to meter- sized volcanic pyroclasts that follow ballistic trajectory. Generally, these dynamics are studied by computer modellings and observations of actual eruptions. We applied the eruption simulation experiment which is known as the Trashcano experiment to investigate the relationship between the eruption velocity and the size of projectiles, and the effects of the gas.

The Trashcano experiment is an eruption simulation experiment which produces an explosion using the abrupt vaporization of liquid nitrogen. In our case, plastic balls and three-dimensional models of volcanic blocks were used to imitate ejecta. Their movement were observed by two high-speed cameras. We reconstructed trajectories of ejecta in three dimensions based on obtained high-speed images. The velocity of ejecta were calculated based on those trajectories and the ejection velocity of them were estimated by extrapolating the velocity curve.

The plot of the ejecta momentum (mv where m is the mass of the ejecta and v is the velocity) against the cross-sectional area of ejecta shows an upward linear trend. This implies that the ejection velocity depends on the cross-sectional area of the ejecta because the cross-sectional area receives the pressure which is equivalent to the force per unit area affecting during the time step Δt ($P = mv/\Delta tA$)). We interpreted this trend as meaning that the time step Δt of each ejecta is equal, and the ejection velocity depends on the cross-sectional area of the ejecta.

Keywords: Ballistic projectiles, Trashcano experiment, Ejection velocity

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ERUPTION DYNAMICS AND CONDUIT PROCESS OF THE 52-ka MANINJAU CALDERA FORMING ERUPTION, WEST SUMATRA, INDONESIA

*Indranova Suhendro[1], Atsushi Toramaru[1], Agung Harijoko[2,3], Haryo Edi Wibowo[2,3]

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The eruptive products from caldera forming eruption usually includes non-welded and welded ignimbrite. The formation of welded ignimbrite modifies the whole structure of the deposit, hence limits the understanding of caldera forming eruption. Interestingly, the 52-ka caldera forming eruption of Maninjau in West Sumatra, Indonesia, only produce the non-welded ignimbrite that distributed to the whole direction from the main volcanic edifice. The absence of welded ignimbrite has allowed us to conduct detail comparison for each erupted ignimbrite from different directions and advance the understanding of caldera forming eruption. We attempted to correlate the stratigraphy and reconstruct the eruption stages based on componentry combined with petrography, chemical analyses of plagioclase, and melt compositions by FE-EPMA and clarify the conduit process by textural analyses bulk-density and bubble number density (BND).

Ignimbrite from the 52-ka eruption consists of two distinctive types of white pumice (transparent and non-transparent). Transparent white pumice (T-WP) are rich in pheno-bubble (pre-existing bubble in magma chamber with diameter >0.1 mm), poor in matrix-bubble (syn-eruptive bubble with diameter <0.1 mm), and relatively fragile. In contrast, non-transparent white pumice (NT-WP) are phenobubble-poor, matrix bubble-rich, and relatively strong. The 52-ka eruption also produces non-transparent type of grey and banded pumice. Based from colour difference, grey pumice can be classified as follows: light grey pumice (NT-LGP), pale grey pumice (NT-PGP), dark grey pumice (NT-DGP). Lithic component is relatively homogeneous with the domination of pre-caldera lava with minor quartzite and metasedimentary rocks. The most complete stratigraphic section (from lower to upper part) only can be found in the ±100m-deep Sianok valley and corresponds to eastern ignimbrite deposit. From this location, we found the increment of lithic content towards the stratigraphic height thus become our backbone to justify the eruption stages and make correlation with other ignimbrites. Particularly, we divided the eruption stages to three level: early (0-10 lithic wt.%), middle (10-20 lithic wt.%), final (>20 lithic wt%). As a result, most of the eastern ignimbrites correspond to early stage, while northern and some of western side correspond to middle stage, and southern, most of western, and some eastern side correspond to final stage. The increment of lithic towards the eruption time is consistent with the increment of NT-WP, grey pumice, banded pumice, and decrement of T-WP. There is no difference in mineralogy, crystallinity, melt, and plagioclase compositions between T-WP and NT-WP (pl>qz>bt>px>ox, average 0.8 %, 76-81 wt.% SiO_2, An_{20-30}, respectively), hence we assume that both pumices originated from same magma chamber. Before the eruption, the white-magma chamber mingled with crystal rich (average 25 %, pl>px>bt>ox), quartz-free grey-magma (70-79 wt.% SiO2, modal anorthite: An_{50-60}). We suggest that the upper part of the giant pre-eruptive white-magma body was supersaturated with pheno-bubble, producing T-WP during the early-middle stage. While the lower part of white-magma body was relatively poor in pheno-bubble, influenced by injection of grey magma, and evacuated during the caldera collapse, producing NT-WP, grey pumice, banded pumice, and lithic during the final stage.

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The modal density of white pumice decreases from the early to final stage. We interpret this as the effect of more intense matrix-bubble nucleation resulted by decrement of pheno-bubble. Namely, the number density of pheno-bubble is responsible for limiting the secondary nucleation of matrix-bubble. The decrement of pheno-bubble will give rise to matrix-bubble nucleation and reduce the area of glass thus reduce the bulk density. This is consistent with our result that white pumice from the early and middle stages are composed by lower BND compared to the final stage.

Keywords: caldera forming eruption, Maninjau, componentry, chemical analyses, textural analyses, bubble number density

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[E] Oral | S (Solid Earth Sciences)：S-VC Volcanology

[S-VC43] Magma crystallization, fragmentation, and their roles on volcanic eruption

convener:Takahiro Miwa(National research institute for earth science and disaster prevention), Satoshi Okumura(Division of Earth and Planetary Materials Science, Department of Earth Science, Graduate School of Science, Tohoku University), Pranabendu Moitra(University of Arizona)

Crystallization of magma during magma ascent in the conduit has a large impact on the dynamics of volcanic eruptions. Magma viscosity and brittleness increase with crystallization. This change of rheological properties may cause brittle fragmentation of low-viscosity basaltic magma during highly explosive subplinian and Plinian eruptions. On the other hand, crystallization may form rigid crystal frameworks, causing efficient outgassing through the interaction between the crystal frameworks and growing gas bubbles in ascending magma, resulting in effusive eruptions. This session aims to integrate information of elementary processes to develop physical models of multiphase magma ascent and eruption. In this view, we welcome innovative and multidisciplinary contributions from experimental volcanologists, numerical modelers, petrologists, and also geophysicists who develop and extend techniques to explore crystallization and bubble-crystal interactions, and their effects on fragmentation and outgassing of multiphase magma during effusive and explosive eruptions.

[SVC43-01] Highly explosive basaltic eruptions: magma fragmentation induced by rapid crystallisation

★Invited Papers

*Mike Burton[1], Fabio Arzilli[1], Giuseppe La Spina[1], Margherita Polacci[1], Nolwenn Le Gall[2], Margaret Hartley[1], Danilo Di Genova[3], Biao Cai[4], Nghia Vo[5], Sara Nonni[1], Robert Atwood[5], Edward Llewellin[6], Richard Brooker[7], Heidy Mader[7], Peter Lee[2] (1.Department of Earth and Environmental Sciences, University of Manchester, Manchester M13 9PL, UK, 2.Department of Mechanical Engineering, University College London, London, UK, 3.Institute of Non-Metallic Materials, Clausthal University of Technology, Zehntner Str. 2a, 38678 Clausthal-Zellerfeld, Germany, 4.School of Metallurgy and Materials, University of Birmingham, Birmingham B15 2TT, UK, 5.Diamond Light Source, Harwell Science and Innovation Campus, Didcot OX11 0DE, UK, 6.Department of Earth Sciences, Durham University, Durham DH1 3LE, UK, 7.School of Earth Sciences, University of Bristol, Bristol BS8 1RJ, UK)

[SVC43-02] Petrological Constraints on the Magma Fragmentation Pressure on the Hoei Eruption (AD 1707) of Fuji Volcano - Implications for the dynamics of Basaltic Plinian Eruptions

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[SVC43-03] Role of crystallization and conduit structure on small transitions of Strombolian eruption at Suwanosejima volcano, SW Japan

*Taketo Shimano[1], Atsushi Yasuda[2], Masato Iguchi[3] (1.Graduate School of Environment and Disaster Research, Tokoha University, 2.Earthquake Research Institute, University of Tokyo, 3.Disaster Prevention Research Institute, Kyoto University)

[SVC43-04] Importance of Q as a measure of the fragmentation potential

★Invited Papers

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[SVC43-05] Heterogeneities in Crystal from YTT (74 ka) and the Implications for Toba Magma Chamber Systems

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[SVC43-06] Crystal-size distribution and micro-textural variation of Holocene volcanic products from the last 2000 years eruption of Kelud Volcano, Indonesia: an approach to understand the conduit dynamics.

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Highly explosive basaltic eruptions: magma fragmentation induced by rapid crystallisation

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Basaltic eruptions are the most common form of volcanism on Earth and planetary bodies. The low viscosity of basaltic magmas generally favours effusive and mildly explosive volcanic activity. Highly explosive basaltic eruptions occur less frequently and their eruption mechanism still remains subject to debate, with implications for the significant hazard associated with explosive basaltic volcanism. Particularly, highly explosive eruptions require magma fragmentation, yet it is unclear how basaltic magmas can reach the fragmentation threshold.

In volcanic conduits, the crystallisation kinetics of an ascending magma are driven by degassing and cooling. So far, the crystallisation kinetics of magmas have been estimated through *ex situ* crystallization experiments. However, this experimental approach induces underestimation of crystallization kinetics in silicate melts. The crystallization experiments reported in this study were performed *in situ* at Diamond Light Source (experiment EE12392 at the I12 beamline), Harwell, UK, using basalt from the 2001 Etna eruption as the starting material. We combined a bespoke high-temperature environmental cell with fast synchrotron X-ray microtomography to image the evolution of crystallization in real time. After 4 hours at sub-liquidus conditions (1170 ˚C and 1150 ˚C) the system was perturbed through a rapid cooling (0.4 ˚C/s), inducing a sudden increase of undercooling. Our study reports the first *in situ* observation of exceptionally rapid plagioclase and clinopyroxene crystallisation in trachybasaltic magmas. We combine these constraints on crystallisation kinetics and viscosity evolution with a numerical conduit model to show that exceptionally rapid syn-eruptive crystallisation is the fundamental process required to trigger basaltic magma fragmentation under high strain rates. Our in situ experimental and natural observations combined with a numerical conduit model allow us to conclude that pre-eruptive temperatures <1,100˚C can promote highly explosive basaltic eruptions, such as Plinian volcanism, in which fragmentation is induced by fast syn-eruptive crystal growth under high undercooling and high decompression rates. This implies that all basaltic systems on Earth have the potential to produce powerful explosive eruptions.

Keywords: Basalt, Explosive eruption, Crystallisation

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Petrological Constraints on the Magma Fragmentation Pressure on the Hoei Eruption (AD 1707) of Fuji Volcano - Implications for the dynamics of Basaltic Plinian Eruptions

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Basaltic volcano systems erupt in various ways, from weak effusive to explosive Plinian eruptions. However, the magma ascent dynamics and fragmentation mechanism of basaltic Plinian eruptions have remained unclear. One feasible explanation is that the crystallization and rheological transition of magma during the ascent could induce brittle fragmentation and Plinian-style basaltic eruptions. Furthermore, the temperature, initial water content, crystallization timescale, and final equilibrium pressure are critical for crystallization. In this regard, this study adopted the petrological method of estimating magma temperature and final equilibrium pressure using analyses of natural scoriae from the Hoei eruption (AD 1707), which is a basaltic sub-Plinian eruption and the last large eruption of the Fuji volcano. Furthermore, a numerical conduit flow model was used to test the possibility of reaching the fragmentation criteria and the effect of conduit geometry. The Hoei scoria has a microlite content of 51%-60%, which can increase the apparent viscosity of the Hoei magma by several orders of magnitude more than the melt viscosity. Most of the crystal phase (~90%) is composed of plagioclase, and the presence of olivine, augite, and Fe-Ti oxide implies a final equilibrium pressure-temperature condition. High-temperature experiments were performed within a temperature range of 1060 ℃-1120 ℃ under low pressure (< 20 MPa) to test the equilibrium pressure-temperature condition of the Hoei scoriae. We used two oxidation buffers (Ni-NiO and Re-ReO_2) because the chemical equilibrium phase of a mineral is also related to the oxidation condition. We established the final equilibrium condition of the Fuji Hoei eruption as 1080 ℃ - 6 MPa - ΔNNO + 1.0~1.5 in terms of equilibrium crystallinity and the chemical equilibrium phase of pyroxene. Direct evidence for the conduit geometry of the Hoei eruption is limited. However, as this study shows, the appropriate conduit geometry can be estimated by the geological constraints of the discharge rate and final equilibrium pressure. The crystallization during the basaltic magma ascent significantly changes the viscosity, and this effect can also be tested using the conduit flow model.

Keywords: Basaltic Plinian eruption, Fuji Volcano, Crystallization, Fragmentation, Hoei eruption

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Role of crystallization and conduit structure on small transitions of Strombolian eruption at Suwanosejima volcano, SW Japan

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Suwanosejima volcano is one of the most active and continuously fresh magma-fed volcanoes in Japan. The whole rock composition of this volcano is basaltic andesite with almost constant SiO2 content ca. 56 wt.%. Eruption activity in recent decades is classified into four stages; quiescent, strombolian, intermittent, and explosion stage in order of sequence. The sequence has been repeated for years with each stage from days to months of duration. During the last 20 years of activity, ash samples have been collected with some volcanic bombs landed around the active vent that covers the products of the four stages.

Ash samples are mainly consists of glassy vesicular and crystalline denser particles with some amount of isolated crystals. The classification threshold of the two types is the crystallinity of about 45vol.% which is calculated from K2O content of the matrix glass. The ratio of the two main components change with eruptive activity. Vesicular types are up to 80% during Strombolian stage whereas they decreases down to about 50% during intermittent stage and then to ca. 30% during explosion stage. In addition, the crystallinity of the glassy particles gradually increased and eventually indistinguishable with crystalline types when number of explosion increased. During each stage, the products of larger size had characteristic shapes respectively. Fluidal or vesicular spatters are common in Strombolian stage with large amount of flaky scorias. Vesicular blocky bombs are dominant during intermittent stage, some of which are fragments of conduit breccia. Then, blocky dense bombs are common in explosion stage.

From these findings, it is concluded that transition into explosive activities from strombolian is due to the change in magma property by crystallization up to more than 45%. Then, intermittent ash emitting activity begins when the crystalline part of ascending magma in a conduit exceeds ca 50vol%. Strong explosion seems to begin when crystalline part exceeds 70% with highly crystalline glassy part. Such temporal changes of short interval in the ratio of crystalline part of magma could be explained only by crystallization at shallow level with small conduit radius that upcoming fluidal magma can seal the vent breccia with small amount to raise pressure of gas pocket just beneath the vent.

Keywords: crystallization, conduit environment, Strombolian eruption

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Importance of Q as a measure of the fragmentation potential

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Fragmentation, which dramatically enhances the mobility of viscous magma, is one of the fundamental processes of an explosive eruption. Silicate melt with a viscosity of 10^{10} Pas can fragment in a brittle manner when the shear rate is faster than >0.01/(relaxation time). However, for a low viscous basaltic magma with a viscosity of $<10^3$ Pas, the required shear rate becomes $>10^5$ s^{-1}; this is an unrealistically rapid deformation rate. Instead, a low viscosity basaltic magma can fragment in a hydrodynamic manner, but observed pyroclastic deposits suggest they were brittly fragmented. The crystals in the magma increase the effective viscosity, and thus the relaxation time, lowering the required shear rate to cause a brittle fracture. Indeed, the elongation experiments show that the particle suspension fractures in a brittle manner (Moitra et al. 2018). The suspension sometimes has several relaxation time scales different from the Maxwell fluid with a unique relaxation time scale. Using Q may be appropriate to assess the possibility of fragmentation for such a complex fluid. Q is the ratio of the elastic to the viscous component of viscoelastic fluid and equivalent to the quality factor known as an inverse of the attenuation of the seismic waves. We can obtain Q by using oscillatory rheology measurements at various deformation rates (Namiki and Tanaka, 2017).

To know the relation between Q and the possibility of fragmentation of a complex fluid, we measured the rheology including Q and strength of high porosity rhyolitic magma at 500–950 degree C (Namiki et al., 2020). The occurrence of brittle fractures is observed in the low-temperature magma (<800 degree C). In this temperature range, the measured Q is high. That is, the elastic energy originated by deformations avoids attenuation and is stored in the bubbly magma until released by fracturing. Our measurements show that Q>1 is a required condition for the fragmentation of complex magma. Our measurements also show that the measured shear modulus and strength are several orders of magnitude lower than bubble-free rhyolite melt, implying that high porosity magma cannot avoid fracturing during magma ascent. Thus, Q can be a measure of the possibility of fragmentation of a complex magma. Knowing the attenuation of the seismic wave is useful to evaluate magma temperature and the possibility of a fragmentation event that may determine subsequent volcanic activities.

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Keywords: magma, bubble, rheology

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Heterogeneities in Crystal from YTT (74 ka) and the Implications for Toba Magma Chamber Systems

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Toba Caldera Complex, Indonesia is well known as the largest Quaternary caldera (87x33 km) that formed by four major eruptions among which the biggest one is the eruption of the Youngest Toba Tuff (YTT) about 74,000 years ago. Textural study of the pumice clast from YTT has been done to estimate the decompression rate by using bubble number density data. The result shows that decompression rate of Toba Caldera forming eruption varies in two order magnitude ranging from 10^6 –10^8 Pa/s. Southern pumices show the lower value than pumices from northern caldera. Similarly, new data about lithic distributions and mineral components of YTT from the northern and southern caldera showed several different characteristics. This fact suggests a possibility of different magma generation processes between southern and northern deposits. Therefore, understanding both conduit and chamber processes is needed to reveal the origin of differences in deposits. This study aims to elucidate magma chamber condition by characterizing the deposit especially crystals from YTT eruption.

Characterizations of Toba Tuffs have been made but not been enough to discuss YTT in detail. In this study, we focus on spatial heterogeneities in YTT deposits. Samples from four different locations were employed for the analyses. Component analysis was carried out on components larger than 2 mm. Whole-rock geochemical data were obtained by XRF. Petrography analysis for 37 thin sections was conducted using optical microscope. Textural analysis was carried out for 170 free-crystals and 25 selected thin sections using microphotographs taken by SEM and further analyzed using image processing software. Chemical analysis for free-crystals was carried out by SEM-EDS, while for pumices grain of 22 thin sections was conducted using EPMA.

Geochemical data showed that YTT magma is rhyodacitic to rhyolitic in whole-rock compositions with wide range of SiO_2 (69.15–76.83 wt.%). There are differences in abundance and type of pumices, free-crystals, and lithic in each location. Major minerals are plagioclase, biotite, sanidine, and quartz. Common characteristics of northern and southern part deposit is that most of crystals are fractured, some forming aggregates, has anhedral shape and wide variation in size (0.003 mm^2-13.113 mm^2). However, there are differences between northern and southern deposits: presence of amphibole with larger size, orange quartz, sieve texture, patchy zoning, oscillatory zoning, crystal clots, domination of quartz and sanidine as free-crystals, and wider range of anorthite (An_{25}– An_{87}) is mostly found in northern deposits.

Plagioclase composition from northern part shows bimodal distribution suggesting that crystallization does not occur simultaneously by single process. Furthermore, plots of anorthite number versus size and of average anorthite number versus crystal content show random distribution, suggesting the complex crystallization of plagioclase: other processes than fractional crystallization in magma chamber. Moreover, presence of antecryst and disequilibrium textures in northern deposit indicates intervention from older rocks or even other systems. Heterogeneities in crystal from northern and southern deposits suggest that YTT deposits are generated by multiple eruptions from independent, at least two magma chambers.

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Keywords: Toba Caldera, the Youngest Toba Tuff (YTT), Heterogeneities in Crystal, Conduit Process, Chamber Process, Multiple eruptions

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Crystal-size distribution and micro-textural variation of Holocene volcanic products from the last 2000 years eruption of Kelud Volcano, Indonesia: an approach to understand the conduit dynamics.

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The Kelud volcano has become one of the most active volcanoes Java which had produced several eruption sequences during the past several decades. It is located on eastern part of Java Island and developed as part of bigger volcanic chain, the Sunda arc. The pre-historic activity of Kelud has started since the development of the volcano above the older volcanic basement in late Pleistocene. Although most products of Kelud came from compositionally similar magma (basaltic andesite to andesite), it was recorded that the Kelud volcano had showed explosive activities which mostly preceded by lava dome formation. The eruption sequence as well as the petrological features that caused the changes of eruption behavior are not yet well documented. This study serves discussions about the evolution of syn-eruptive ascent of magma related to the decompression- and degassing-induced crystallization. The investigation of the conduit process in terms of change in eruption style focuses the observation on textural and geochemical variations from groundmass microlite.

The volcanic products mostly composed by the alternation of pyroclastic density currents (PDCs) deposits along the tephra fallout products. It is widely distributed along the eastern through the southern flanks of the Kelud. 1.) The PDCs are characterized by massive successions of block and ash flow deposits with the presence of the fine-grain rich degassing pipe and the low-angle cross stratification. The componentry of these deposits is mainly dominated by the dome fragments and often contain juvenile materials. 2.) In contrast, the fallout deposits show the mantle bedding structures and are identified by the abundance of the juvenile materials as the dominant component. Time-controlled samples were collected from the designated interval, linked to eruption sequence and style of activity. The samples include scoria, pumice and dense lithic from both effusive activity of dome-forming event and explosive activity. Microscopically, phenocryst and groundmass have similarity in mineral assemblages. The mineral assemblages of the Kelud volcanic products show relatively proportional through the time which consist of plagioclase, clinopyroxene, orthopyroxene and Fe-Ti oxide.

The textural analysis focused the observation and textural quantification of feldspar microlite as a dominant phase in groundmass glass. Quantitative textural analysis of feldspar microlites within the groundmass, including measurement of areal number density (NA), microlite mean size, crystal aspect ratio (S/L), crystallinity of groundmass (ϕ), and crystal size distribution (CSD) show indication of the shallow processes contribution in changing the eruption style of different eruption sequences. The feldspar shows variation in size, occurrence and especially crystal habits, which varies from acicular to rectangular prism and dominated by swallowtail, hopper and box-work/skeletal shape. A wide range of anorthite content (25 - up to 85 mol%) of analyzed samples trough different eruption sequences indicates that most likely the feldspar composition is affected by H2O activity in terms of dry solvus condition. Furthermore, the progressive changes in feldspar morphology from skeletal to swallowtail inferred the variations in decompression rate during magma ascent.

The CSDs of feldspar microlite showed slightly difference in number of crystal population with decreasing of crystal size. This trend is then interpreted to emerge that both crystallization regime of growth-dominated and nucleation-dominated occurred during feldspar microlite crystallization. The

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variation in both crystallization time and nucleation rate suggested that the generation of products with different eruption style is influenced by the style of ascent path resulted from changes in state of undercooling (ΔT).

Keywords: Kelud, tephra, eruption style, feldspar microlite, CSD analysis

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[E] Oral | S (Solid Earth Sciences)：S-GC Geochemistry

[S-GC48] Volatiles in the Earth - from Surface to Deep Mantle

convener:Takeshi Hanyu(Japan Agency for Marine-Earth Science and Technology, Research Institute for Marine Geodynamics), Gray E Bebout(Lehigh University), Hirochika Sumino(Department of Basic Science, Graduate School of Arts and Sciences, The University of Tokyo), Yuji Sano(Division of Ocean and Earth Systems, Atmosphere and Ocean Research Institute, University of Tokyo)

Volatiles play an important role in the dynamical and chemical processes in the Earth. The presence of volatiles drastically changes mineral stability and rheological behavior of the rocks. Chemical fractionation, such as partial melting, hydration, and dehydration are controlled by volatiles in the rocks. Volatiles enhance the production of magmas and drive their ascent and volcanic eruption. The atmosphere and hydrosphere have been generated by variety of degassing events from the mantle through volcanism. Some volatiles in the Earth's surface have been suggested to be recycled back into the mantle beyond subduction zones. Although the significance of volatiles in the Earth's evolution has been recognized, each of these processes is poorly constrained. We therefore welcome contributions from experimental, observational, and modeling studies that help shed light on the behavior, chemical/physical characteristic, and flux/budget of volatiles, such as hydrogen, carbon, nitrogen, noble gases, halogens, and sulfur. We encourage studies linking the behavior of multiple volatile elements and their isotopic compositions. Studies investigating the linkage between volatile and solid geochemical tracers, the phase equilibria of volatile-bearing mantle assemblages, and the effect of volatiles on the physical properties of the mantle are also welcome.

[SGC48-01] Spatial distribution of halogen compositions near the paleo slab-mantle wedge boundary, example from the Sanbagawa metamorphic belt

*JIE REN[1], Hirochika Sumino[1], Yui Kouketsu[2], Simon Richard Wallis[3] (1.Graduate School of Arts and Sciences, The University of Tokyo , 2.Graduate School of Enviromental Studies, Nagoya University, 3.Graduate School of Science, The University of Tokyo)

[SGC48-02] Multiple halogen components in subcontinental lithospheric mantle revealed by single-grain analysis of mantle-derived xenoliths

*Hirochika Sumino[1], Sota Niki[2], Ray Burgess[3], Masahiro Kobayashi[4], Hiroyuki Kagi[2] (1.Department of Basic Science, Graduate School of Arts and Sciences, The University of Tokyo, 2.Geochemical Research Center, Graduate School of Science, University of Tokyo, 3.School of Earth and Environmental Sciences, University of Manchester, 4.Tokyo Metropolitan Industrial Technology Research Institute)

[SGC48-03] C-N-He-Ar Cycling at the Hikurangi Subduction Margin, New Zealand

Gabe S Epstein[1], *Gray E Bebout[1,2], Bruce W Christenson[3], Hirochika Sumino[4], Ikuko Wada[5], Cynthia A Werner[6], David R Hilton[7] (1.Dept. Earth and Environmental Sciences, Lehigh University, USA, 2.Okayama University, Institute for Planetary Materials, 3.National Isotope Center, GNS Science, New Zealand, 4.Dept. of Basic Science, University of Tokyo, 5.Dept. of Earth Sciences, University of Minnesota, USA, 6.USGS-Contractor, USA, 7.Scripps Institution of Oceanography, USA)

[SGC48-04] Helium and carbon characteristics in forearc fluids of Central America

★Invited Papers

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[SGC48-05] Evidence for volatile-rich mantle transition zone beneath NE China: implication from the geochemistry of melt inclusions from Wudalianchi basalts

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[SGC48-06] Crustal and mantle degassing in continental China

★Invited Papers

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Spatial distribution of halogen compositions near the paleo slab-mantle wedge boundary, example from the Sanbagawa metamorphic belt

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The heavy halogens (Cl, Br, I) are highly soluble in fluids, and highly incompatible during partial melting of peridotite. Furthermore, in subduction zones their ratios, especially I/Cl ratios, vary over several orders of magnitude depending on the source (e.g. mantle, subducting slab, sediments, and sedimentary pore fluids), making them good tracers for fluid sources in subduction systems. To constrain how slab-derived fluids modify halogen compositions in the mantle wedge and how volatiles are cycled in subduction zones, we analyzed and observed the spatial distribution of halogen compositions across a paleo slab-wedge mantle boundary *(Kawahara et al, 2016)* in the Shiraga metaserpentinite body of the Sanbagawa belt.

To analyze halogens contained in rocks with low concentrations, samples were neutron irradiated at the Kyoto University Research Reactor to convert halogens (^{37}Cl, ^{79}Br and ^{127}I) into noble gas isotopes (^{38}Ar, ^{80}Kr, ^{128}Xe), which have lower detection limit. The extraction (crushing and heating) and measurement were conducted by magnetic sector mass spectrometer at the University of Tokyo.

The halogen data of fluids derived from crush extraction (thought to be fluid inclusions) show relatively high I/Cl ratios with stable Br/Cl ratios. These features are distinct from the fluid of normal mantle and altered ocean crust but are similar with data for mantle wedge peridotites exhumed from ~100 km depth *(Sumino et al, 2010)*, which are considered to partially preserve the signals of sedimentary pore fluids.

In addition, for the crush extraction, the serpentinite body shows overall decreasing I/Cl ratios with increasing distance from the slab-wedge mantle boundary, and this trend is discontinuous at the boundary. The halogen data derived from heat extraction show a similar spatial distribution but with lower I/Cl ratios for all samples.

The high I/Cl values in the mantle wedge are not explicable by the adjacent slab data. Alternatively, it can be explained by progressive dilution of an original fluid with high I/Cl, as it was transported through the slab-wedge mantle interface, and penetrated upward into the mantle wedge, where it was mixed with mantle-derived fluid with low I/Cl. This model implies that the original fluid was derived from the deeper part of subduction zone rather than the immediately adjacent and structurally underlying sediment, which is in good agreement with some previous studies on dehydration processes and fluid flow in subduction zones.

Keywords: Subduction zone, Halogen, Sanbagawa metamorphic belt

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Multiple halogen components in subcontinental lithospheric mantle revealed by single-grain analysis of mantle-derived xenoliths

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Volatile recycling back to the Earth’ s mantle at subduction zones has a significant, yet poorly constrained impact to the volatile budget in the mantle. Halogens with marine pore-fluid signatures have previously been discovered in mantle wedge peridotites, suggesting that pore-fluid-derived volatiles can survive the subduction cycle to subarc depths and modify the subcontinental lithospheric mantle (SCLM) [1,2]. To better constrain how such subduction fluids modifies the halogen composition of SCLM, we analyzed halogens in single grains/ a few grains of olivine, ortho- and clino-pyroxene crystals separated from mantle xenoliths from Southern Patagonia, Kamchatka, and the Philippines, in which several halogen components in addition to a MORB-like one have been previously identified in bulk and mineral separates [2,3]: (A) a pore-fluid-like component with high Br/Cl and I/Cl ratios similar to bulk mantle wedge peridotites [1,2]; (B) a Cl-enriched component relative to MORB, similar to bulk altered oceanic crust (AOC) and metasomatised intraplate mantle xenoliths [4,5]; and (C) a component enriched in Br and moderately in I compared to MORB, which resembles fluids in AOC, diamonds and mantle xenoliths in Russian kimberlites [4,6,7]. Halogens in the mineral grains were measured with neutron-irradiation and noble gas mass spectrometry combined with crushing and laser heating extraction.

Whereas only component (A) was observed in bulk samples from Kamchatka and the Philippines containing abundant water-rich fluid inclusions [2], components (B) and (C) were also identified in their olivines. In contrast, the component (A) is a relatively minor component in Southern Patagonian samples. These suggest that mantle wedge metasomatism by pore-fluid derived volatiles would be obscured by fractionation processes in SCLM [5], while AOC-related signatures survive more robustly.

[1] Sumino *et al.* (2010) *EPSL*. [2] Kobayashi *et al.*(2017) *EPSL*. [3] Sumino *et al.* (2018) *Goldschmidt abstract*. [4] Chavrit *et al.*, (2016) *GCA*. [5] Kobayashi *et al.* (2019) *G-cubed*. [6] Burgess *et al.* (2009) *GCA* . [7] Broadley *et al.* (2018) *Nature Geo*.

Keywords: Halogen, Mantle, Heterogeneity, Subcontinental lithospheric mantle, Mantle xenolith

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C-N-He-Ar Cycling at the Hikurangi Subduction Margin, New Zealand

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We are evaluating the cycling of C, N, and noble gases at the Hikurangi margin, with ~35 analyses of gases from across the forearc-arc-backarc and further analyses planned for April-May 2020. We present C-N concentrations and isotope compositions of sediments outboard of the trench and wall-rock metasediment in the Taupo Volcanic Zone (TVZ). We compare these data with noble gas and C-N data for gases from fumaroles and thermal springs. Ongoing work includes thermal modeling, thermodynamic calculations of prograde devolatilization, and estimation of TVZ CO_2 output flux.

The incoming sediment section at IODP Site 1520 consists of uppermost terrigenous trench-fill (7 ±3 wt.% carbonate, 0.39 ±0.17 wt.% organic C), pelagic sediment (61 ±21 wt.% carbonate, 0.24 ±0.15 wt.% organic C), and lowermost volcaniclastics (13 ±14 wt.% carbonate). Isotope compositions are relatively uniform, with $\delta^{15}N$ = +4.4 ±0.9‰ (AIR), $\delta^{13}C_{carb}$ = +0.9 ±1.1‰ (VPDB), and $\delta^{13}C_{red}$ = -25.9 ±1.2‰ (VPDB). Wall-rock metasediments have $\delta^{15}N$ = +2.4 to +6.4‰, $\delta^{13}C_{red}$ = -25.0 ±1.9‰. Trench-fill sediments are largely removed by accretion, thus the carbonate-rich section likely contributes more to the gas emissions.

The dominant C-bearing gas phase in the forearc is CH_4 ($\delta^{13}C$ = -35 to -53‰) and that within the TVZ gases is CO_2 ($\delta^{13}C$ = -2 to -10‰). Forearc noble gas ratios have crustal to atmospheric values (± minor mantle contribution; $^3He/^4He$ = 0.2-1.7 R_A and $^{40}Ar/^{36}Ar \geqq 296$), while He-Ar and C-N isotope values of gases from the TVZ are consistent with mantle and recycled sedimentary contributions ($^3He/^4He$ = 4–7 R_A, $\delta^{15}N$ = +1.3 ±0.9‰, and $[N_2/^{36}Ar]/AIR$ = 1–10). Overlap in $\delta^{13}C_{red}$ and $\delta^{15}N$ of incoming sediments and wall rocks complicates differentiation of C sources but, given the accretion of the trench-fill sequence, the apparent sediment-derived C_{org} component (about 30%, after [1]) and N in the gases could reflect contamination by Torlesse/Waipapa wall rocks.

[1] Sano & Marty (1995) Chem. Geol. 119, 265-274.

Keywords: subduction zone, noble gas, carbon, nitrogen, New Zealand, Hikurangi

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Helium and carbon characteristics in forearc fluids of Central America

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Volatile movement between Earth’s surface reservoirs (crust, sediments, atmosphere and oceans) and the deep mantle occurs at subduction zones. Typically, outputs are characterized as emissions from volcanic centers, however more recently it has become apparent that potentially significant outputs may be occurring in the forearc and backarc regions. Carbon fluxes associated with arc and backarc localities are relatively well-constrained for the Central America Volcanic Arc (CAVA)[1,2,3], however, until recently[4], the forearc flux via cold seeps, hot springs and groundwaters were poorly constrained.

The border between Costa Rica and Panama represents the transition between the orthogonal subduction of the Cocos Plate and the oblique subduction of the Nazca Plate relative to the Caribbean Plate. We present unpublished He and CO_2 isotope and relative abundance data for the from forearc fluids of southern Costa Rica and western Panama in (n=43) water and (n=22) gas samples. These data allow us to determine the extent of tectonic, chemical and biological controls on forearc carbon outgassing. Helium isotope ($^3He/^4He$) values range from 0.3 to 8.8 R_A (where air = $1R_A$). The upper range of He isotope values measured is consistent with to - slightly above - published He isotope results for CAVA volcanoes. In Panama, helium isotope values are remarkably high (approaching plume-like values), in fluids from non-active volcanic areas, suggesting that subduction of the Galapagos hotspot track may be influencing geochemical signatures in modern fluids. Carbon isotopes of CO_2 ($\delta^{13}C$) vary from −29.7‰ to +6.7‰ vs. PDVB, suggesting a variety of fractionation processes are at work in this complex region. These data are modelled to show that CO_2 loss due to calcite precipitation may be an important process, similarly to what was recently shown in Costa Rica’s Nicoya Peninsula[4]. $CO_2/^3He$ values of the seeps are also variable and fall between 10^3 and 10^{12}, with the low values being consistent with a significant sink due to calcite precipitation. In summary, we show that 1) there is a pervasive (deep) mantle component in all forearc samples, and 2) extensive CO_2 fractionation is occurring in the low temperature forearc region across southern Costa Rica and Panama.

[1] Shaw et al., 2003.

[2] De Leeuw et al., 2007.

[3] de Moor et al., 2017.

[4] Barry et al., 2019.

[5] Sano and Marty, 1995.

Keywords: Carbon, Helium, Central America

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Evidence for volatile-rich mantle transition zone beneath NE China: implication from the geochemistry of melt inclusions from Wudalianchi basalts

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Water, carbon dioxide, sulfur, fluorine, and chlorine are the most popular volatiles in the Earth’s mantle (McDonough and Sun, 1995; Salters and Stracke, 2004). These volatile elements affect the mantle dynamics such as magma genesis, magma compositions, and mantle physics. It is, therefore, quite important to understand contents and behaviors of these volatile elements in the mantle. Because of difficulty to exactly estimate these volatile compositions of volcanic rocks using thermodynamics methods, these volatile compositions in MTZ are still controversial. Sporadic intraplate volcanism occurred around the Wudalianchi, northeastern China, in the Miocene (9.6 –7.0 Ma), middle Pleistocene (0.56 –0.13 Ma), and recent (1719 –1721 AD) periods, which is considered to be originated in hydrous MTZ affected by the stagnant Pacific slab lying beneath this area (e.g., Kuritani *et al.*, 2013). In this study, we obtained 47 basaltic samples from the Quaternary volcanoes in Wudalianchi area and analyzed whole-rock and mineral chemical compositions as well as volatile contents of olivine-hosted melt inclusions in order to clarify the origin of the volcanism and to estimate volatile compositions of MTZ, such as H_2O, CO_2, S, Cl, and F.

Major element compositions of whole-rock and olivine-hosted melt inclusions were analyzed by an X-Ray Fluorescence spectrometer (XRF), Electron Probe Micro Analyzer (EPMA), respectively. Volatile contents in melt inclusions were measured by Secondary Ion Mass Spectrometry (SIMS). Whole-rock compositions of these basalts are enriched in K_2O (4.4 –6.0 wt%) and depleted in FeO (7.1 –9.6 wt%) showing tight liner compositional trends from an SiO_2 content of 45.0 to 54.0 wt%. Olivine phenocrysts containing melt inclusions show Fo# (=100Mg/(Mg+Fe)$_{mol}$) from 81.3 to 85.4, but melt inclusions have lower Mg# (=100Mg/(Mg+Fe)$_{mol}$) from 65.2 to 78.3 than a melt in equilibrium with host olivine phenocryst, implying overgrowth of host olivine after entrapment of a melt inclusion. Therefore, we corrected compositions of melt inclusions to be in equilibrium with a host olivine by adding olivine (hosted-olivine overgrowth is 4 –9 wt%). Corrected compositions of melt inclusions possess limited range of SiO_2, MgO, and P_2O_5 contents from 51.8 to 53.9 wt%, 4.3 –5.4 wt%, and 0.9 –1.2 wt%, respectively, variation of which can be explained by fractionation of olivine, clinopyroxene, plagioclase, magnetite. The water and carbon dioxide contents in melt inclusions are 0.1 –1.2 wt%, 0 –2480 ppm, respectively. In particular, variable CO_2 contents (0 –2450 ppm) with limited variation of H_2O contents at more than 1.0 wt% correspond with a decompressive degassing trend of magma suggesting that H_2O contents (>1.0 wt%) of melt inclusions are original water contents in magma chamber. The highest H_2O content of 1.2 wt% shows good agreement with previous estimation (H_2O content 1.1 –1.4 wt%) by Kuritani *et al.* (2013). Overall variations of S, F, and Cl can be reasonably reproduced by Rayleigh fractional crystallization model suggesting that most samples have not degassed for S, F, and Cl. Fluorine contents (1230 –1510 ppm) of undegassed melt inclusions for given H_2O contents (1.1 –1.2 wt%) are still higher than the DMM –FOZO trend proposed by Shimizu *et al.* (2019). Degree of partial melting for Wudalianch basalts were estimated to be 7 –14 % using incompatible trace element compositions of primary melts that were estimated by the addition of 2 –10 wt% olivine crystals to the least fractionated magma. As a result, H_2O, F, and Cl contents of the source

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mantle are ~500, ~50, and ~60 ppm, respectively, that are higher than DMM (H_2O : 190 ppm, F : 13 ppm, Cl : 5 ppm (Shimizu *et al.*, 2016)), implying the mantle transition zone above the stagnant Pacific slab is not only H_2O-rich, but also F-rich and Cl-rich compositions.

Keywords: alkaline basalt, melt inclusion, northeastern China, volatile

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Crustal and mantle degassing in continental China

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The release of volatile elements (e.g., carbon, nitrogen and noble gases) in response to volcanic and tectonic processes occurs at plate boundaries, volcanic and tectonically active settings. Volatile degassing is prevalent in present-day continental China, which is comprised of continental tectonic blocks (e.g., orogenic belts, continental rifts and cratonic regions). Here, we briefly review the crustal and mantle degassing features of different tectonic units in the region, and specifically focus on the implications of volatile outgassing for regional tectonic affinities associated with growth of the Tibetan Plateau.

Helium isotope ($^3He/^4He$) data (reported in R_A, where R_A is air $^3He/^4He$) indicate that crustal and/or mantle degassing rates are variable for individual tectonic units of present-day continental China. Compared to tectonic degassing controlled by active faulting processes, magma degassing related to Quaternary volcanism is more efficient in transporting mantle volatiles to the surface (i.e., higher $^3He/^4He$). This feature has been identified in several Quaternary volcanic fields, especially the Changbaishan and Tengchong volcanoes that are characterized by Holocene eruptions of silicic magmas. Fluids with a resolvable mantle helium component ($^3He/^4He > 0.1\ R_A$) are also observed in hydrothermal fluids from active faults of ancient cratonic regions, such as Tarim craton and North China craton. In contrast, the Sichuan basin within the Yangtze craton is dominated by crustal degassing ($^3He/^4He < 0.1\ R_A$).

Thermal springs are extensively distributed in the Tibetan Plateau, making it an ideal laboratory for window of volatile outgassing and its tectonic implications for evolution of orogenic belts. In southern Tibet and the Himalayan region, there is a general northward increasing trend in $^3He/^4He$ values of hydrothermal fluids, suggesting transition from accretionary wedge dominated by crustal degassing to magmatic front that shows mantle helium contributions. The southeastern part of the Tibetan Plateau (SETP) represents an on-going spreading marginal area of the orogenic plateau due to India-Asia collision. Helium isotope mapping defines a zone of significant mantle degassing in the SETP. The release of mantle fluids strongly correlates with active faulting systems. In particular, non-radiogenic $^3He/^4He$ values ($^3He/^4He = 0.57–3.79\ R_A$) are observed in the bending section of the Xianshuihe-Anninghe fault, which is a block boundary fault with localized high shear strain. In contrast, lower degrees of mantle ^3He emissions ($^3He/^4He < 1\ R_A$) dominate the active faults with lower shear strain rates in the SETP interior. Such helium degassing patterns can reflect spatial variations in strain rates of different strike-slip fault systems under the control of the India-Asia collision and resistance by the Yangtze craton. Combined with regional tectono-magmatic history and plate reconstruction results, we propose that the present-day mantle degassing in the SETP has close affinities with tectonic and magmatic responses to westward rollback of the Indian slab, which initiated 13 to 10 million years ago. Strain reorganization triggered by the Indian slab rollback led to lateral expansion and localized surface uplift of the SETP, suggesting that mantle dynamics may have played an important role in southeastward growth of the Tibetan Plateau during late Cenozoic.

Keywords: Crustal degassing, Mantle degassing, Tectonic implications, Continental China

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[E] Oral | S (Solid Earth Sciences)：S-GC Geochemistry

[S-GC48] Volatiles in the Earth - from Surface to Deep Mantle

convener:Takeshi Hanyu(Japan Agency for Marine-Earth Science and Technology, Research Institute for Marine Geodynamics), Gray E Bebout(Lehigh University), Hirochika Sumino(Department of Basic Science, Graduate School of Arts and Sciences, The University of Tokyo), Yuji Sano(Division of Ocean and Earth Systems, Atmosphere and Ocean Research Institute, University of Tokyo)

Volatiles play an important role in the dynamical and chemical processes in the Earth. The presence of volatiles drastically changes mineral stability and rheological behavior of the rocks. Chemical fractionation, such as partial melting, hydration, and dehydration are controlled by volatiles in the rocks. Volatiles enhance the production of magmas and drive their ascent and volcanic eruption. The atmosphere and hydrosphere have been generated by variety of degassing events from the mantle through volcanism. Some volatiles in the Earth's surface have been suggested to be recycled back into the mantle beyond subduction zones. Although the significance of volatiles in the Earth's evolution has been recognized, each of these processes is poorly constrained. We therefore welcome contributions from experimental, observational, and modeling studies that help shed light on the behavior, chemical/physical characteristic, and flux/budget of volatiles, such as hydrogen, carbon, nitrogen, noble gases, halogens, and sulfur. We encourage studies linking the behavior of multiple volatile elements and their isotopic compositions. Studies investigating the linkage between volatile and solid geochemical tracers, the phase equilibria of volatile-bearing mantle assemblages, and the effect of volatiles on the physical properties of the mantle are also welcome.

[SGC48-08] Investigating past eruptive activity of a silicic submarine volcano using FTIR volatile analyses

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[SGC48-09] Reactive evolution of carbonated silicate melt in the mantle lithosphere

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[SGC48-10] . *The conditions of sub-lithospheric diamond formation constrained from ferric iron-rich exsolution in ferropericlase inclusions in diamond* .

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[SGC48-11] The effects of carbon concentration and silicate melt structure on the metal-silicate partitioning of carbon in a shallow magma ocean

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[SGC48-12] Subduction barrier for argon

★Invited Papers

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Investigating past eruptive activity of a silicic submarine volcano using FTIR volatile analyses

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Eruptions of silicic magmas like rhyolite are controlled by the rate and extent of bubble growth that occurs when magmatic volatiles, chiefly H_2O and CO_2, exsolve into the vapour phase during magma ascent. When erupted magma cools quickly enough to form volcanic glass, the dissolved volatile contents of this glass form a geochemical record that can be used to interpret degassing and eruption processes. However, silicic volcanic glasses are vulnerable to secondary hydration (i.e. slow diffusive addition of water from the surrounding environment in the time since eruption), which overprints the eruptive volatile record. Silicic submarine eruption products are especially vulnerable to this hydration. Moreover, the relative lack of material suitable for radiocarbon dating means that it is difficult to obtain ages for late Quaternary submarine eruptions. Using new Fourier Transform Infrared spectroscopy (FTIR) methods for vesicular and hydrated glasses, we demonstrate that it is possible to use this volatile record to investigate past eruptive activity of submarine volcanoes. We present data for Oomurodashi, an active, shallow, silicic submarine volcano only 60 km from the entrance to Tokyo Bay. Geochemistry confirms Oomurodashi is the source of a ~11.5 ka subaerial tephra deposit on the nearby inhabited islands of Izu-Oshima and Toshima. We infer on the basis of pumice volatile contents and tephra characteristics that this deposit was formed by explosive submarine phreatomagmatic activity that produced the shallow central crater in the submarine edifice. Volatile contents of in situ submarine lavas are lower than expected for their current water depth and comparison with past sea level implies that these effusive eruptions occurred at ~8-9 and ~12 ka during times of lower sea level. Although all matrix glasses have experienced hydration, water speciation data suggest this is consistent with low temperature secondary hydration following eruption rather than hydration during cooling within a submarine plume. Oomurodashi has also erupted submarine pumice with different densities, quench depths and dispersal histories; however, any pumice sufficiently buoyant to produce floating pumice rafts will have been lost from the local geological record. FTIR volatile analyses of distant marine pumice will be invaluable for understanding how potentially hazardous pumice rafts form.

Keywords: FTIR, water speciation, submarine volcanism

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Reactive evolution of carbonated silicate melt in the mantle lithosphere

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The deep Earth’ s interior is a large reservoir of carbon and deep-rooted oceanic hotspots usually produce CO_2-rich magmas. The melting of mantle with CO_2 is shown to produce Si-undersaturated alkalinn melts, and, thus, CO_2 may play a key role in the origin of these magmas. However, volatiles tend to be lost during natural volcanism, and it is usually difficult to identify the role of these volatiles during the genesis of these lavas. Here we report geochemical analyses of a suite of volcanic rocks formed by the deep-rooted Caroline hotspot in the Pacific. The most primitive magmas have depletion of SiO_2 and high field strength elements and enrichment of rare earth elements that are in concert with mantle-derived primary carbonated melts. The carbonated melts show compositional variations that indicate reactive evolution within the overlying mantle lithosphere, during which the evolving melts obtained depleted components from the lithospheric mantle. The carbonated melts were de-carbonated and modified to oceanic alkali basalts by precipitation of perovskite, apatite and ilmenite that significantly decreased the concentrations of rare earth elements and high field strength elements. These magmas also experienced a late stage of non-reactive fractional crystallization after the reactive evolution was completed. We propose that the carbonated melts would experience two stages, reactive and un-reactive, of evolution during their transport through in thick oceanic lithospheric mantle. The mantle lithosphere plays a key role in de-carbonation and conversion of deep-sourced carbonated melts to alkali basalts. This work was financially supported by the National Natural Science Foundation of China (91858206, 41876040).

Keywords: carbonated silicate melt, reactive evolution, alkali basalt, hotspot, Caroline seamount chain

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. *The conditions of sub-lithospheric diamond formation constrained from ferric iron-rich exsolution in ferropericlase inclusions in diamond*

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The rocks-salt structured Mg-Fe oxide, ferropericlase, is one of the most common minerals found as an inclusion in sub-lithospheric diamonds, where it appears with a wide range of Fe/(Fe+Mg) ratios. It is important to be able to understand the formation conditions of such inclusions as they provide some of the only direct evidence for processes that are part of the deep mantle carbon cycle. In a number of TEM investigations exsolution of Fe^{3+} –rich phases, normally described as being part of the magnetite-magnesioferrite solid solution, have been identified within such ferropericlase inclusions. This is somewhat surprising because it implies that ferropericlase becomes saturated in Fe_2O_3. At low pressures this would indeed result in the exsolution of magnetite-magnesioferrite solid solution but this only occurs at oxygen fugacities that are higher than those at which diamond or graphite would be stable. At pressures higher than 8 GPa, however, experiments have shown that other mixed valence iron oxide phases with the stoichiometries Fe_4O_5 and Fe_5O_6 are stable, which may well cause a decrease in the maximum Fe_2O_3 content of coexisting ferropericlase. In order to understand the exsolution of Fe_2O_3 -bearing oxides from ferropericlase inclusions in diamonds and to determine the conditions or the changes in conditions required for this to occur, it is essential to be able to describe phase relations in the FeO-MgO-Fe_2O_3 system at high pressures and temperatures. This information will not only allow the oxygen fugacity of diamond formation to be assessed but can potentially provide information on the post entrapment conditions experienced by diamonds.

In this project we examine the conditions at which mixed valence iron oxides become stable and determine the maximum Fe^{3+}/Fe_{tot} ratio of coexisting $(Fe,Mg)_{1-x}O$ ferropericlase using both experimental measurements and thermodynamic modelling. Multianvil experiments have been performed between 6 –25 GPa and 1200-1800˚C using a starting composition of $(Mg_{86}Fe_{14})O$ and $(Mg_{50}Fe_{50})O$ plus varying amounts of Fe_2O_3 (20%, 10%, 5%). Pt powder was added to the experiments to act as a redox sensor and minor amounts of Ni, Cr, Mn and Na were also added. Samples were then analysed using scanning electron microscopy, the electron microprobe, Mössbauer spectroscopy and X-ray diffraction.

In the recovered experiments, ferropericlase was found to coexist with magnetite-magnesioferrite solid solution up to 12 GPa and $Mg_2Fe_2O_5$-Fe_4O_5 solid solution at higher pressures. In all experiments the oxygen fugacities could be determined from three different equilibria simultaneously, and in the calculation of the oxygen fugacity a ferropericlase model in the FeO-$Fe_{2/3}O$-MgO system was employed and exchange of Mg and Fe^{2+}in magnetite was accounted for.
In this model only at pressures above 16 GPa the calculated oxygen fugacity of $(Fe,Mg)_4O_5$ exsolution is compatible with the diamond stability field. As it is likely that the exsolution observed in natural ferropericlase inclusions occurred after entrapment in the diamond, it must have occurred either as pressures increased after entrapment or temperatures decreased. The first scenario might imply that the diamonds were then further subducted after formation, while the second scenario might arise if the diamonds were then later stored in the subcontinental lithosphere. From precise determinations of the Fe

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$^{3+}/Fe_{tot}$ ratios of ferropericlase inclusions coexisting with exsolved mix valence iron oxides and through characterisation of the exsolved oxides themselves, it should be possible to differentiate between these scenarios.

Keywords: Deep carbon cycle, Ferropericlase , diamond formation

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The effects of carbon concentration and silicate melt structure on the metal-silicate partitioning of carbon in a shallow magma ocean

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Abundance and speciation of carbon in planetary mantle affect volcanic activity, physical properies (e.g., solidus temperature) of mantle minerals, and the chemical composition of planetary atmospheres. Thus, elicidating the distribution and chemical speciation of carbon in terrestrial planets provides important clues to understand the chemical evolution and habitability of planets. Previous studies have conducted high-pressure experiments on liquid metal-silicate partitioning of carbon and found that carbon is highly siderophile [e.g., 1-3]. This result indicates the carbon-depleted planetary mantle after the core formation. However, the carbon abundance in the current Earth’ s mantle is much more abundant than prediction based on experiments [e.g., 1-3]. In order to explain this discrepancy, the late accretion of carbon-rich bodies has been invoked [e.g., 1-3]. However, this explanation is *ad-hoc*, and previous experimental studies have used a graphite capsule, which causes carbon-saturated conditions. Given that bulk Earth is not saturated with carbon and the activity coefficient varies with the concentration of target element, it is necessary to perform experiments at carbon-undersaturated conditions.
In this study, we conducted high-pressure experiments on liquid metal-silicate partitioning of carbon using a SiO2 capsule and multi-anvil apparatus at 2 GPa and 1923 K. The starting materials were prepared from mixtures of metallic Fe and Ni, and oxide. For silicate compositions, we used two types of compositions: EH-type enstatite chondrite and mid-ocean ridge basalt. 0.2 wt% of carbon was added to these starting materials as Na_2CO_3. Carbon in quenched metallic liquid and silicate liquid were analyzed by electron probe micro-analyzer and secondary ion mass spectrometry, respectively. Chemical species of volatiles and the melt structure of quenched silicate glasses were analyzed by Raman spectroscopy. The experimental results show that the metal-silicate partition coefficient of carbon at carbon-undersaturated conditions is lower than that reported using a graphite capsule. Raman spectroscopic analyses show the presence of CH species and amorphous carbon in silicate and that the carbon abundance in silicate liquids increases with increasing non-bridging oxygen. These results suggest that the metal-silicate partitioning behavior of carbon depedns both on carbon concentration and silicate melt structure. In this talk, we will also discuss the application of experimental results to the Earth.

[1] Dasgupta et al., 2013, *Geochim. Cosmochim. Acta* 102, 191-212.
[2] Chi et al., 2014, *Geochim Cosmochim. Acta* 139, 447-471.
[3] Li et al., 2016, *Nat. Geosci.* 9, 781-785.

Keywords: Carbon, Core-mantle partitioning, Magma ocean

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Subduction barrier for argon

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1. Japan Agency for Marine-Earth Science and Technology

It is known that volatile components contained in subducted slab are released by dehydration of hydrous minerals and back to the Earth's surface under subduction zones, which is known as "subduction barrier". In contrast, volatiles might be carried into the deep mantle, because volcanic gases from the mid-oceanic ridge or hotpots contains significant amount of volatiles. In the case of argon (Ar), geochemical data indicate Ar from the mantle is the recycled component that is derived from Earth's atmosphere. However, the mechanism of recycle of Ar at the deep mantle is still an open question.

We perform density functional theory to investigate the melting temperature and thermal pressure of Ar. We also use high-pressure experiments to determine the room temperature EOS (equation of state) of Ar. The combination of first-principles molecular dynamics calculations and high-pressure experiments allows us to determine reliable physical properties, such as the EOS and melting temperature, over a wide range of pressures and temperatures.

The results show that the estimated density of Ar is smaller that of the PREM mantle, which indicates that the density crossover does not occur at the bottom of the lower mantle. The calculation data indicate that a melting temperature has a significant pressure dependence. If the pressure-temperature path of the subducted slab is lower than the critical condition, ~750 K and ~7.5 GPa, solid Ar can be carried down into the deep mantle. Melting of solid Ar in the upwelling mantle plume occurs at the bottom of the transition zone. Thus, solid Ar plays an important role in Ar recycling in the Earth's interior.

[1] Ono, S. Fate of subducted argon in the deep mantle. *Sci Rep* **10**, 1393 (2020). https://doi.org/10.1038/s41598-020-58252-8

Keywords: Argon, Mantle, Phase diagram

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[E] Oral | S (Solid Earth Sciences)：S-TT Technology & Techniques

[S-TT50] Synthetic Aperture Radar and its application

convener:Yohei Kinoshita(University of Tsukuba), Yu Morishita(Geospatial Information Authority of Japan), Shoko Kobayashi(Tamagawa University), Takahiro Abe(Earth Observation Research Center, Japan Aerospace Exploration Agency)

ALOS-2 and Sentinel-1, which have highly enhanced capacity compared to previous SAR satellites, were launched in 2014, and their utilization has been widely expanding as data have accumulated for approximately five years. Other long-operating SAR satellites like TerraSAR-X and Cosmo-SkyMed also contribute to expanding the SAR utilization. Now we are facing a new and abundant era of the satellite SAR, along with a worldwide trend to an open and free data policy of satellite data, under the situation of next-generation advanced and/or constellated SAR satellite plans by both public agencies (e.g. ALOS-4 and NISAR) and private sectors. In addition, SAR technologies with other platforms, such as ground-based SAR with high temporal resolution and UAV (Unmanned Aerial Vehicle) SAR with flexible operability, have also been developed and used for various targets. These facts indicate that the SAR utilization has become widespread in both basic researches (e.g., earth science) and diverse applications (e.g., disaster prevention and forest monitoring). In this session, we would like to invite various kinds of research and application results with regard to SAR, sharing our knowledge and having a discussion for the advancement of the SAR utilization.

Introduction

[STT50-01] Trial of deforestation detection accuracies improvement for JJ-FAST algorithm by using deep learning.

*Manabu Watanabe[1], Christian Naohide koyama[1], Masato Hayashi[2], Isumi Nagatani[2], Takeo Tadono[2], Masanobu Shimada[1] (1.School of Science and Engineering, Tokyo denki university, 2.JAXA/EORC)

[STT50-02] **Changes in surface conditions and permafrost environment of a summit area of the Daisetsu Mountains, Hokkaido, Japan**

*Go Iwahana[1], Toshio Sone[2], Masao Uchida[3], Tokuta Yokohata[3] (1.International Arctic Research Center, University of Alaska Fairbanks, 2.Institute of Low Temperature Science, Hokkaido University, 3.National Institute for Environmental Studies)

[STT50-03] **Determination of the dipping direction of a blind reverse fault from InSAR: Case study on the 2017 Sefid Sang earthquake, Northeastern Iran**

*Nematollah Ghayournajarkar[1], Yo Fukushima[2] (1.Graduate School of Science, Tohoku University, 2.International Research Institute of Disaster Science, Tohoku University)

[STT50-04] **DefVolc: Interface and web service for fast computation of volcano displacement**

*Valerie Cayol[1], Farshid Dabaghi[2], Yo Fukushima[3], Marine Tridon[1], Delphine Smittarello[4], Olivier Bodart[2], Jean-Luc Froger[1] (1.CNRS, UCA, LMV, OPGC, IRD, Clermont-Ferrand, France, 2.UdL, ICJ, Saint-Etienne, France, 3.IRIDeS, TU, Tohoku, Japan, 4.UGA, USMB, CNRS, IRD,IFSTTAR, ISTerre, Grenoble, France)

Discussion

Trial of deforestation detection accuracies improvement for JJ-FAST algorithm by using deep learning.

*Manabu Watanabe[1], Christian Naohide koyama[1], Masato Hayashi[2], Isumi Nagatani[2], Takeo Tadono[2], Masanobu Shimada[1]

1. School of Science and Engineering, Tokyo denki university, 2. JAXA/EORC

JICA-JAXA Forest Early Warning System in the Tropics (JJ-FAST, [1]) is first and only one SAR-based deforestation detection system monitoring tropical forest globally. The deforestation detection algorithm currently used in the JJ-FAST is threshold-based algorithm. In case that gamma_0 difference between latest and past data exceeds empirically decided threshold level, the area is regarded as a deforestation site [2]. Eleven deforestation sites with the size of 1x1 deg. are selected from South America, South-East Asia, and Africa, and are used to do an accuracy evaluation. The overall accuracies for the threshold based algorithm are estimated to be more than 80% for the sites, where the number of deforestation is less than 100 sites within 1x1 deg. On the other hand, the accuracies, especially for the producer’s accuracies, are often worse for the deforestation site, where the number is more than 100 sites. If the lower threshold levels are adopted, the producer’s accuracies are improved, while the use’s accuracies are decreased.
To fix this problem, deep learning are introduced to improve the producer’s accuracies for the dense deforestation detection sites. A test site are selected in Brazil, where 652 deforestation were detected between July 13 and August 24, 2018 within 1x1 deg. (Upper left lon. & lat: W075, S08). Input chip images are made for each polarization (HH, HV, HH-HV ratio), and color composite image is produced from latest and past image.
The threshold level 1 is used, and the detection accuracies for the threshold method are estimated. Only 212 out of 652 deforestation sites are correctly detected for the threshold method with threshold level 1, and the 171 sites are detected falsely. In case that the threshold level 2, where the threshold level is 0.5 dB smaller than Threshold level 1, is adopted, producer’s accuracies are improved, while the user’s accuracies worsen to be 40.2%. Falsely and correctly detected site images are used as the training data, and deep learning are applied to improve the producer’s accuracies obtained with threshold 2. Two well-known network model, AlexNet [3] and GoogLeNet [4], are tested in this time. AlexNet have five convolution layers, and often used as standard model. But no improvement are obtained in our dataset. GoogLeNet introduces inception module, which consists of several pooling and convolution layers and makes larger network.
The results are presented in the figure below. While the user’s accuracies are slightly decreased, the producer’s accuracies is 60.7 %, and almost twice as large as the one for the threshold method with threshold 1. Threshold method only use information about intensity variation, while the deep learning uses not only the intensity variation, but also texture information within and surrounding the deforestation site. This additional information may make better estimation accuracies.

[1] JJ-FAST, http://www.eorc.jaxa.jp/jjfast/jj_index.html, accessed on February 17, 2019
[2] Manabu Watanabe, et al., IMPROVEMENT OF DEFORESTATION DETECTION ALGORITHMS USED IN JJ-FAST, Proceedings of 2019 IEEE International Geoscience & Remote Sensing Symposium, 'INSPEC Accession Number: 19138057, 2019
[3] A. Krizhevsky, I. Sutskever, and G. E. Hinton. Imagenet classification with deep convolutional neural networks. In Proc. of NIPS, 2012.
[4] C. Szegedy, W. Liu, Y. Jia, P. Sermanet, S. Reed, D. Anguelov, D. Erhan, V. Vanhoucke, and A.

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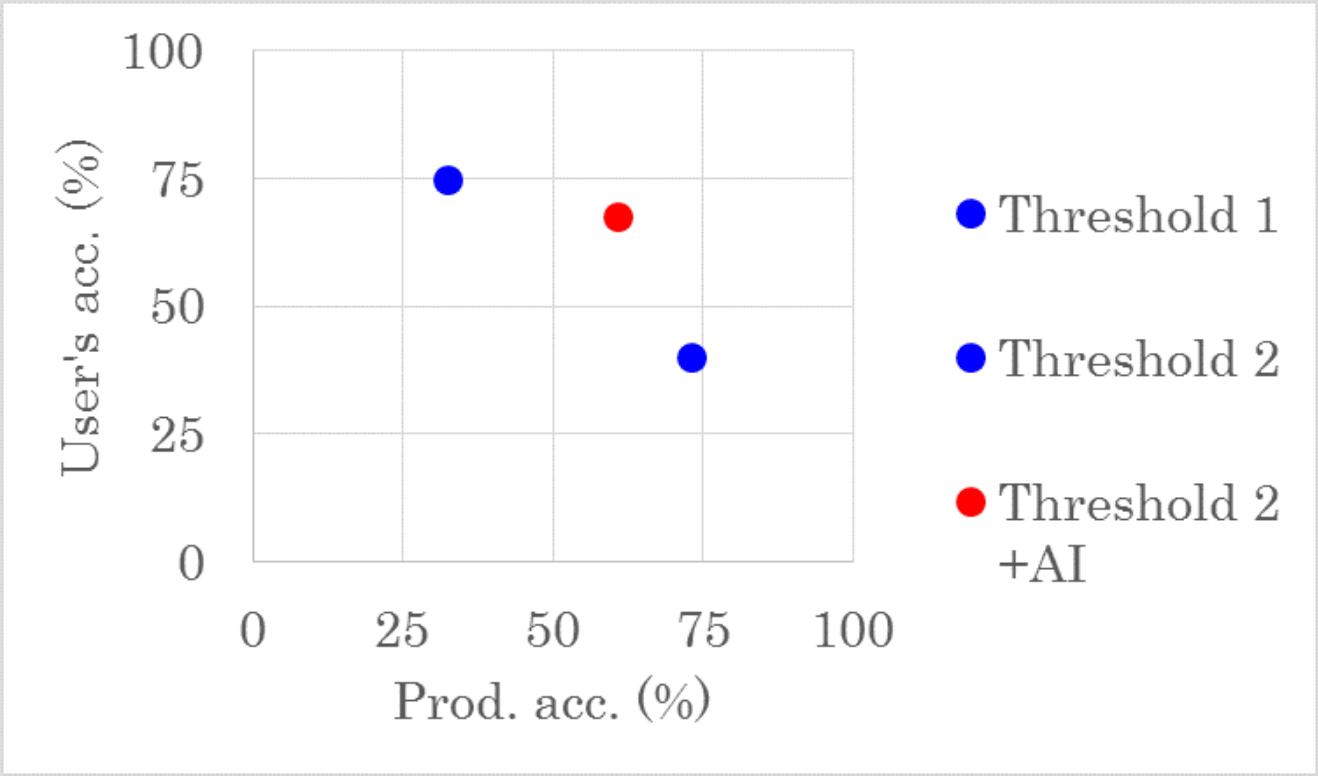
Rabinovich. Going deeper with convolutions. In Proc. of CVPR, 2015.

Keywords: Forest monitoring, deforestation detection, PALSAR-2, AI



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Changes in surface conditions and permafrost environment of a summit area of the Daisetsu Mountains, Hokkaido, Japan

*Go Iwahana[1], Toshio Sone[2], Masao Uchida[3], Tokuta Yokohata[3]

1. International Arctic Research Center, University of Alaska Fairbanks, 2. Institute of Low Temperature Science, Hokkaido University, 3. National Institute for Environmental Studies

This paper reports about results of permafrost and the micrometeorological monitoring by microwave and optical remote sensing and detected changes in surface conditions at a summit area of the Daisetsu Mountains, Japan. Mountain permafrost is distributed in a complex manner over a large area of the upper approximately 1700m of the Daisetsu Mountains (43˚N, 142˚E). Numerous periglacial landforms were identified from the 1960s to 1980s suggesting the occurrence of perennially cryotic ground in this area. Our recent long-term monitoring confirmed the occurrence of permafrost in multiple windswept areas. Given the increasing number of reports about rapid permafrost thaw and landform changes in the Arctic under the global warming, it is of broad concern to understand a situation in mountain permafrost environment which influences changes in entire mountain ecosystem in the future. A 4m tower with micrometeorological instruments was installed at a representative point (Goshiki station) of the mountain permafrost zone (2038m a.s.l.) in July 2005. Micrometeorological measurements including monitoring of thermal and hydrological conditions in the ground were conducted from 2005 to 2018 at the Goshiki Station. In addition, we investigated a set of remote sensing data (high-resolution optical and microwave imagery) in order to discuss environmental controls of the occurrence and temporal variation of the mountain permafrost. The mean annual air temperature fluctuated between -3.4 and -4.7 ˚C with no obvious inter-annual trends. Consecutive northwesterly driving wind prevents snow accumulation in the mountain permafrost site and enhances the energy exchange between ground and atmosphere in winter. The active layer thickness was in a range between 1.0 and 1.7m around the Goshiki Station. Permafrost base was at a depth deeper than 10 m at least. Permafrost temperature at the depth of 8-10m showed a monotonous increase at rates between 0.03 and 0.07 ˚C/year from 2010 to 2017, while upper layers displayed no marked increasing trend in ground temperature. The annual mean air temperature was comparable to those of Siberian or Alaskan Tundra; however, the relative humidity had been quite high with large summer precipitation (about 700-1000mm). The summer precipitation easily penetrates through a highly permeable active layer and significantly affects the near-surface thermal regime. The surface radiation conditions were controlled largely by the precipitation and ground surface phenology. We found no significant trends in surface changes in optical remote sensing and in-situ micrometeorological monitoring, although there are large fluctuations in measured parameters depending on weather conditions. L-band SAR interferometry measured seasonal surface displacement up to 20 cm/year and stacking analysis showed inter-annual subsidence ranging a few cm/year some areas with little vegetation covers. Slow slope movements were also detected in some block slopes and vegetated slopes, presumably associated with permafrost. The surface displacement behavior measured by our InSAR analysis largely depended on geomorphological and topological conditions, which was also closely related to ground freeze and thaw regimes. Our results demonstrated applications of the InSAR technique for monitoring of high mountains in Japan and identify areas of rapid changes in ground-surface conditions, which provides important information for land management and adaptation strategies in the future warming mountain environment.

Keywords: InSAR, Permafrost, Frozen ground, mountain, slope, land slide

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Determination of the dipping direction of a blind reverse fault from InSAR: Case study on the 2017 Sefid Sang earthquake, Northeastern Iran

*Nematollah Ghayournajarkar[1], Yo Fukushima[2]

1. Graduate School of Science, Tohoku University, 2. International Research Institute of Disaster Science, Tohoku University

Determining the fault parameters of an earthquake is fundamental for studying the earthquake physics, understanding the seismotectonics of the region, and forecasting future earthquake activities in the surrounding area. Dense crustal deformation data such as InSAR are useful for fault parameter determination, but determining the dipping direction of a blind fault is often challenging. The 5 April 2017, Mw 6.1 earthquake occurred near the city of Sefid Sang, northeast of Iran, provides an excellent case for exploring the potential of Interferometric Synthetic Aperture Radar (InSAR) data for determining the dipping direction of a blind reverse fault. Using Advanced Land Observing Satellite-2 (ALOS-2) and Sentinel-1A interferograms of four different observation directions and a fault slip inversion method that allows thorough exploration of the fault geometry led to two candidates of reverse fault models, dipping either to the northeast or the south. The results show that the fault models of both dipping directions explain the data well, with a slight advantage in the northeast-dipping fault model in terms of the misfit when the atmospheric corrections were applied. The northeast-dipping fault model was, in addition, more consistent with the strike of the mapped active faults in the region and with the aftershock distribution, from which we infer that the 2017 Sefid Sang earthquake occurred on a northeast-dipping dextral reverse fault. The preferred fault model has a strike angle of 314.6˚, dip angle of 43.9˚ and rake angle of 128.3˚, and a slip distribution of maximum 1.11 m at depth of 5 km equivalent to Mw 6.0.
This study illuminates the difficulty of determining the dipping direction of blind faults even with InSAR measurements from multiple directions, but also that correcting for the atmospheric noise and comparing with other kinds of data can help infer the fault dipping direction.

Keywords: Northeastern Iran, Sefid Sang earthquake, InSAR, Coseismic crustal deformation, blind fault

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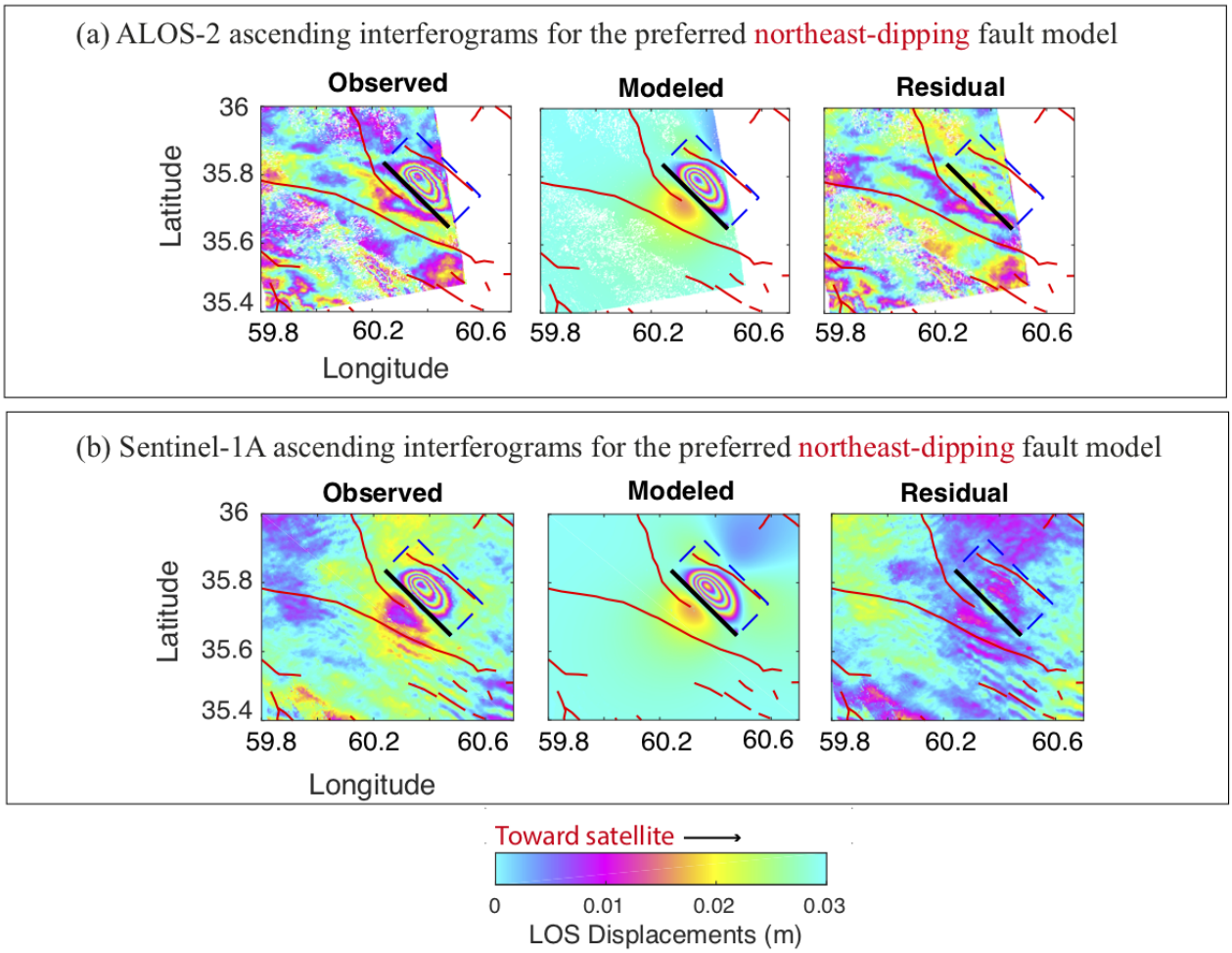

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DefVolc: Interface and web service for fast computation of volcano displacement

*Valerie Cayol[1], Farshid Dabaghi[2], Yo Fukushima[3], Marine Tridon[1], Delphine Smittarello[4], Olivier Bodart[2], Jean-Luc Froger[1]

1. CNRS, UCA, LMV, OPGC, IRD, Clermont-Ferrand, France, 2. UdL, ICJ, Saint-Etienne, France, 3. IRIDeS, TU, Tohoku, Japan, 4. UGA, USMB, CNRS, IRD,IFSTTAR, ISTerre, Grenoble, France

DefVolc is a suite of programs and a web service intended to help the rapid interpretation of InSAR data, acquired on volcanoes at an increased frequency thanks to the various dedicated satellites. Our objective is to help to rapidely inverse volcano displacements, whether these displacements result from fractures (sheet intrusions or faults) or massive magma reservoirs. These sources may have complex geometries, and they may deform simultaneously. Moreover, volcanoes are associated with prominent topographies. This makes the analysis of surface displacements complex. To appropriately analyse the InSAR displacements, we conduct inverse modelling, using 3D elastostatic boundary element models and a neighbourhood optimization algorithm . We simultaneously invert non-linear model parameters (source geometry and location) and linear model parameters (source stress changes), and further assess mean model parameters and confidence intervals. In order to speed up the setting up of inversions, we developed a users friendly graphical interface. In order to accelerate the inversions, they run on clusters. A web server is proposed to registered users in order to run the inversions on University Clermont Auvergne clusters.

Keywords: Modelling, Inversion, web-service

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[E] Oral | S (Solid Earth Sciences)：S-TT Technology & Techniques

[S-TT50] Synthetic Aperture Radar and its application

convener:Yohei Kinoshita(University of Tsukuba), Yu Morishita(Geospatial Information Authority of Japan), Shoko Kobayashi(Tamagawa University), Takahiro Abe(Earth Observation Research Center, Japan Aerospace Exploration Agency)

ALOS-2 and Sentinel-1, which have highly enhanced capacity compared to previous SAR satellites, were launched in 2014, and their utilization has been widely expanding as data have accumulated for approximately five years. Other long-operating SAR satellites like TerraSAR-X and Cosmo-SkyMed also contribute to expanding the SAR utilization. Now we are facing a new and abundant era of the satellite SAR, along with a worldwide trend to an open and free data policy of satellite data, under the situation of next-generation advanced and/or constellated SAR satellite plans by both public agencies (e.g. ALOS-4 and NISAR) and private sectors. In addition, SAR technologies with other platforms, such as ground-based SAR with high temporal resolution and UAV (Unmanned Aerial Vehicle) SAR with flexible operability, have also been developed and used for various targets. These facts indicate that the SAR utilization has become widespread in both basic researches (e.g., earth science) and diverse applications (e.g., disaster prevention and forest monitoring). In this session, we would like to invite various kinds of research and application results with regard to SAR, sharing our knowledge and having a discussion for the advancement of the SAR utilization.

[STT50-05] Ups and downs in the Osaka metropolitan area, Japan, detected by LiCSBAS InSAR time-series analysis

*Yo Fukushima[1] (1.International Research Institute of Disaster Science, Tohoku University)

[STT50-06] Time-series surface displacements in Taiwan using Sentinel-1 wide-swath SAR data

*Shoki Hiranaka[1], Kazuya Ishitsuka[1], Weiren Lin[1] (1.Kyoto University)

[STT50-07] Deep learning InSAR: atmospheric noise removal and small deformation signal extraction from InSAR time series using a convolutional autoencoder

*Bertrand Rouet-Leduc[1], Manon Dalaison[2], Claudia Hulbert[2], Paul Johnson[1], Romain Jolivet[2] (1.Los Alamos National Laboratory, USA, 2.Ecole Normale Superieure, France)

[STT50-08] Mitigation of ionospheric noise in azimuth pixel offset based on the split-spectrum method

*Tatsuya Yamashita[1], Tomokazu Kobayashi[1], Yu Morishita[1] (1.GSI of Japan)

[STT50-09] Detection of huge deformation by SAR interferometry with split-spectrum method

*Taku Ozawa[1], Yuji Himematsu[1] (1.National Research Institute for Earth Science and Disaster Resilience)

Discussion

Ups and downs in the Osaka metropolitan area, Japan, detected by LiCSBAS InSAR time-series analysis

*Yo Fukushima[1]

1. International Research Institute of Disaster Science, Tohoku University

Osaka metropolitan area, composed of cities of Osaka, Kyoto, Nara and the suburbs, is the second largest metropolitan area in Japan. There are approximately twelve million habitants living mainly on flat areas of the Osaka plain, and Kyoto and Nara basins. Some parts of the flat areas are characterized by a dense network of rivers and associated alluvial plains. Recently, Morishita et al. (2020, Remote Sensing) developed LiCSBAS, an open source InSAR time-series analysis package integrated with an automated Sentinel-1 InSAR processor called LiCSAR. The analysis package is surprisingly easy to use, one can run the processing and get the results even without any knowledge about InSAR. As of February 2020, relatively large number of interferograms have been computed and are made open to the public through their portal website (https://comet.nerc.ac.uk/comet-lics-portal/). In this study, I made a preliminary analysis on the Osaka metropolitan area using LiCSBAS processor, with a main purpose to evaluate the usefulness of LiCSBAS.

I processed 369 interferograms having formed from 128 Sentinel-1 SAR descending data (Frame ID: 017D_05514_131312, mean incidence angle 38.6 degrees looking from ESE) acquired between 23 November 2014 and 8 January 2020. The coherence was generally good in the urban areas, whereas the forest areas were automatically masked by the processor based on multiple criteria including coherence. The average LOS (line-of-sight) velocity in the area of interest (135/136/34.5/35.1) showed that the velocity fluctuation was within 10 mm/year (peak to trough) on most of the parts (Figure a). There are fluctuations of ups and downs (precisely, decrease and increase in the LOS displacements in a relative sense) in circular areas of typical diameter of 1-2 km. Since the time-series of displacements of all of these deformed areas exhibit clear secular trend and seasonal variations (Figure b), the signals probably reflect the real deformation. It was found that most of the subsiding areas (blue in the figures) was rice fields in the alluvial plain, possibly indicating the location of marsh areas before habitation (Figure c). Across the Arima-Takatsuki fault zone, a LOS velocity contrast of approximately 1.5 mm/year is observed across the fault (Figure d), but the sense of displacements is opposite to the long-term right-lateral displacements of the fault. Since the fault is located on the edge of a mountain region, there may be significant amount of atmospheric noise causing artifacts.

Acknowledgements: I am grateful to the European Space Agency for making Sentinel-1 data open, and Dr. Yu Morishita and his colleagues in the Centre for Observation and Modelling of Earthquakes, Volcanoes and Tectonics (COMET) who contributed in developing the LiCSAR and LiCSBAS and made the code available online through https://github.com/yumorishita/LiCSBAS.

Keywords: InSAR, Osaka Plain, Crustal Deformation

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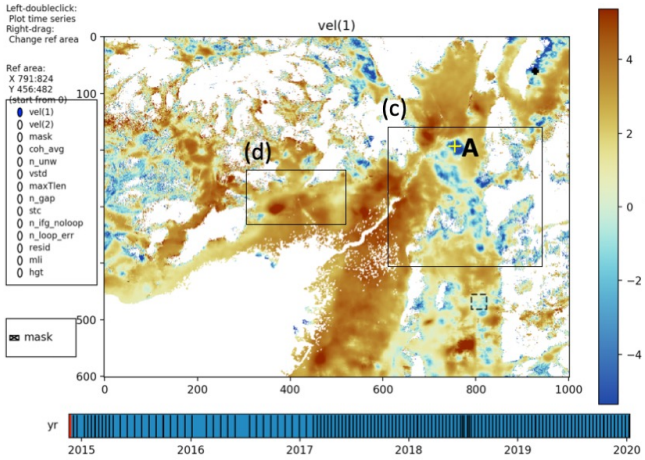
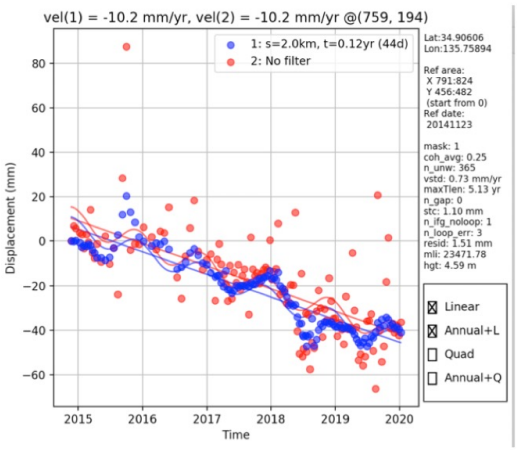
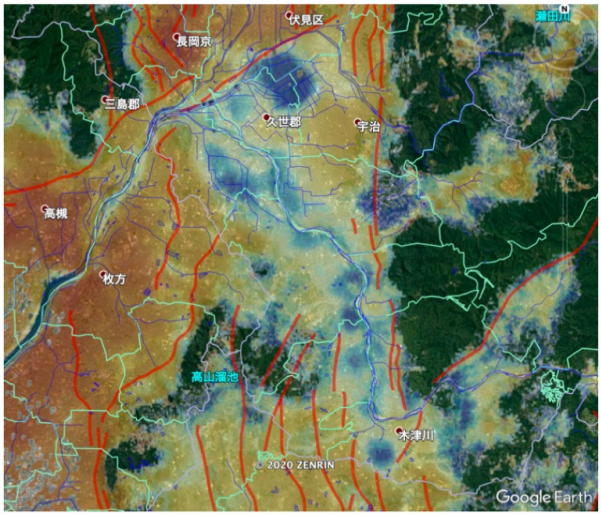
(a) Average LOS velocity (red: toward the satellite)



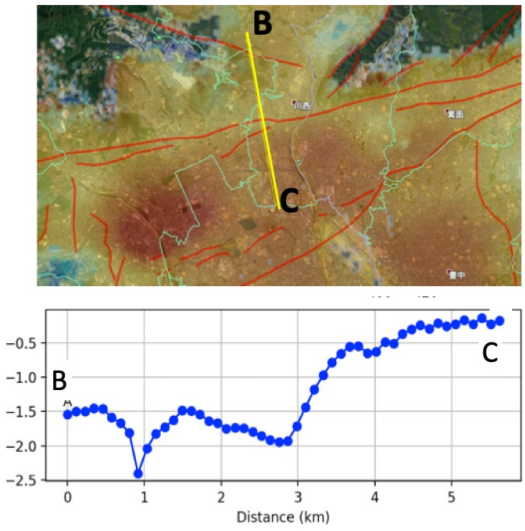
(b) Displacement time-series at point A (ancient lake floor of Ogura-ike)



(c) Zoomed-up figure of (a), superimposed on the Google Earth (red traces: active faults from AIST database)



(d) LOS velocity profile across the Arima-Takatsuki fault



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Time-series surface displacements in Taiwan using Sentinel-1 wide-swath SAR data

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1. Kyoto University

Grasp of surface deformation is important for understanding groundwater activity, exploitation of natural resources and monitoring calculation of the strain. In 2014, the satellite, Sentinel-1, launched by ESA. It has IWS mode which can monitor wide area, about 250 km swath with high resolution. Sentinel-1 is superior to the former satellites so it can grasp surface deformation in more detail.

In my study, I focus on Taiwan island. In Taiwan, the main cause of surface deformation is plate tectonics and massive groundwater pumping. Taiwan is one of the most active tectonic regions in the world and earthquakes frequently occurs like Japan. And recently, groundwater pumping has been a growing concern in western Taiwan. It causes land subsidence due to dropping groundwater level. In my study, I revealed the recent deformation in Taiwan island using SAR data from Sentinel-1 with IWS mode and divided two main cause, plate and groundwater activities. And then, compared with previous researches which used Envisat satellites, I evaluated the effectiveness of my study.

In this study, we process 62 SAR data of ascending orbit from Sentinel-1 between October 2017 and October 2019. We use 115 results from InSAR analysis to generate time series based on the SBAS method. Baseline of all interferograms is less than 200 m. Then, using time series surface deformation, we estimate short-term seasonal deformation and long-term deformation. Specifically, we project time series result like least-squares to sine and linear function.

In the time series result, over 3 cm/year displacement is estimated at one point in the western Taiwan and two in the eastern Taiwan. Seasonal result reveals that seasonal deformation is large in the western but no seasonality is found in the eastern. This means groundwater activity is variable in the western Taiwan. According to Huang et al. (2016), the region faces the anthropogenic groundwater pumping. And in the eastern area, there are no effect of groundwater activity so we think tectonics activity causes deformation.

Because of judgement of validity of these results, we compare some previous research (Huang et al.,2016; Su et al.,2017) using time series analysis. There are same trends of deformation between them and also the same trend with previous research about seasonality (Huang et al., 2016). This means that Sentinel-1 wide-swath SAR data in my research is effectiveness.

Keywords: Sentinel-1, InSAR time-series analysis, Taiwan

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Deep learning InSAR: atmospheric noise removal and small deformation signal extraction from InSAR time series using a convolutional autoencoder

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Spatial and temporal variations of pressure, temperature, and water vapor content in the atmosphere introduce significant errors in interferometric synthetic aperture radar (InSAR) observations of ground deformation. Large amplitude and fast deformations produced during earthquakes are routinely measured using InSAR. However, Interseismic and postseismic deformation -- both smaller and slower -- remains extremely challenging to measure due to atmospheric propagation delays, even after correction for known atmospheric conditions, therefore requiring expert interpretation and *a priori* knowledge of fault systems. To solve this problem, we introduce a deep autoencoder architecture that is tailored to remove atmospheric delays due to turbulences and the layering of the atmoshpere, as well as to identify and extract ground deformation signals of interest. Taking noisy InSAR time series as input and cumulated ground deformation of interest as output, the deep autoencoder we built is purely convolutional, shrinks the time dimension during the encoding, and uses the ground elevation during the decoding. In order to circumvent the lack of training data and the absence of deformation ground truth, we train our model on simulated data in which small synthetic fault deformation signals are heavily corrupted by statistically realistic atmospheric signals. After training on a few million examples of synthetic InSAR time series, application on real InSAR time series reveals very clean and sharp deformation signals on faults known to be deforming, with no *a priori* knowledge of fault systems. The proposed deep autoencoder approach enables the automation of denoising and signal extraction from InSAR time series, making possible the study of small deformations at a global scale.

Keywords: Machine learning, InSAR

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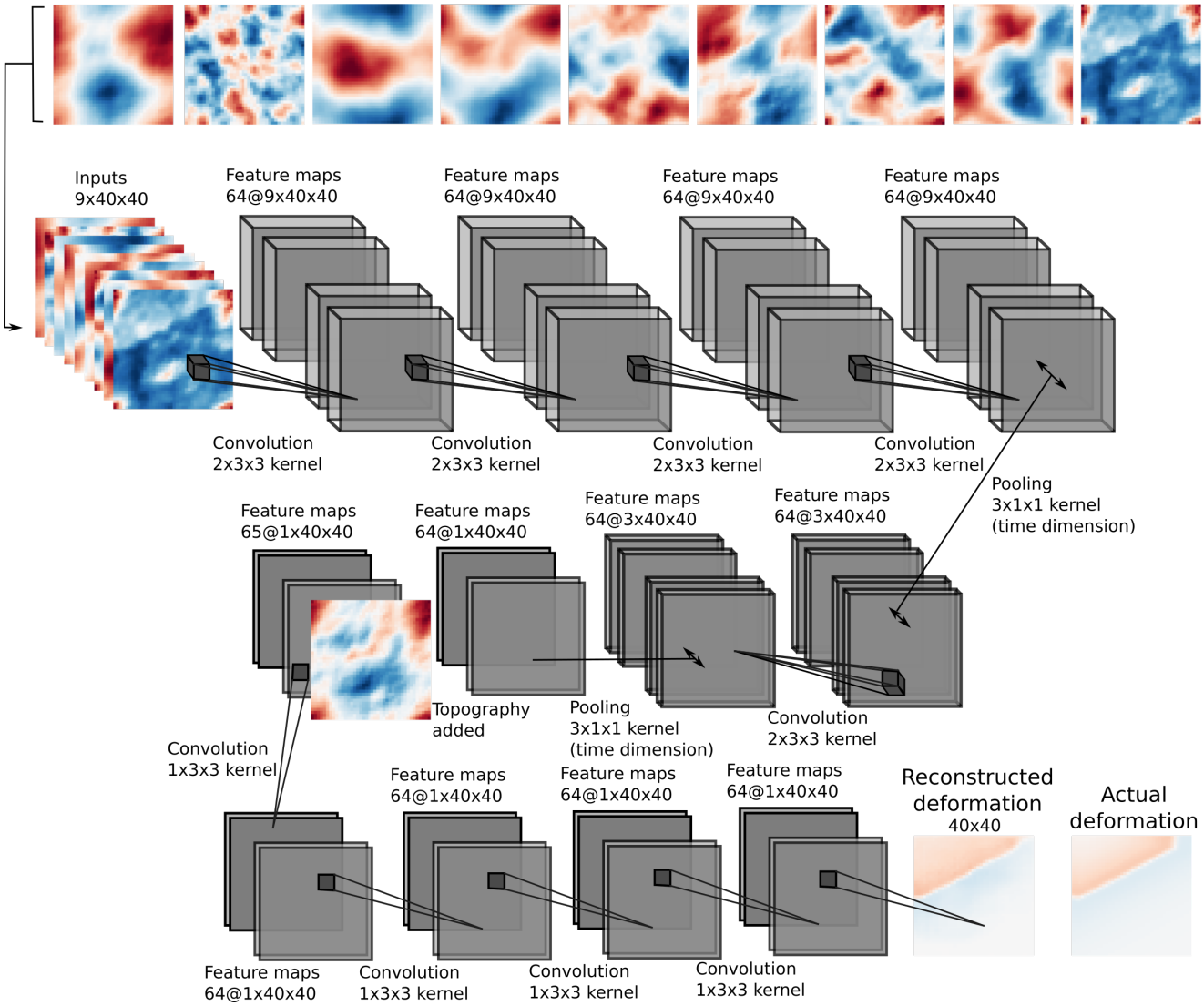

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Mitigation of ionospheric noise in azimuth pixel offset based on the split-spectrum method

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The pixel offset (PO) method has been utilized as a powerful tool to measure large ground movements due to earthquakes and volcanic activities, which is difficult to detect by InSAR. However, data acquired by low-frequency spaceborne SAR such as ALOS-2 are severely affected by ionosphere, which often results in periodic noise patterns called as “azimuth streaks” in the azimuth direction.

Over the past decade, remarkable advances have been made in the theoretical studies on the relation between azimuth pixel offset and ionospheric phase delay, and the split-spectrum method has been developed for ionospheric phase screen in InSAR image. Combining these two theories enables us to separate the ionospheric noise from ground displacements in the azimuth direction and to mitigate the ionospheric noise. Here we propose a new method for mitigation of the azimuth streaks, and show the effects through the application to actual SAR data.

An outline of the implementation for mitigating ionospheric azimuth shift is as follows. First, the ionospheric phase delay is obtained based on the split-spectrum method. Secondly, the approximate quadric surface for the ionospheric phase delay is estimated to be subtracted from the ionospheric phase delay. Subtracting the quadric surface corresponds to the partial elimination of ionospheric azimuth shift after coregistration. In this study, we adopt affine transformation as the coregistration method. Next, the Gaussian filter as the low-pass filter is applied to the residuals between the quadric surface and the ionospheric phase delay. The reason to apply the filter is because high frequency noise can have a negative influence on an evaluation of the azimuth gradient of the ionospheric phase delay later. Here we should be careful that the signal component of the ionospheric phase delay can be smoothed too much to be evaluated properly if the standard deviation (S.D.) of Gaussian filter is larger than the spatial scale of azimuth streaks. Subsequently, the azimuth gradient of the filtered residuals is calculated. Finally, the correction amount is evaluated using the estimated gradient to be subtracted from the azimuth pixel offset.

For the purpose of evaluating the performance of the method for mitigating azimuth streaks, we apply the method to two pairs of ALOS-2/PALSAR-2 stripmap images in Japan area which are severely affected by ionosphere. In the first case, we make Hokkaido region between 2015 and 2016 with little ground movements our target, and in the second case, we focus on the area with large ground movements induced by the 2016 Kumamoto earthquake. In the first case, while the S.D. of the azimuth offset before the correction is 87.2 cm, the value after the correction is 30.2 cm, indicating that the ionospheric azimuth shift can be considerably compensated through the correction. It is noteworthy that the S.D. after the correction is comparable to the theoretical measurement accuracy of azimuth pixel offset (~30 cm).

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Although we also exploit a uniform shift for coregistration, the S.D. after the correction is rather large compared to the value before correcting. In the second case, considering that the image includes significant ground movements, we examine the residuals between the azimuth offset converted from GNSS CORS displacement and the azimuth offset obtained by the PO method, and the S.D. of the residuals. The maximum residuals before and after the correction are 84.5 cm and 44.5 cm, respectively. Moreover, the S.D. of the residuals before and after the correction are 22.7 cm and 14.9 cm, respectively: the deviation gets smaller through the correction. Therefore, although the measurement accuracy after the correction is not better than that of pairs of data that are not affected by ionosphere, the corrected data are expected to be still useful as the supplements for derivation of 3D displacement from pixel offsets and finite rectangular fault models.

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Detection of huge deformation by SAR interferometry with split-spectrum method

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SAR interferometry is used as one of the useful tools to detect surface deformation caused by earthquake, volcanic activity, and so on. However, even though coherence is obtained, it may not be possible to convert to crustal deformation due to difficulties in phase unwrapping, when huge deformation occurs. For example, in the 2016 Kumamoto Earthquake on April 16, 2016 (M_{JMA}7.3), fringes with high coherence were obtained near the fault by SAR interferometry using PALSAR-2 (e.g., Ozawa et al., 2016), but conversion to slant-range change was difficult due to large phase gaps exceeding π radians. In this presentation, we mention a technique for detecting crustal deformation in such regions using the split spectrum method.
Generally, phase difference obtained by SAR interferometry $\Phi_{total}(f)$ is discribed as

$$\Phi_{total}(f) = 4\pi \Delta\rho_{non\text{-}disp} f/c + 4\pi K \Delta TEC/cf + cnst$$

where $\Delta\rho_{non\text{-}disp}$ is non-dispersive slant-range change (e.g., crustal deformation, orbital contribution, atmospheric delay), ΔTEC is valiation of the total electron content along the radar propagation path. The first and the second terms on the right hand side are called the non-dispersive and the dispersive components, respectively. f is radar frequency, c is speed of light, and K, cnst are constants. Dispersive and non-dispersive components can be divided by the split-spectrum method. Its method makes two SLC pairs with high and low frequency applying the band pass filter and divides their components based on the difference in response to the frequency difference in two interferograms made from them (e.g., Rosen et al, 2010; Gomba et al.,2016; Wegmüller et al., 2018). Double difference of two frequency intrefergrams after removing dispersive component is described as

$$\Phi_{diff} = 4\pi \Delta\rho_{non\text{-}disp} (f_{high} - f_{low})/c + cnst.$$

It corresponds to interferometric phase obtained by radar frequency of $f_{high} - f_{low}$. For example, in a case that SM1 mode data of PALSAR-2 (80MHz bandwidth) is used, $f_{high} - f_{low}$ is 40 MHz (the wavelength is 7.5m). In most cases, this interferometric phase is small value within $-\pi$ and $+\pi$ radians, even if a large crustal deformation occurs. Therefore, the phase unwrapping is not necessary.
Applying this method to interferometric pair for the 2016 Kumamoto Earthquake (PALSAR-2, SM1), phase difference exceeding π radian was obtained due to huge crustal deformation. Then, we created three sub-band SAR images from original SAR images, and estimate phase difference between high and low sub-band interferograms, connecting phase differences for high-mid-low sub-band phases.
Comparing slant-range changes obtained from this method and offset-tracking method, they are almost consistent. While the offset-tracking method using a correlation window deteriorates the resolution, this method can obtain the slant range change with the same spatial resolution as the normal SAR interferometry. In this method, noise due to decorrelation is amplified, so its application is limited to data pairs with high coherence. However, if the application condition is good, there is a possibility that the crustal deformation distribution can be obtained with high accuracy even when large crustal deformation has occurred.

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Keywords: InSAR, split-spectrum method, crustal deformation

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[E] Oral | S (Solid Earth Sciences)：S-TT Technology & Techniques

[S-TT51] seismic monitoring and processing system

convener:Takahiro Maeda(National Research Institute for Earth Science and Disaster Resilience)

This session covers scientific and technical issues in seismic monitoring or data processing systems for earthquakes or explosions observation. This includes development or improvement of seismic observation networks, innovative techniques in observation and monitoring, cutting-edge data acquisition and processing techniques in geophysical explorations. Other topics related to geophysical observation are also welcome.

[STT51-01] Automatic identification of airgun signals observed by ocean bottom seismic network

*Koji Tamaribuchi[1] (1.Meteorological Research Institute)

[STT51-02] Processing the Deep-towed Autonomous Continous System (ACS) Data in Joetsu Basin, Niigata Prefecture, Japan

*Fernando Lawrens Hutapea[1,2,3], Takeshi Tsuji[1,2,4], Eiichi Asakawa[5], Masafumi Kato[6] (1.Department Earth Resources Engineering, Kyushu University, Japan, 2.International Institute for Carbon-Neutral Energy Research (WPI-I2CNER), Kyushu University, Japan, 3.Exploration and Engineering Seismology Research Group, Institute Technology of Bandung (ITB), Indonesia, 4.Disaster Prevention Research Institute, Kyoto University, Japan, 5.JGI, Inc. Japan, 6.Japan Oil Gas and Metals National Corporation (JOGMEC), Japan)

[STT51-03] Performance evaluation of seismic observation system using phase-shifted optical interferometry

*Yoshiharu Hirayama[1], Minemori Sato[1], Atsushi Takahara[1], Toshiharu Ikeda[1], Keiji Takeuchi[1], Taiichi Taniguchi[1], Yoshihiro Sawada[2] (1.Hakusan Corporation, 2.Association for the Development of Earthquake Prediction)

[STT51-04] Extracting Noise-Correlation Functions from Analogue Seismograms

Thomas Lee[1], *Miaki Ishii[1], Paul Okubo (1.Department of Earth & Planetary Sciences, Harvard University)

[STT51-05] Crustal Thickness Behind the Tonga Arc Measured by Stacking of pP Precursors

*Lauren McLeod[1], Larry D Brown[1] (1.Cornell Univ.)

[STT51-06] Investigation on the traceable calibration of sensors for monitoring the seismic activities based on the international metrology system

*Wan-Ho Cho[1], Yong-Bong Lee[1], Sung-Soo Jung[1], Byeng-Su Jeon[1] (1.Korea Research Institute of Standards and Science)

Automatic identification of airgun signals observed by ocean bottom seismic network

*Koji Tamaribuchi[1]

1. Meteorological Research Institute

In recent years, dense and high-sensitivity ocean bottom seismic (OBS) networks (S-net, DONET) have been deployed along the Japan Trench and the Nankai Trough. Effective use of these data is extremely important not only for research but also for disaster prevention, as it contributes to improving the accuracy and timeliness of Earthquake Early Warning in the offshore area, and understanding detailed seismicity. On the other hand, many signals different from those observed at inland stations are also detected by the OBS network, such as airgun signals used for seismic surveys. About 200 airgun shots were detected in an hour by using the PF method (Tamaribuchi et al., 2016; Tamaribuchi, 2018, EPS), which is an automatic hypocenter determination process for the JMA unified earthquake catalog. Therefore, it is important to properly exclude these airgun signals to improve the accuracy of the automatic process of the earthquake catalog.

Pulse-like signals of relatively high frequency are observed near the source. However, it is difficult to discriminate between natural earthquakes and airgun signals, since distinct features are not seen at a distance from the source. Airgun signals are generated at equal intervals of about 10–30 seconds, and those amplitudes and shapes are similar. In this study, we report an attempt to discriminate between natural earthquakes and airguns by using the autocorrelation by taking into account the similarity of the amplitudes and shapes of the airgun signals.

In the case of the M7.4 off Fukushima Prefecture earthquake, which occurred on November 22, 2016, an airgun survey was performed in the south of the aftershock area, off Ibaraki Prefecture on the same day. We applied the automatic classification method by autocorrelation to this seismic waveform. As a result, the number of aftershocks was reduced by only 2%, whereas the event detection by airgun was reduced by 91%. Furthermore, we applied this method to cases along the Nankai trough, and its effectiveness was also confirmed.

The waveform data are available from the Data Management Center of NIED (https://doi.org/10.17598/NIED.0009).

Keywords: Automatic hypocenter determination, Airgun survey, OBS

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Processing the Deep-towed Autonomous Continous System (ACS) Data in Joetsu Basin, Niigata Prefecture, Japan

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The deep-towed Autonomous Continuous System (ACS) is a marine seismic reflection data acquisition method developed by JGI, Inc. The ACS utilizes high frequency seismic source (ranging from 700 Hz to 2300 Hz) and multi-channel receivers that both source and receivers can be located close the seafloor. High frequency seismic reflection acquisition is suitable to obtain high-resolution image of shallow geological structures, and this seismic result is commonly used for analyzing submarine geo-hazard potentials, analyzing marine or hydrothermal systems, finding shallow gas reservoirs, and mineral deposits. Since ACS data acquisition can be operated near the seafloor (maximum depth is 2 km from sea-level), the ocean’ s (strong) current makes the position of both receivers and sources irregular (un-stable) and it is hard to measure the absolute depth of both receivers and sources. During data acquisition, the un-stable depth of both sources and receivers not only make the recorded seismic reflection curve (hyperbolic curve) rugged, but also makes the velocity analysis process more difficult because the velocity semblance is not clear. In this research, we processed the ACS seismic data located in Joetsu Basin, Niigata Prefecture, Japan. The Joetsu Basin is known as an area that has gas hydrate potential. Furthermore, we did not only process ACS data using a conventional seismic reflection method, but we also proposed a method to recover the rugged hyperbolic curve, so the velocity semblance became clearer and made the velocity analysis easier. Finally, we delivered the seismic stack section that may indicate the location of gas hydrate in our seismic line.

Keywords: deep-towed seismic acquisition, high resolution exploration, marine seismic reflection, shallow exploration

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Performance evaluation of seismic observation system using phase-shifted optical interferometry

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Introduction
In order to evaluate the performance of a seismic observation system using phase-shifted optical interferometry (the following, optical sensor system), we observed using this system continuously for about one month in the Tono Yamazaki Observation Tunnel of Tohoku University.

Principle of the optical interferometry
This optical sensor system uses a method to observe the displacement of a spring-mass-damper-system sensor by interferometry. Specifically, an optical pulse whose part is shifted by $\pi / 2$ is branched, one is reflected by the reference surface, and the other is reflected by the vibration surface of the pendulum, and one is appropriately delayed to cause interference. This measures the displacement of the vibrating surface (Fig. 1). The pendulum vibrates in response to ground motion input and the amplitude detected in the lower frequency domain than the natural frequency of the pendulum is proportional to the acceleration of the ground motion, so it becomes an accelerometer (ref. 1, 2).

Observation
The Yamazaki Station is a granite tunnel, and one of the group seismic observation networks around the Tono seismological observatory. This station is shared by Tono Yamazaki (code TYS, latitude 39.3772N, longitude 141.5932E, altitude 346m) in F-net of NIED. The optical sensor system was installed at the Tono Yamazaki Station on December 17, 2019, and observed continuously until January 16, 2020. The Tono Yamazaki Station is a straight tunnel with a total length of about 50m. There is an observation room immediately after the entrance, three doors on the way, and a sensor room at the back. The optical transmitter / receiver was installed in the observation room, and three sets of three-component optical sensors were installed in the sensor room. The optical cable connecting the optical transmitter / receiver and optical sensors was passed through a gutter. The natural frequency of the sensor is 2 sets at 24 Hz and 1 set at 100 Hz. For comparison, JU410 micrometermeter made by Hakusan Corporation equipped with a servo accelerometer (JA-40GA, made by Japan Aviation Electronics) was installed in the sensor room from December 17 to 19, 2019. In addition, the data of STS-2 of NIED F-net in the sensor room was also compared with our record.

Result
1) Comparison with the servo accelerometer
The noise spectra of optical sensor and JU410 were obtained using the data during quiet nights when no earthquake occurred. Each sampling frequency is 100 Hz. The optical sensor system is bandpass filtered from 0.1Hz to 30Hz. The gain setting of the JU410 is ×5, the maximum measurement range is ±2G, and a minimum phase filter with a cutoff of 40% is applied. Fig. 2 is a graph of the PSD of JU410 and the optical sensor with a natural frequency of 24 Hz, using a 30-minute recording from 1:00 am to 1:30 am on December 18, 2019. It can be seen that the noise level of the optical sensor is lower than that of the servo accelerometer.
2) Comparison with STS-2

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Fig. 3 is a graph of a PSD using data of about 30 minutes from 0:30 am to 1:00 am on January 16, 2020. The record of STS-2 is differentiated and converted to acceleration. From Fig. 3, it can be seen that the noise level of the optical sensor system almost coincides with the noise level of STS-2 in the range of about 0.13 Hz to about 20 Hz. That is, in this frequency band, it is determined that the optical sensor system detects ground motion noise of Tono Yamazaki Station.

Future tasks

Since the optical sensor has no electronic components in the detector, it can be operated in a high-temperature environment, and short-term high-temperature tests have confirmed that it can operate normally up to about 200 ˚C. It is necessary to confirm the durability of performance in the future.

Acknowledgments

From Research Center for Prediction of Earthquakes and Volcanic Eruptions, Graduate School of Science, Tohoku University has been granted permission to use the Tono Yamazaki Station. Mr. Kono of Tono Seismological Observatory, Tohoku University provided great support at the site. The F-net data of the Tono Yamazaki Station was downloaded from the NIED Hi-net website and used.

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2) Tsutsui et al., J. Disaster Res., vol.14 (2019) pp. 592-603.

Keywords: Phase-shifted optical interferometry, Noise observation, PSD

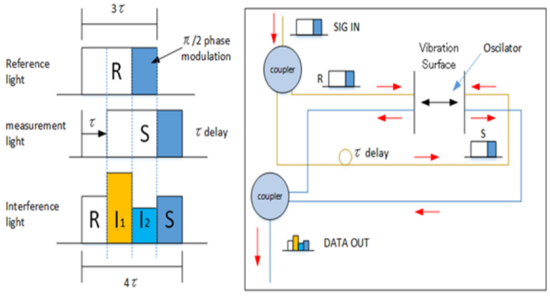

Fig. 1: Schematic diagrams of reference light, measurement light, and interference light, and basic configuration of the system.

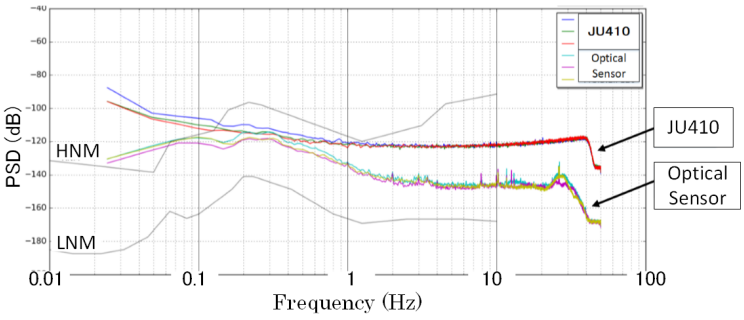

Fig. 2: Comparison of PSD between JU410 (gain x 5) and optical sensor with natural frequency 24Hz.

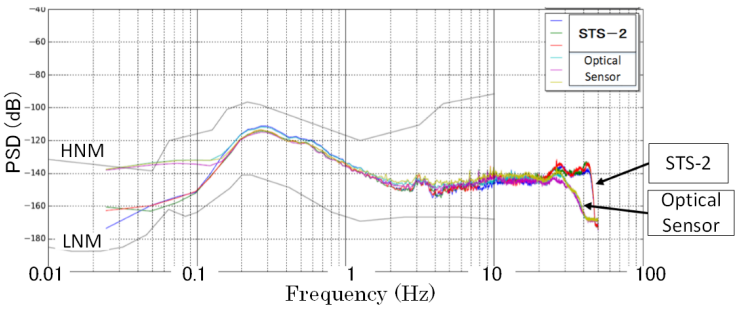

Fig. 3: Comparison of PSD between STS-2 and optical sensor with natural frequency of 24Hz.

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Extracting Noise-Correlation Functions from Analogue Seismograms

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Ambient noise correlation functions have been shown to be a powerful tool for investigating subsurface processes through subtle changes in seismic wave speeds with time. In order to capture slowly-varying effects, it is critical to extend the observation duration as long as possible. While waiting to accumulate more digital recordings over years to come, it is possible to begin to utilize seismograms recorded during the pre-digital era. Analogue seismographs have been recording ground motion for more than 100 years, and in many cases, daily continuous seismogram records exist over multiple decades. Even though an unknown fraction has been discarded, many of the seismogram collections are still intact and available. Correlation of the background noise recorded by these analogue seismograms expands the time window over which the subsurface evolution can be examined.

There are, however, difficulties associated with analogue recordings, with one of the obvious challenges being extracting digital time series from analogue seismogram images. If digital time series are available, then the biggest issue facing the calculation of the ambient noise correlation function is the relative time uncertainty. The analogue data are recorded during a time predating GPS clocks and, often, the time has been kept by separate mechanical clocks at each station. These clocks are calibrated to some central time at regular or irregular intervals. The implication is that, at any given time, seismogram timing at two stations may not be synched. Additional uncertainties in relative time between two stations can be introduced when recording media are changed, typically from one day to the next, making stacking of noise correlation functions over multiple days impractical.

We overcome these difficulties by estimating relative time corrections between two stations using the symmetry property of noise correlation functions. We demonstrate this by analyzing digitized time series from multiple analogue seismograms recorded at two stations in Hawai`i in 1988. Time corrections on the order of seconds are obtained, which are compatible with those estimated using teleseismic arrivals and modern recordings of corresponding arrivals. The magnitudes and signs of the time corrections change considerably between sets of recordings from consecutive days, suggesting that change of media may be a significant source of uncertainty. The relative time corrections enable stacking of noise correlation functions over multiple days to enhance coherent signals, and the resulting function is comparable to noise correlation functions calculated using data from 2018 recorded at the contemporary equivalent stations.

Keywords: analogue seismograms, noise correlation function, relative time correction

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Crustal Thickness Behind the Tonga Arc Measured by Stacking of pP Precursors

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1. Cornell Univ.

Precursors to the depth phase *pP* have been shown in some areas to be underside reflections from internal discontinuities within the lithosphere, particularly the Moho. If these precursors are recorded by dense arrays of seismometers, the signal processing techniques developed for reflection surveys using controlled sources at the surface can be applied to create an “upside-down” seismic reflection profile. Previous studies using this technique were primarily carried out with broadband seismometers. Here we use short period recordings from Japan’s Hi-net array for intermediate- and deep-focus earthquakes in the Tonga-Kermadec subduction zone to measure crustal thickness within the Lau and South Fiji Basins and along the Lau Ridge. Because many Hi-net stations are located at the same sites as broadband stations in Japan’s F-net, we are able to directly compare the ability of short-period and broadband seismometers to detect and resolve underside reflections. Our measurements sample areas that have been inaccessible to traditional surface seismic measurements. We have used modeling to address complications of bathymetric variability at the bounce points and receiver side heterogeneity. We have found the crust to vary in thickness from about 7 km to 20 km. Our measurements agree with existing measurements of crustal thickness from surface seismic refraction surveys where they overlap.

Keywords: seismic reflection, pP precursors, subduction zones, Tonga

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Investigation on the traceable calibration of sensors for monitoring the seismic activities based on the international metrology system

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1. Korea Research Institute of Standards and Science

Sensors to monitor the seismic activity, such as broadband seismic sensors and infrasound sensors based on the micro-barometer are the special types of vibration and acoustic sensor having high sensitivity and covering extremely low frequency. Traditionally, the calibration of such instruments has been separately operated from the international metrology system and the method of calibration is not traceable from the International System of Units (SI). Recently, Comprehensive Nuclear Test Ban Treaty Organization (CTVTO) has mentioned about the necessity of connection of the seismic measurement area to international metrology system. This is because the reliability assurance become more important due to the increase of seismic activities and extension of the international monitoring system (IMS) operated by various independent institutes and countries. Lately, the ISO standard for calibrating the seismic sensor has been published [ISO 16063-42; ISO 16063-43; ISO 16063-45], however these methods are limited to the comparison and in-situ method therefore the reference based on the absolute calibration having the traceability to SI unit is essential.

In this study, the potential primary calibration methods for the seismic sensor and infrasound sensor are investigated with the consideration of traceability to the international metrology system. For the seismic sensor, it is a special type of vibration sensor with high sensitivity for low frequency therefore the primary calibration method for vibration measurement can be applied for the calibration of seismic sensors. Here, the method based on the interferometer [ISO 16063-11] was applied to calibrate the sensitivity of broadband seismic sensors, Streckeisen STS-2 and STS-2.5. The homodyne laser interferometer with quadrature output was applied and displacement as a function of time was estimated by the sine approximation method. To excite the system down to 0.1 Hz, the long-stroke excitation system (SPEKTRA APS-600) was employed. With this system, the absolute sensitivity calibration of seismometer was conducted for 0.1 Hz –20 Hz range.

The standard of sound-in-air measurement is based on the laboratory standard (LS) microphone [IEC 61094-1] and the primary method for calibration is based on the reciprocity method [IEC 61064-2]. This approach is quite reliable and precise however only applicable to LS microphone. Therefore, the calibration of infrasound sensor can be done by comparison with the LS microphone. However, this approach has several limitations especially for non-audible frequency range, such as low signal-to-noise ratio. The method called laser pistonphone which measure the volume change directly by using the laser interferometer, similar to the vibration was propose as a potential method to overcome this problem. Here, the primary calibration method based on the reciprocity and the laser pistonphone were applied to the calibration of infrasound region down to 2 Hz and the feasibility of these method was investigated. Also, the calibration of infrasound sensor was conducted by the comparison method with the calibrated LS microphone.

As a result, the primary calibration methods for monitoring the seismic activity are investigated and the traceability chain is proposed for these types of sensors.

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Keywords: Calibration, traceability, seismic sensor, infrasound sensor

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[E] Oral | S (Solid Earth Sciences)：S-TT Technology & Techniques

[S-TT52] Seismic Big Data Analysis Based on the State-of-the-Art of Bayesian Statistics

convener:Hiromichi Nagao(Earthquake Research Institute, The University of Tokyo), Aitaro Kato(Earthquake Research Institute, the University of Tokyo), Keisuke Yano(The University of Tokyo, Graduate School of Information Science and Technology), Takahiro Shiina(Earthquake Research Institute, The University of Tokyo)

Recently, a big seismic database has been being constructed that collects data of vibrators implemented in such as buildings, lifelines and smartphones, in addition to seismic data of the conventional continuous/temporal dense seismic observation arrays. Development of methodologies and algorithms, which are inadequate at this moment, optimized to comprehensively analyze the seismic big data is essential in order to utilize the big database as much as possible for prevention/mitigation of earthquake disasters and clarification of earthquake phenomena. On the other hand, recent progress of Bayesian statistics is significant, which is the mathematical basis of various methodologies, such as machine learning, especially deep learning, to extract valuable information from big data. The state-of-the-art of Bayesian statistics is expected to substantially advance seismic big data analyses.
This session mainly accepts presentations that focus on analyses of seismic big data, especially related to analysis methods based on Bayesian statistics such as machine learning, sparse modeling and data assimilation, and their applications to real seismic data. Presentations related to mathematical or statistical theories beneficial to data analyses, feasibility studies of algorithms eventually applicable to real seismic data, and the current status of seismic observations and analysis results are also highly welcome.

[STT52-01] Multiple classes of non-tectonic emergent and impulsive seismic noise identified in continuous waveforms

★Invited Papers

*Christopher W Johnson[1,2], Yehuda Ben-Zion[3] (1.Scripps Institution of Oceanography, 2.Los Alamos National Lab, 3.University of Southern California)

[STT52-02] Uncertainty Quantification for Inhomogeneous Frictional Features in a Slow-Slipping Fault Based on a Large-Scale Four-Dimensional Variational Data Assimilation

*Shin-ichi Ito[1], Masayuki Kano[2], Hiromichi Nagao[1] (1.The University of Tokyo, 2.Tohoku University)

[STT52-03] A hidden Markov model for overlapping of seismic waves

*Sumito Kurata[1], Keisuke Yano[1], Fumiyasu Komaki[1] (1.Graduate School of Information Science and Technology, The University of Tokyo)

[STT52-04] Prediction of Aftershocks With Gaussian Process Regression: Application to the 2004 Chuetsu Earthquake

*Kosuke Morikawa[1], Hiromichi Nagao[2], Shin-ichi Ito[2], Yoshikazu Terada[1,3], Shin'ichi Sakai[2], Naoshi Hirata[2] (1.Osaka University, 2.The University of Tokyo, 3.RIKEN AIP)

[STT52-05] On statistical declustering of global earthquake catalogue

★Invited Papers

*Debashis Mondal[1], Suhas Sastry[1] (1.Oregon State University)

Multiple classes of non-tectonic emergent and impulsive seismic noise identified in continuous waveforms

*Christopher W Johnson[1,2], Yehuda Ben-Zion[3]

1. Scripps Institution of Oceanography, 2. Los Alamos National Lab, 3. University of Southern California

The proper classification of emergent and impulsive seismic noise is critical for detection of microearthquakes and developing a complete understanding of ongoing weak ground motions. Tectonic events occupy a small percentage of each day and seismic records contain numerous natural and anthropogenic signals. Recent studies have demonstrated that ongoing low-amplitude ground motion is dominated by various weak sources originating at the surface from anthropogenic and atmospheric interaction. Characterizing new classes of waveforms originating from wind generated ground motions, air-traffic, automobiles, and other non-tectonic signals can provide insightful information when designing a machine learning training data set. In 2014 a dense array (0.36 km^2) of 1,100 vertical geophones recorded ground motions on the San Jacinto fault for 30 days. The data provides detailed waveforms to detect microearthquakes and observe surface and atmospheric processes that manifest as impulsive and emergent signals. We apply a new methodology to label continuous records as random noise or non-tectonic signals, and develop a novel training data set with varying types of emergent and impulsive noise. Unsupervised learning is applied using engineered and autoencoder extracted data features from the non-tectonic signals to subdivide the waveforms into multiple classes of non-tectonic noise. Random noise and multiple classes of non-random noise waveforms are used to train a convolutional neural network that labels the continuous records for the entire array. The results identify tectonic events and different classes of non-tectonic waveforms as coherent signals in the array, with some originating at the surface within the study area. This effort to identify waveforms as new classes of non-tectonic signals provides insight to deformation in the shallow subsurface and surface generated ground motions that can potentially obscure microseismic events.

Keywords: noise classification, machine learning, seismic waveforms

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Uncertainty Quantification for Inhomogeneous Frictional Features in a Slow-Slipping Fault Based on a Large-Scale Four-Dimensional Variational Data Assimilation

*Shin-ichi Ito[1], Masayuki Kano[2], Hiromichi Nagao[1]

1. The University of Tokyo, 2. Tohoku University

Dynamics of slipping motion of a fault largely depends on spatial inhomogeneous frictional features on the fault. Thus, it is essential to estimate the spatial frictional features from the observations of the slipping motion and to identify essential parts of frictional features that contribute to the main motion of the slipping by quantifying uncertainties involved in the estimated frictional features.
Data assimilation (DA) is a Bayesian-based numerical technique that, from limited observational data, enables us to estimate unobservable quantities together with their uncertainties by evaluating a posterior probability density function (PDF). However, “curse of dimensionality” makes the evaluation impossible easily when applying conventional DAs to large-scale simulation models used in the solid Earth science. To avoid this problem, we proposed a variational DA method that enables us to obtain estimates together with their uncertainties within a practical computational time and resources. Our method, in which a second-order adjoint method is implemented, does not depend on the number of degrees of freedom (NDF) involved in a given simulation model to obtain uncertainties, whereas the conventional DAs needs computational cost proportional to an exponential order of NDF.
This study applies our new DA method to a fault model that mimics slow-slipping region along the Bungo Channel. The fault model employs a rate-and-state dependent friction law, in which the frictional parameters are spatially dependent. Due to this feature, NDF of this fault model is so large that the conventional DAs cannot be applied. Through applying our DA method to the fault model using synthetic data of slip velocity on the fault, we investigate the estimates of frictional features and their uncertainties, and subsequently, we quantify the relation between the slow-slipping motion and the uncertainties of frictional features.

Keywords: Uncertainty quantification, Frictional feature

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A hidden Markov model for overlapping of seismic waves

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Hidden Markov models (HMM) have been used for finite-state mixture data and has a variety of applications. HMM consists of an unobserved state process and an observed process. A hidden state process is characterized by a transition probability matrix representing the probabilities of the change from one state to another state at a time point. This process is not observed so needs to be estimated. This talk focuses on the use of HMM in the analysis of the running spectra. Running spectrum (spectrogram) is the time series representing the change of spectrum of frequencies. By fitting HMM to running spectra, we separate the time series into a couple of states, and each state has different feature about frequency. As a result, we obtain the estimated parameters of frequency characteristic at each state, say, "wave A is mostly made from the 3 Hz component" or "wave B consists of high frequency components." However, a naive application of classical HMM often leads to some modeling bias because observed data are usually a "mixture" of important signals and noises. In the seismology, an earthquake arrives time and time again such as body waves, reflected waves, and converted waves. An earthquake swarm contains multiple seismic phenomena that have different features.
To avoid such modeling bias of classical HMM, we propose a method that can accommodate the "overlapping" of states. Our approach builds upon a state space model which is an extension of classical HMMs. Moreover, it can remove an assumption that "there is only one state at each time point." To this end, we introduce a latent variable that indicates "dominating rate" of each state. Our method provides three kinds of estimates simultaneously: parameter estimates for observed process, the transition probabilities of hidden states, and the dominance rate of each hidden state. Additionally, we examine the performance of our method by using both synthetic and real seismic data.

Keywords: Seismology, Statistics, Hidden Markov model, State space model

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Prediction of Aftershocks With Gaussian Process Regression: Application to the 2004 Chuetsu Earthquake

*Kosuke Morikawa[1], Hiromichi Nagao[2], Shin-ichi Ito[2], Yoshikazu Terada[1,3], Shin'ichi Sakai[2], Naoshi Hirata[2]

1. Osaka University, 2. The University of Tokyo, 3. RIKEN AIP

The main shock of a large earthquake often makes it difficult to identify a number of subsequent aftershocks. Knowing the distribution of magnitudes and arrival times of the aftershocks is essential to figure out the characteristics of the sequence of earthquakes, which enables us to predict the frequency of earthquakes depending on space and time. Such the distribution of aftershocks should be estimated within a couple of days eventually since most of the large aftershocks occur within one day from the main shock. However, an exact count of all aftershocks right after a main shock is very hard due to large signal-to-noise ratio, so that an estimated distribution of the aftershocks is usually biased.

To overcome the difficulty, we incorporate a detection function into the likelihood, and apply the gaussian process regression, which is a Bayesian and nonparametric method, to the detection function. The gaussian process regression has been drawing an attention due to the largeness of the functional class that can represent, in fact, it has recently been known that it has some relations with deep learning. With the use of gaussian process regression, not only the parameter of the distribution of the aftershocks and the detection function, but the credible interval of the parameters and the detection function can be also obtained. We have also proposed a Bayesian computational algorithm to compute the hyperparameters. Our proposed method is applied to the 2004 Chuetsu earthquake.

Keywords: Bayesian method, detection-rate function, gaussian process regression

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On statistical declustering of global earthquake catalogue

*Debashis Mondal[1], Suhas Sastry[1]

1. Oregon State University

Declustering of global earthquake catalogue into mainshocks, foreshocks and aftershocks is an important problem on its own, particularly for studying patterns of global seismicity. Declustering often leads to better understanding of not just mainshock-aftershock relationship, but also swarms, bursts, gaps, switching, and their distributions which can be key to various data-driven discoveries. There is a large body of literature on statistical declustering of earthquakes. In this talk, we will look into the question of magnitude, space and time interaction among mainshocks using nearest neighbor clustering method. We will also discuss point process models for declusering of global earthquake data and potential computational and other challenges.

Keywords: Scale-free networks, Mixture model, Point process

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[E] Oral | S (Solid Earth Sciences)：S-TT Technology & Techniques

[S-TT53] Airborne surveys and monitoring of the Earth

convener:Shigekazu Kusumoto(Graduate School of Science and Engineering for Research, University of Toyama), Takao Koyama(Earthquake Research Institute, The University of Tokyo), Yuji Mitsuhata(AdvancedIndustrial Science and Technology), Shigeo Okuma(Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (AIST))

Airborne surveys are useful to better understand the whole and/or the detailed structures of the Earth and their variations. They can be implemented from a traditional manned and newly-developed unmanned aircraft to efficiently map very large or remote areas with difficult access. We invite studies on theory, instrumentation, processing, modeling or inversion and applications of airborne surveys.

[STT53-01] Compute environment agnostic scientific research platform for exploration geophysics

★Invited Papers

*Pavel Golodoniuc[1], Davis Aaron[1], Samuel Bradley[1], Shane Mule[1], John Hille[1] (1.CSIRO)

[STT53-02] Investigation of geological structure using airborne electromagnetic survey method in which transmitter and receiver are towed by drone.

★Invited Papers

*Youichi Yuuki[1], akira shinsei[1], satoshi tomimori[1], Zenshiro Saito[1], akira jomori[2], atsuyoshi jomori[2] (1.Oyo corporation, 2.Neo Science)

[STT53-03] Special Techniques for Airborne Survey Technologies Using Unmanned Helicopters in Noboribetsu Volcano

*Tomoya Hayakawa[1], Keitaro Yoshikawa[2], Takeshi hashimoto[3] (1.NIPPON KOEI CO., LTD., 2.Hokkaido Regional Development Bureau, 3.Hokkaido University Institute of Seismology and Volcanology)

[STT53-04] Repeated aeromagnetic survey of Noboribetsu volcano

Akinori Satoh[1], *Takeshi Hashimoto[1], Tomoya Hayakawa[2], Keitaro Yoshikawa[3], Takao Koyama[4] (1.Institute of Seismology and Volcanology, Graduate School of Science, Hokkaido University, 2.Nippon Koei Co.,Ltd, 3.Hokkaido Regional Development Bureau, 4.Earthquake Research Institute, The University of Tokyo)

[STT53-05] Evaluation of a UAV-enabled Magnetometer for Geophysical Survey in Volcanic Areas

*Shigeo Okuma[1], Masahiko Makino[2], Ayumu Miyakawa[1], Tadashi Nakatsuka[1], Shogo Komori[3], Yoshiki Sugino[1], makoto yanagida[4], Atsushi Oshida[5] (1.Insititute of Geology and Geoinformation, National Institute of Advanced Industrial Science and Technology (AIST), 2.Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (AIST), 3.Research Institute for Geo-Resources and Environment, National Institute of Advanced Industrial Science and Technology (AIST), 4.Hanshin Consultants Co., Ltd., 5.Kawasaki Geological Engineering Co., Ltd.)

[STT53-06] The initial report of aeromagnetic studies for Nishinoshima

*Noriko Tada[1], Hiroshi Ichihara[2], Takao Koyama[3], Kiyoshi Baba[3], Akimichi Takagi[4], Fukashi Maeno[3], Minoru Takeo[3] (1.Japan Agency for Marine-Earth Science and Technology, 2.Nagoya University, 3.Earthquake Research Institute, The University of Tokyo, 4.Japan Meteorological Agency)

Compute environment agnostic scientific research platform for exploration geophysics

*Pavel Golodoniuc[1], Davis Aaron[1], Samuel Bradley[1], Shane Mule[1], John Hille[1]

1. CSIRO

Earth scientists rely on large datasets for analysis, interpretation and prediction of rock properties at different scales. Exploration geophysicists operate with complex data and numerical codes to solve forward and inverse modelling problems. For many small- to medium-sized exploration companies, access to new analytical methods might be unfeasible due to the amount of data and computing resources required. This also restricts researchers in delivering new methods to early adopters who are more agile than large companies but can lack resources and expertise to set up the necessary infrastructure. Herein we address both limitations by offering early adopters' access to cutting-edge techniques and providing researchers with a link to end-users.

We develop a platform that enables visual interaction with geophysical data and allows seamless integration with complex numerical codes at various scales –from a desktop data processing to the inversion of hundreds of kilometres of airborne electromagnetic data in a Cloud, private compute cluster or a High-Performance Computing facility. The architecture, in which everything is packaged as a Docker container, allows individual applications to run in different environments without recompiling. Containers are dynamically built using an open declarative scripting language and can be shared via a common Docker Registry. The containerisation also eliminates potential library dependency conflicts as each container represents an isolated execution environment that is configured for a specific program. Our application scales from a desktop to a Docker Swarm Cluster to a Cloud with ease and shrinks back when computing resources are no longer in use. The approach develops lightweight Cloud-hosted applications tailored to specific needs, thus not limiting users to a single application. A set of Docker containers implementing complex analytical procedures can be deployed and run either locally or externally. In the latter case, the computational load can be balanced through a range of means, e.g., growing the Docker Swarm or delegating computationally heavy tasks to a dedicated server.

Our approach is cost-efficient and enables a link between researchers and explorers. It offers access to cutting edge research while protecting researchers' intellectual rights.

Keywords: geophysics, visualisation, exploratory data analysis, human-computer interaction, electromagnetics, data processing

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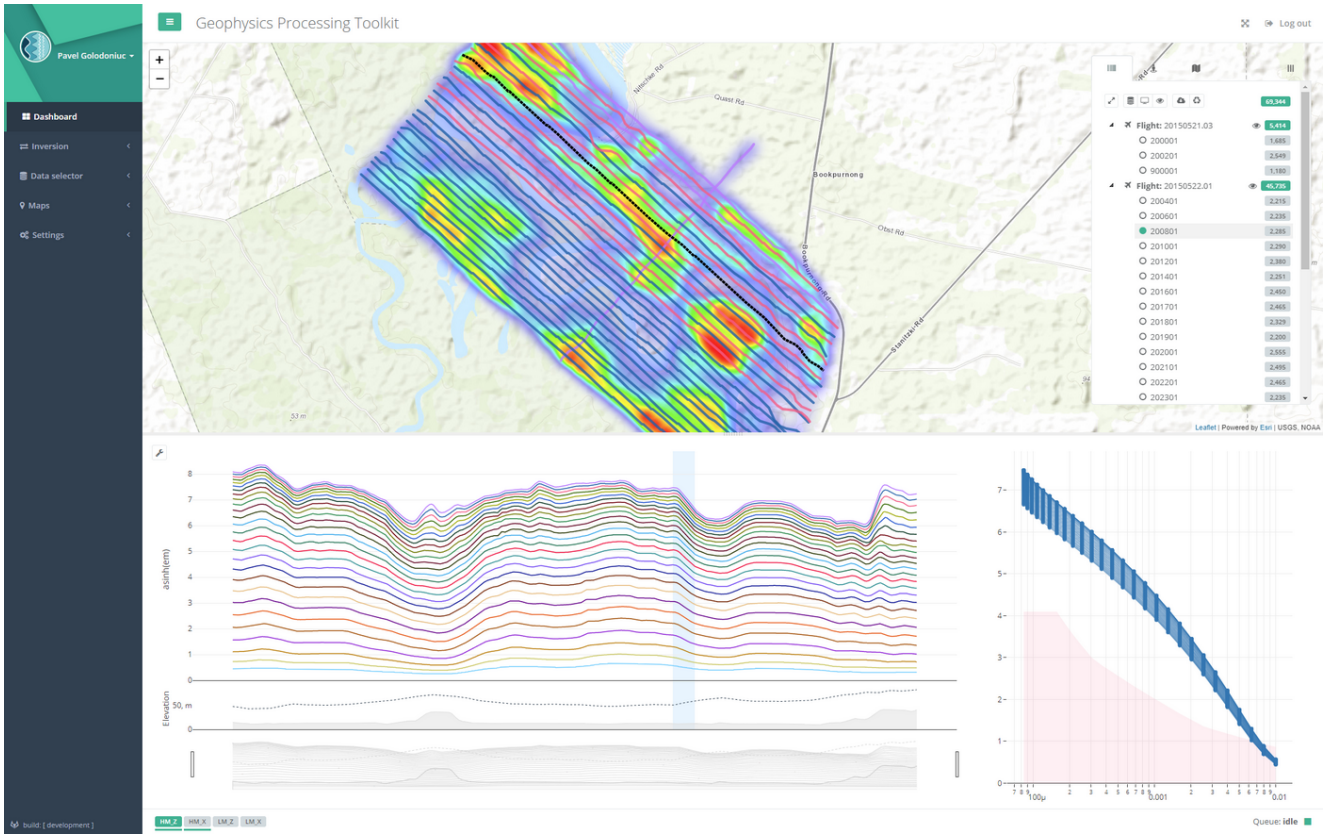

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Investigation of geological structure using airborne electromagnetic survey method in which transmitter and receiver are towed by drone.

*Youichi Yuuki[1], akira shinsei[1], satoshi tomimori[1], Zenshiro Saito[1], akira jomori[2], atsuyoshi jomori[2]

1. Oyo corporation, 2. Neo Science

There are two types of airborne electromagnetic survey methods: Airborne electromagnetic survey methods(GREATEM), in which a transmission source is installed on the ground and measured in the air, and a survey method in which electromagnetic waves are transmitted from the air and received in the air. Due to the diversification of platforms to be used, miniaturization and high performance, and miniaturization of exploration equipment, ground-source airborne electromagnetic survey has been developed using a multicopter (as drone). Investigations of small areas can be explored quickly and at low cost.
We have also developed a system that can reduce the size and weight of the equipment to be mounted on aircraft, and can also mount the transmitting device on the drone. The drones used also improved in performance, and improved flight control technology enabled them to fly at the same time.
We have newly developed a transmitting device to be mounted on a drone, and performed measurements by flying two drones towing the transmitting device and the receiving device at the same time.
In this presentation, we report the results of a geological survey conducted in the Nobi Plain, Gifu Prefecture.
The transmission device was developed in the "Strengthening National Resilience (Disaster Prevention and Mitigation)" of the "Strategic Innovation Creation Program (SIP)".

Keywords: Drone airborne electromagnetic survey, Drone

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Special Techniques for Airborne Survey Technologies Using Unmanned Helicopters in Noboribetsu Volcano

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1. Introduction
Because the use of unmanned robot technology is an effective way for performing studies in entry-restricted areas during volcanic activity, we have been working to develop survey technologies using a small unmanned helicopter owned by the Hokkaido Regional Development Bureau on Tarumae Volcano, Usu Volcano, and Noboribetsu Volcano through industry-university-government collaboration. In this paper, we discuss the special techniques that we employed with regards to airborne survey technologies, namely, installing antennas using a lift type vehicle, sampling volcanic ejecta, and measuring thickness of volcanic ash as well as discuss the equipment used and specific methods for performing these tasks.

2. Small unmanned helicopter specifications and survey location:
In this study, we used YAMAHA RMAX-G1 type. The helicopter's maximum flight time is roughly 90minutes with a range of up to a 5km radius from the base station. Its payload capacity is 10kg at an elevation of 0meters at 20ºC.
In this study, the survey location was the Noboribetsu volcano, and set up a takeoff/landing pad at an elevation of 578.7m near Kaminoboribetsu. We flied the helicopter to the northern slope of the Mt. Hiyoriyama 2.0km away, all studies were conducted from the air.

3. Installing antennas using a lift type vehicle:
Wireless transmission between the base station and the small unmanned helicopter consists of a 2.4GHz data communication band for operations, and an analog 1.2GHz band for camera images. Both bands require good visibility. Trees may often not have a blocking effect, but we used a lift type vehicle to install both antennas higher than the tree. The lift type vehicle is the so-called "super deck" with a platform of approximately 2.5×1.5m. It allows two people. With the use of this, we were able to assign both the antenna operator and visual helicopter watchperson at the high platform, and the antennas could be attached to the handrails.

4. Volcanic ejecta sampling method:
For volcanic ejecta sampling, the helicopter was again hovered roughly 50-60m above the ground, and a hanging sampler was lowered by winch to collect volcanic ejecta. Before the operation, we fixed a 2x2m square blue sheet in place at the target point, and laid volcanic ash onto this sheet to a few cm. The pumice type (there are around Hiyoriyama, Kt-1 tephra) and the fine grain volcanic ash type (from Sakurajima) were installed. We tested samplers as the ball types and the bucket types. The ball type samper were sticked volcanic ash evenly in both cases. The bucket type was superior in sampling 190g of the fine grain volcanic ash compared to 124g of the pumice.

5. Measuring volcanic ash thickness
The method of measuring volcanic ash thickness is photographing the marker that can identify the volcanic ash thickness from the sky. The markers used different heights, shapes, and colors, referring to

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Tsutsumi et al. 2019, and set the height to 10mm, 20mm, and 30mm, we identified whether it was more than 10mm thick.

6. In closing:
In order to implement emergency studies during an eruption, we will need to have command of these special techniques as part of our know-how.

References
Tsutsumi H, Okazaki S, Yamamoto Y, Kamijo T, Tagta S, Sekimoto A(2019); The Study of Simple Measurement of Volcanic Ash Deposit(Part 2); 2019 Conference Japan Society of Erosion Control Engneering

Keywords: Unmanned Helicopters, Volcano

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Repeated aeromagnetic survey of Noboribetsu volcano

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1. Institute of Seismology and Volcanology, Graduate School of Science, Hokkaido University, 2. Nippon Koei Co.,Ltd, 3. Hokkaido Regional Development Bureau, 4. Earthquake Research Institute, The University of Tokyo

We have been developing a novel airborne survey technology by using an unmanned helicopter owned by the Hokkaido Regional Development Bureau under the framework of an industry-government-academy project. As a part of this project, we performed the third aeromagnetic survey at Noboribetsu volcano in 2019, following the past campaigns in 2016 and 2017. The unmanned helicopter was quite advantageous from the viewpoint of detecting temporal changes, since the UAV, being aided by GPS navigation, can autonomously repeat flying a designated path with a high accuracy. Magnetic field changes associated with volcanic activity have been frequently reported in previous studies. A recent research has summarized that many of such changes occur even in inter-eruptive periods with a timescale of several months to years (Hashimoto et al., 2019). At Noboribetsu volcano, we first detected a localized but seemingly significant magnetic field changes in our successive surveys.

In the course of the data processing, we, at first, removed the geomagnetic disturbance of extra-terrestrial origins by taking a simple difference between the field data of each airborne survey and the ground reference station. Then, we obtained the temporal changes between 2016-2017 and 2017-2019 by taking the field difference at the selected pairs of measurement points within 5 meters from the relevant two campaigns. Actually, maximum displacement between the closest pair was considered to be roughly 10 m, since the magnetic sensor was towed on a 4.5 m cable to avoid the magnetic noise from the helicopter body, while the positioning data was obtained by the GPS receiver on the airframe. On the other hand, the magnetic field gradient in the air was fairly small at generally less than 1 nT/m. Therefore, we considered an error range for the temporal changes in our magnetic survey was +/-10 nT.

In contrast to the comparison between 2016 and 2017 surveys, where no significant temporal change was found, we detected a remarkable dipolar pattern (A in Fig.1) around the peak of Mt. Hiyoriyama in the middle of the difference map between 2017 and 2019. In addition, a broad depression (B in Fig.1) was found in the southwestern part of Jigokudani geothermal field. The origin of the latter, corresponding to the steep escarpment at the southern edge of the geothermal field, was questionable, since it was monopolar and also corresponded to the strong negative anomaly in the original field map of 2017. Meanwhile, the former showed a clear dipolar pattern suggesting re-magnetization, although its peak-to-peak amplitude was close to the confidence limit. We applied the 3D inversion of Utsugi (2019) to the 2017 magnetic anomaly to obtain a subsurface magnetization structure. As the result, magnetization was imaged to be relatively low in the shallow part beneath the area from Mt. Hiyoriyama to Lake Oyunuma, implying a high temperature and/or hydrothermal alteration. Furthermore, the 3D inversion for the differential map between 2017 and 2019 suggested a very localized re-magnetization just beneath Mt. Hiyoriyama, where some weak fumaroles were always seen at the top. We suspected that the re-magnetization since 2017 was a signature of shallow cooling associated with a temporarily depleted background thermal activity of this area. Our study has demonstrated practical feasibility and effectiveness of the repeated aeromagnetic survey using the unmanned helicopter as a monitoring tool even under an access regulation when the Volcanic Alert Level is raised.

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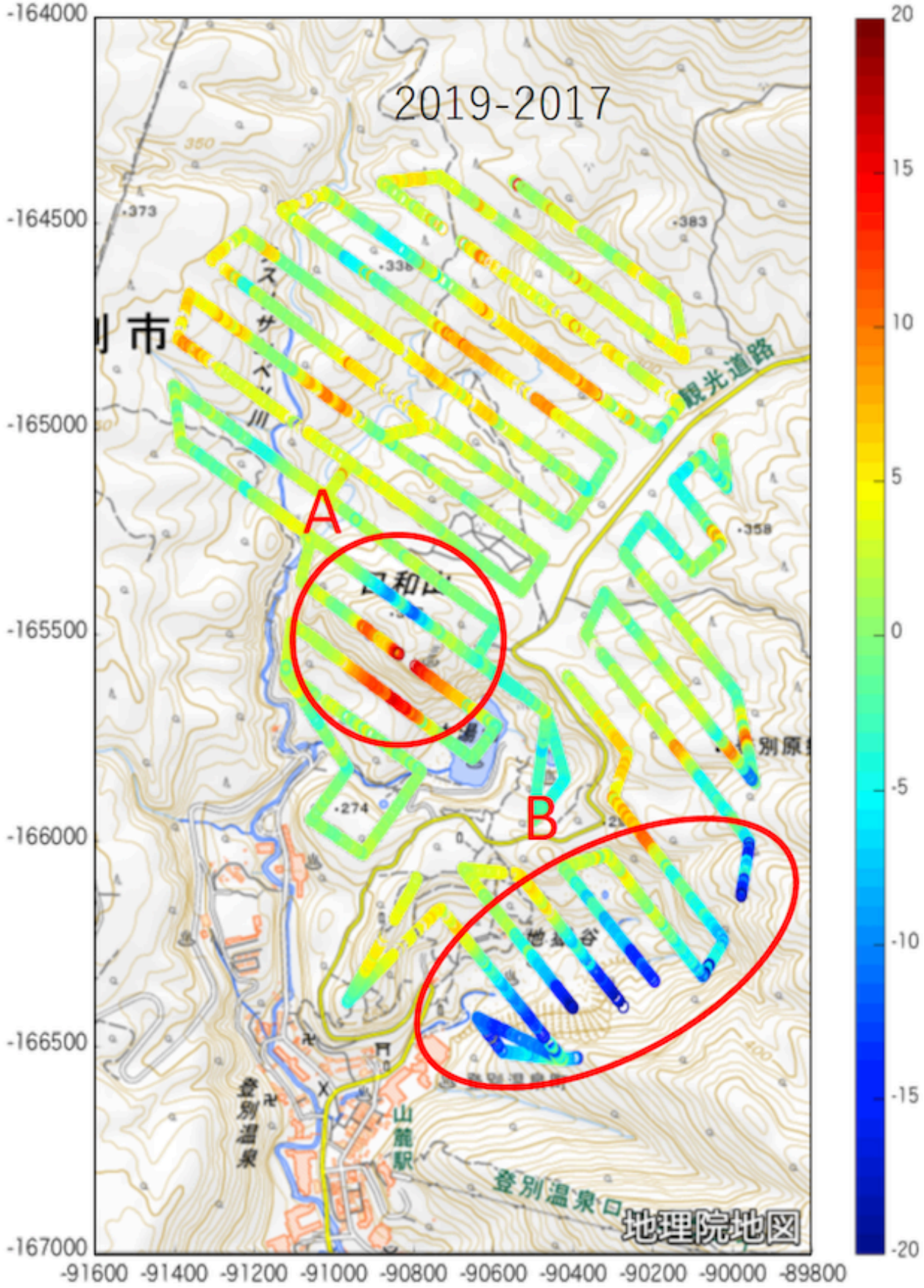
Keywords: aeromagnetic survey, unmanned helicopter, Noboribetsu volcano



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Evaluation of a UAV-enabled Magnetometer for Geophysical Survey in Volcanic Areas

*Shigeo Okuma[1], Masahiko Makino[2], Ayumu Miyakawa[1], Tadashi Nakatsuka[1], Shogo Komori[3], Yoshiki Sugino[1], makoto yanagida[4], Atsushi Oshida[5]

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We have been developing a drone magnetic survey system for geophysical survey in volcanic areas these years. At the initial stage, we developed such a survey system with a portable Cs magnetometer though it is relatively heavy (4 ~ 5 kg). Through the experiences of practical tests in volcanic areas, we learnt difficulties to fly such a system using a drone in a stable attitude mainly from its weight.
Recently a UAV-enabled magnetometer "MagArrow" has been developed by Geometrics, USA. This is an innovative laser pumped Cesium vapor magnetometer based on MEMS technology. The system comprises internal electronics including two Cs sensors, GPS and IMU in an aerodynamic carbon shell and works at a sampling rate of 1 kHz. It weighs only around 1 kg and is suitable for UAS surveys.
In 2019, we introduced the system to conduct some practical tests of the magnetometer for geophysical survey in volcanic areas. First, we confirmed a necessity to get meaningful measurements by averaging signals at a sampling rate of 1 kHz. We also made a rotational test on a plate to confirm the system's directional error with an amount of ±5 nT. The system was hung from a hexacopter, PRODRONE PD6-AW2/PD-FC1 on which a differential GNSS receiver and its data logger were additionally installed. The payload of the drone (8 kg) is big enough to accommodate both a MagArrow (1 kg) and the additional equipment (1.65 kg).
Some preliminary tests flights were conducted beforehand in drone parks in Fukushima and Ibaraki Prefectures, north of Tokyo. It took some time to find a suitable way how to hang the MagArrow from the drone since it has been turned out that the system is susceptible to wind probably because of its shape and light weight. We found a compromise procedure to make the system's flying attitude more stable. Then, we applied the system to test flights inside the caldera of Izu-Oshima Volcano, south of Tokyo. Unfortunately, many typhoons attacked Izu-Oshima Island in 2019, causing difficulties in surveying on calm days with a wind speed less than 2 m/s. Because of the harsh weather, the flights covered only a half of the provisional survey area. However, the system itself worked well to observe total magnetic field with a precise positioning by the differential GNSS receiver.

Keywords: magnetic survey, drone, UAS, drone magnetic survey, volcano, Izu-Oshima volcano

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The initial report of aeromagnetic studies for Nishinoshima

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An aeromagnetic survey is a method to measure the total magnetic field or three component magnetic field by a sensor mounted on an airborne vehicle and is useful for monitoring volcanic activities. Recent technical development yields more popular use of drones instead of helicopters or airplanes for aeromagnetic surveys because of low cost and easy operation.
Nishinoshima is an oceanic island arc volcano constituting Izu-Ogasawara (Bonin) island arc, which locates about 1000 km south of Honshu island in Japan. The eruption since 2013 produced huge amount of andesite lava. In order to understand a magnetization structure and distribution of rocks beneath Nishinoshima, we measured the total magnetic intensity by using a drone.
We used the drone, DJI Matrice 600, with a potassium magnetic sensor, which was modified by TIERRA TECNICA Ltd. We measured the total magnetic intensity, latitude, longitude, height, and altitude at 20 Hz. The position of the drone was measured by GPS, and the altitude above the ground was measured by using a laser altimeter. Each flight time was set to be within 17 minutes because of the capacity of the drone’s batteries. Flight speed was between 2 and 8 m/s.
The drone took off and landed on the deck of an ocean weather ship “Keifumaru” belonging to Japan Meteorological Agency in both September 2018 (KS18-07) and June 2019 (KS19-05). The drone was operated by HEXaMedia Inc.. In KS18-07, we conducted two flights (one N-S direction and one E-W direction), which was the first trial of applying aeromagnetic survey using drone to an oceanic island. Flight altitude was fixed at approximately 100 m above sea level. In KS19-05, we conducted 17 flights, 16 N-S directions and one E-W direction. Two flights of them were at the same location and altitude as the two flights in KS18-07. Flight altitude of the other 15 flights was fixed at approximately 80 m above the ground. The total observed area is about 3 km by 3 km.
We estimated the magnetization structure of the shallow part of Nishinoshima by using the 3-D inversion (Utsugi, 2019). The main calculation area is 4 km by 4 km and 2 km deep, and the area is surrounded by 1000 km grids. The mesh size in the main calculation area is 50 m by 50 m by 50 m. We used the topography data of 50 m by 50 m grid around Nishinoshima provided by Japan Coast Guard.
In this presentation, we will introduce our observantions and discuss a magnetization structure of the shallow part of Nishinoshima.

Keywords: Nishinoshima, magnetization structure, aeromagnetic survey, drone

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[E] Oral | S (Solid Earth Sciences)：S-TT Technology & Techniques

[S-TT54] Creating future of solid Earth science with high performance computing (HPC)

convener:Takane Hori(R&D Center for Earthquake and Tsunami, Japan Agency for Marine-Earth Science and Technology), Yuji Yagi(Graduate School of Life and Environmental Sciences, University of Tsukuba, Tsukuba), Katsuhiko Shiomi(National Research Institute for Earth Science and Disaster Resilience)

Due to the development in computer science and computational science, large-scale or many times forward simulations and/or inversion analyses have become available recently. In solid Earth science, large-scale seismic wave propagation and crustal deformation with high fidelity models based on high resolution observation data have been demonstrated; uncertainty in crustal deformation caused by material properties and structures can be investigated based on many-time calculations for different material properties and structures; fault slip inversion analyses for non-Gaussian error distribution, etc. Thus, we will invite researchers who are applying HPC technology in forward simulations and inversion analyses and discuss how to improve more the collaboration between computer & computational sciences and solid Earth science not only in Japan but also from US and/or Europe. We are welcome submission by the researchers who are interested in this scope, especially students and young researchers.

[STT54-01] Exploiting exascale computing to unravel multi-physics and multi-scale earthquake dynamics and seismic wave propagation

★Invited Papers

*Alice-Agnes Gabriel[1], Bo Li[1], Duo Li[1], Thomas Ulrich[1], Carsten Uphoff[1] (1.Department of Earth and Environment Sciences, Ludwig-Maximilians-Universitat Munchen)

[STT54-02] Development and application of large scale numerical simulations for earthquake generation, ground motion and non-linear soil amplification

*Takane Hori[1], Tsuyoshi Ichimura[2], Kohei Fujita[2], Ryoichiro Agata[1] (1.Research Institute for Marine Geodynamics, Japan Agency for Marine-Earth Science and Technology, 2.Earthquake Research Institute, The University of Tokyo)

[STT54-03] Computing 3-D Viscoelastic Earthquake Cycle Models for Cascadia Using Large-Scale, High-Fidelity Finite Element Methods

*Kaj M Johnson[1], Takane Hori[2], Tsuyoshi Ichimura[3], Kohei Fujita[3] (1.Indiana University Bloomington, 2.Research Institute for Marine Geodynamics, JAMSTEC , 3.Earthquake Research Institute & Department of Civil Engineering, The University of Tokyo)

[STT54-04] Fast and scalable finite-element solvers for three-dimensional urban earthquake simulation

*Kohei Fujita[1], Tsuyoshi Ichimura[1], Takuma Yamaguchi[1], Muneo Hori[2], Lalith Wijerathne[1] (1.Earthquake Research Institute, The University of Tokyo, 2.Japan Agency for Marine-Earth Science and Technology)

[STT54-05] Finite element solver for large-scale three-dimensional soil liquefaction analysis

★Invited Papers

*Ryota Kusakabe[1], Tsuyoshi Ichimura[1], Kohei Fujita[1], Muneo Hori[2], Lalith Wijerathne[1] (1.Earthquake Research Institute, The University of Tokyo, 2.Japan Agency for Marine-Earth Science and Technology)

[STT54-06] Large-scale finite element simulation of earthquake ground motion and its numerical verification aiming for enhanced earthquake damage estimation

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Exploiting exascale computing to unravel multi-physics and multi-scale earthquake dynamics and seismic wave propagation

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Earthquakes are highly non-linear multiscale problems, encapsulating the geometry and rheology of propagating shear fractures that render the Earth’s crust and emanate destructive seismic waves. Using physics-based earthquake scenarios, modern numerical methods and hardware specific optimisations sheds light on the dynamics, and severity, of earthquake behaviour.
The potential of in-scale earthquake rupture simulations for augmenting earthquake source observations is demonstrated in two recent examples: i) the 2016 Mw7.8 Kaikoura, New Zealand earthquake, considered the most complex rupture observed to date and causing surface rupture of at least 21 segments of the Marlborough fault system. High resolution dynamic rupture modeling [1] unravels the event's riddles in a physics-based manner; ii) the 2018, Mw7.5 Sulawesi earthquake occurring on the Palu-Koro strike-slip fault system sourcing an unexpected localised tsunami within Palu Bay [2]. The achieved degree of realism and accuracy in both examples is enabled by the open-source software SeisSol [3,4] which couples high-order accurate space-time solutions of wave propagation with frictional fault failure, off-fault inelasticity and viscoelastic attenuation.
I will discuss future directions for exploiting expected exascale computing infrastructure, specifically, representing complex geometries with novel geometric transformations and multi-physics by diffuse interfaces on adaptive cartesian meshes, thus avoiding manual meshing [5]. I will also touch on possibilities to go beyond earthquake scenarios unlocking the predictive power of forward simulations by a recently developed dynamic source inversion approach using a Bayesian framework and by statistical learning.

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Keywords: Computational Seismology, Earthquake Rupture Dynamics, High Performance Computing

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Development and application of large scale numerical simulations for earthquake generation, ground motion and non-linear soil amplification

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As one of the Post-K priority issue projects, named “Development of Integrated Simulation Systems for Hazards and Disasters Caused by Earthquakes and Tsunamis”, we have developed the codes of large scale numerical simulations for earthquake generation, ground motion and non-linear soil amplification based on the HPC technology for non-linear finite element simulation (Ichimura et al., 2015; Fujita et al., 2016; Ichimura et al., 2018). It is possible to calculate static deformation and elastic wave propagation for 10^{12} degree-of-freedom FEM model. These codes are preparing to run on the “Fugaku” supercomputer. Furthermore, based on the developed technology, we are planning to construct high-fidelity FEM applications which government and companies will use for crustal deformation calculations, long-period ground motions, and non-linear soil amplification due to great earthquakes such as in Nankai trough, Sagami trough, etc. We are also planning to calculate large-scale viscoelastic crustal deformation and elastic wave propagation for the realistic Earth structure. These results will be used for reference of static and dynamic Green’s functions using three-dimensional heterogeneous underground structure.

Keywords: FEM, earthquake, Large scale simulation

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Computing 3-D Viscoelastic Earthquake Cycle Models for Cascadia Using Large-Scale, High-Fidelity Finite Element Methods

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To better understand and plan for the effects of the next great Cascadia subduction zone earthquake, it is important to constrain which areas of the fault are fully locked and may rupture seismically, which areas rupture aseismicially in slow slip events, which areas are freely creeping, and how they relate to one another. In particular, the spatial relationship between the locked zone and the slow slip, or Episodic Tremor and Slip (ETS) zone is poorly resolved in Cascadia but highly important for estimating the potential increase in megathrust earthquake probability during and following ETS events. A number of recently published interseismic locking inversions using geodetic data show a gap between the fully locked zone and the top of the ETS zone, implying that the ETS zone is not significantly stressing the fully locked zone. Current locking models in Cascadia show significant variation in the inferred locking within this critical gap, due in part to epistemic (model) uncertainty. Most geodetic inversions assume a linear or quasi-linear gradient in interseismic creep rate below the locked zone which precludes sharp gradients in transitional creep and likely biases the fully locked zone to shallow depths. Furthermore, many geodetic inversions for coupling in Cascadia also neglect the effects of viscoelastic mantle flow and heterogeneous elastic properties.

In this study we explore the nature of the critical gap between the ETS and locked zones by identifying the range of locking models in Cascadia which adequately fit available horizontal and vertical geodetic data considering both the effects of viscoelastic mantle relaxation following previous earthquakes and elastic heterogeneity of the lithosphere. We conduct backslip inversions using 3D viscoelastic Greens functions generated with finite element code GAMERA. We assume there is some long-term slip rate given by the relative plate motion that doesn’ t contribute to deformation of the overriding plate. All deformation is assumed to come from interface coupling. In the forward model, we impose a saw-tooth backslip history on every patch. Steady backslip is interrupted with sudden co-seismic slip events at regular intervals. The unknown for each patch in the inversion is the backslip rate, which is bounded between zero and the long-term slip rate. The co-seismic slip magnitude on each patch is determined by the backslip rate. To compute earthquake cycles, the viscoelastic Greens functions must be computed out to effectively fully relaxed mantle state (~1500-15000 longest material relaxation times). These calculations are computed using an unstructured low-order implicit finite-element method.

Keywords: earthquake cycle, viscoelastic mantle, interseismic coupling

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Fast and scalable finite-element solvers for three-dimensional urban earthquake simulation

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Considering the effect of 3D heterogenous underground structure and surface topography is important for improving reliability of earthquake response simulation of urban areas. Furthermore, consideration of coupling between ground and structure is desired for improving reliability of simulation results for highly important structures. The finite-element method with unstructured 3D solid elements is suitable for these simulations as it can model problems with complex geometry and heterogeneous material properties. However, its large computational cost has limited it from being used in large-scale seismic applications. To overcome this situation, we are developing fast and scaleble finite-element solvers for large-scale supercomputer systems. In this talk, we will show our development of the finite-element solvers and show some examples of urban earthquake simulation on the K computer at RIKEN (82944 compute-node 10 PFLOPS system) and the Intel Xeon Phi based Oakforest-PACS system at Joint Center for Advanced High Performance Computing (8192 compute-node 25 PFLOPS system).

Keywords: Finite Element Method, Urban Earthquake Simulation, High Performance Computing

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Finite element solver for large-scale three-dimensional soil liquefaction analysis

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Soil liquefaction induced by earthquake has caused damages such as ground settlement, lateral flow, tilting of buildings, uplift of manholes and destruction of infrastructures. To examine mechanism of soil liquefaction and mitigate damages it causes, a variety of methods have been developed. Several constitutive law for liquefiable soil were proposed and numerical simulations using them were performed. However, most of the analysis used two-dimensional model because of the huge computational cost of three-dimensional (3D) analysis.

Along with the accumulation of spatial data and development of computer architecture and computational techniques in recent years, expectations have risen for large-scale 3D seismic soil liquefaction analysis. Fast and scalable finite-element based solvers have been developed for large-scale 3D seismic response analysis not considering soil liquefaction. Based on one of them, we developed a finite element solver for large-scale 3D seismic soil liquefaction analysis in previous study.

Even though our previous study enabled large-scale 3D seismic soil liquefaction analysis, there are several inefficiencies in the previous solver. It used the method for seismic response analysis not considering soil liquefaction. It did not consider the differences between the seismic response analysis without soil liquefaction and soil liquefaction analysis. In soil liquefaction analysis, liquefiable layers and non-liquefiable layers are under different constitutive laws, and have different convergence characteristics in solving the governing equation. Not considering these differences causes load imbalance in parallelization and lowers the performance. Also, the method was not suitable for our target supercomputer architecture when used in soil liquefaction analysis.

We developed a revised solver for large-scale 3D seismic soil liquefaction analysis to overcome these problems. The solver uses hybrid parallelization with MPI and OpenMP. We revised the domain partitioning scheme to improve load balancing among MPI processes. The element reordering was used to improve load balancing among OpenMP threads. In addition to the revision of load balancing method, we developed an algorithm to solve the governing equation which is accelerated by considering the characteristics of soil liquefaction. These methods were developed so that our target supercomputer architecture, many-core wide SIMD architectures was efficiently utilized. The developed method achieved 5.1-fold speedup over the previous solver.

As an application analysis, we performed soil liquefaction analysis using large scale highly detailed 3D model that mimics actual ground structure near an estuary. The model has 21,616,202 elements and 89,146,716 degrees of freedom. A 29,500-time-step analysis was carried out on Oakforest-PACS, an Intel Xeon Phi (Knights Landing: a manycore CPU with wide SIMD)-based supercomputer system. The computation time was 16 hours and 12 minutes.

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Large-scale finite element simulation of earthquake ground motion and its numerical verification aiming for enhanced earthquake damage estimation

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Estimation of long-period ground motions caused by a giant subduction-zone earthquake that is likely to occur in the future is important for promoting earthquake disaster countermeasures in urban areas. For this purpose, it is necessary to carry out numerical simulations of seismic wave propagation in a complex underground structure for an appropriate source fault model. Earthquake ground motion has been estimated by using the finite difference method (FDM) in the damage estimations conducted by the government (e.g. Cabinet Office, 2015). On the other hand, detailed databases of underground seismic velocity structures have been developed (Koketsu et al. 2012). In performing numerical simulations that reflect complex topography and seismic velocity structures based on these databases, the advantage of the finite element method (FEM) using unstructured elements over structured-grid-based methods such as FDM has been pointed out (Ichimura et al. 2007). FEM is also superior in handling various source fault models flexibly. A barrier for introducing FEM in the ground motion prediction was the associated high computational cost. FDM calculation is based on a structured grid, which is highly efficient in memory access. By contrast, FEM generally incorporates unstructured elements, with which the memory access becomes less efficient and it is difficult to solve large-scale problems with a practically enough speed. It has also been known that the calculation cost for constructing the computation mesh using unstructured elements possibly becomes a bottleneck rather than the calculation of the ground motion itself. However, recent developments in the field of high-performance computing have enabled us to perform both constructions of unstructured mesh and calculations of earthquake ground motion in enough short time even for very large-scale problems of the order of 10^{10}-10^{11} degrees of freedom using a world-class supercomputer (e.g. Ichimura et al. 2018). Therefore, we expect that it will be possible to conduct a more accurate prediction of earthquake ground motion in a wider range of problems by replacing FDM with FEM in the damage estimation by the government. Aiming for such a goal, we here carry out numerical verifications of the calculation of earthquake ground motion based on FEM, comparing the results with those obtained by using FDM that has been conventionally used for damage estimation by the government.

We first considered the earthquake motion in a stratified layer model due to a point source for benchmarking, which has a quasi-analytical solution and is known to be accurately handled by FDM. The problem setting was the same as one of the benchmark tests for strong motion prediction by Yoshimura et al. (2012). We obtained the results that are in good agreement with the semi-analytical solutions and FDM codes that are used in national research laboratories and construction companies. At present, we are further considering problem settings that demonstrate the advantages of FEM, such as the so-called “Moon-basin” problem (Sánchez-Sesma and Luzón 1995), in which a soft sedimentary layer is installed in the basin structure. In the conference, we will discuss the convergence of the numerical solution calculated by using FEM, while comparing it with FDM calculations.

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Keywords: Earthquake ground motion, Finite element method

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[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG55] Petrology, Mineralogy & Resource Geology

convener:Yu Nishihara(Geodynamics Research Center Ehime University), Koichi Momma(National Museum of Nature and Science), Tatsuo Nozaki(Submarine Resources Research Center, Research Institute for Marine Resources Utilization, Japan Agency for Marine-Earth Science and Technology), Nobutaka Tsuchiya(Department of Geology, Faculty of Education, Iwate University)

We widely invite presentations in the fields of petrology, mineralogy and resource geology. Especially description of minerals and rocks, investigation of their origin and evolution by field investigation and/or laboratory experiments, and development of new methods are accepted.

[SCG55-01] The relationship between the morphology of entablature and the magma cooling process in the Genbudo lava, Iwate Prefecture

*Takashi Hoshide[1], Nao Ishibashi[1] (1.Faculty of International Resource Sciences, Akita University)

[SCG55-02] Preliminary paleomagnetic results from the manganese wad deposit at the Sanbe hot springs, Shimane.

*Kazuo Kawasaki[1], Sunao Kobayashi[2] (1.School of Sustainable Design, University of Toyama, 2.Department of Earth Sciences, University of Toyama)

[SCG55-03] Geochemistry of Middle Permian Tavantolgoi sandstone: Implications for paleoclimate and provenance

*Bat-Orshikh Erdenetsogt[1], Enkhbayar Bolormaa[1], Dashpuntsag Nansalmaa[1], Baigalmaa Norov[1], Bat Bold[1], Luvsanchultem Jargal[1] (1.National University of Mongolia)

[SCG55-04] Proposal for novel quantitative classification method of below the hundred-micron particle in soils using a microscope Raman spectroscopy combined with an automated image analysis.

*Daisuke Sasakura[1], Aiko Hayauchi[1] (1.Malvern Japan ,Div of Spectris Co.Ltd,.)

[SCG55-05] High-pressure phase relations of K-bearing NAL phase with implications to aluminosilicate inclusions in superdeep diamonds in kimberlites

*Masaki Akaogi[1], Fumiya Kimura[1], Hiroshi Kojitani[1] (1.Department of Chemistry, Faculty of Science, Gakushuin University)

[SCG55-06] Rheology of bcc-iron at high-pressure and -temperature

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The relationship between the morphology of entablature and the magma cooling process in the Genbudo lava, Iwate Prefecture

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Two different types of columnar jointing, colonnade and entablature, develop in a single layer of lavas and welded tuffs. In general, the width of a column in colonnade is larger and straight, whereas the width of a column in entablature is relatively smaller and curved. The causes of these two structures have been discussed for many years, but have not been yet fully understood.

The Genbudo lava exposed along the Kakkonda River in Shizukuishi-cho, Iwate Prefecture is located in the southwestern part of Iwate volcano. This is considered to be belonging to the younger Amihari volcanic group by Nakagawa (1987). The thickness of the Genbudo lava is about 70m or more. The upper 50 m of the lava is composed of the entablature, the lower 20 m is of the colonnade. We conducted the outcrop and textural observations of the entablature on the lava to consider the origin of the entablature.

In the colonnade, the three-dimensional shape of the part surrounded by fractures is a hexagonal column. On the other hand, in the entablature, the three-dimensional shape of the part surrounded by fractures is not a column but a curved plate with a thickness of about 5-10 cm. When observing a curved plate, the shape of the largest surface of the plate is fan-shaped, and small fractures occur at the edge of the fan at intervals of about 2 to 4 cm. These small fractures develop almost perpendicular to the larger fracture that defines the edge of the fan. In addition, the edge of the fan with small fractures exhibits blacker than the other parts.

Thin sections of each part of the lava were prepared, and the groundmass textures were observed using a polarizing microscope and SEM-EDS. We found that the crystallinity of each part decreases in the following order: Colonnade > Entablature in the area away from the small fractures > Entablature in the area where the small fractures develop.

This suggests that in the entablature, when the lava was still unconsolidated, quenching occurred along the existing fracture.

Keywords: columnar joint, cooling rate, entablature

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Preliminary paleomagnetic results from the manganese wad deposit at the Sanbe hot springs, Shimane.

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Paleomagnetic results are reported for the manganese wad deposit at the Sanbe hot spring, Shimane, Japan. The hot spring is located at the foot of Mt. Sanbe, an active volcano, which erupted three times within last 10000 years, i.e., at ~1300 years ago, ~3600 years ago and ~5600 years ago. The study area consists of two layers: an upper ~2.1 m thick manganese (Mn) wad layer and a lower ~30 cm thick tephra layer. Oriented specimens were collected with 7 cc non-magnetic plastic cubes at 15 levels from the Mn wad layer between ~1.6 m and ~2.1 m from the surface and at 12 levels from the tephra layer. Paleomagnetic analyses on 86 Mn wad specimens and 73 tephra specimens isolates a stable characteristic remanent magnetization (ChRM) in mainly maghemite in the tephra specimens only. The mean ChRM directions at each sampling level likely retains paleosecular variation, and a paleomagnetic age of ~2200 years B.P. is determined when the mean ChRM directions are compared with the paleosecular variation records for Lake Biwa, Japan. The observed ~2200 years B.P. of the tephra layers provides a minimum age for the deposition of the Mn wad deposit, and therefore the physicochemical condition of the regional hydrothermal system must have been changed after this age.

Keywords: Paleomagnetism, Manganese wad, Quaternary

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Geochemistry of Middle Permian Tavantolgoi sandstone: Implications for paleoclimate and provenance

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The Tavantolgoi deposit, which has more than six billion tons of coal reserves, is situated in southern Mongolia. In 2018, more than 22Mt coal was produced from the deposit. During the exploration program completed in 2017, eighteen sandstone and two andesite samples for petrographical and geochemical analysis were collected from the upper part of coal-bearing Middle Permian Tavantolgoi Formation, which was intersected completely by 960 m deep bore hole.
Petrographically, the sandstones are classified as litharenite reflecting relatively weak weathering intensity in source area, probably due to arid or semiarid climate conditions. Provenance analysis indicates that the sandstones are sourced from transitional arc and undissected arc that were probably formed during the closure of Paleoasian ocean between southern Mongolia and North China block.
Geochemistry of major oxide and trace element result are summarized as below. CAI values from major oxides of the studied samples vary between 66.7 and 81.5 with an average of 77.0, reflecting weak to moderate intensity of weathering in source area. The plotted data on A-CN-K diagram displays that sandstones were sourced mainly from early Permian andesite and dacite, which are widely distributed around Tavantolgoi. It is also supported by Al_2O_3/TiO_2 (avg. 19.6), TiO_2/Zr (avg. 57.7) and petrographical study.
C-value, indicator of paleoclimate, in the sandstone ranges from 0.15 to 1.3 with an average of 0.50, suggesting semiarid and semiarid to semimoist condition. However, some samples accumulated during the short period of arid and moist conditions. Rb/Sr and Sr/Cu of the studied samples are consistent with those of C-value. In addition, Sr/Ba (avg. 0.56), Th/U (avg. 2.8) and Ni/Co (avg. 2.0) of the samples suggest that the sandstones were deposited in paleoenvironment with fresh and oxic water.

Keywords: sandstone geochemistry, Middle Permian, Tavantolgoi, Mongolia

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Proposal for novel quantitative classification method of below the hundred-micron particle in soils using a microscope Raman spectroscopy combined with an automated image analysis.

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Introduction

It is well known that importance of particle characterization on soil to investigate of geoscience. The characteristics of particle is including various information such as history of factual energy by distortion of ground, transportation process of material and chemical inside of ground and physical property reflects of soil mechanics. Particle morphology as physical properties and the chemical properties such as the elemental populations and crystal properties are important as primary attribute for characteristics of particle on soil investigation.
To investigate of morphological analysis as a volume-based analysis, especially a grain size, a sieving is well performed on greater than 4- phi (1/63, 63um) scaled range. However, finer than 4-phi are complicate to perform due to clogging and low flowabilities on samples. Therefore, investigation on this range are sedimentation analysis and manually optical microscope analysis (OM) as time consuming methods.Especially, OM analysis is the near impossibility of measuring a statistically significant number of several ten thousand number of particles as recommended in ISO 13322-1,2.
Recent advances in computer technology have allowed for the development of a new automated particle image analysis (APIA) approach. A principle of APIA is based on uses digital imaging technology to allow for the acquisition of 2D particle projection images of a statistically significant number of particles. This technique has allowed for the calculation of a wide range of size and shape with quantitative information. Recently, several studies reported to an automated particle image analysis (APIA) are well performed for soil particle analysis especially finer than hundred-micron particles[1][2].
Furthermore, existing a grain size analysis are nearly impossible to investigate with chemical analysis. This is because, the various chemical analysis can measure for chemical composition as a bulk information, however, it do not allow the study of the composition of individual particles of different morphology as integrated information. The statistical Raman spectroscopic (SRS) method is a novel approach which can resolve this problem. Using this method, the Raman spectra of several hundred particles is determined after size and shape classification of each individual particle by APIA. Raman spectroscopy can be used to acquire the spectra of any inorganic compounds which are included in soils. Therefore, Raman spectroscopy can be used for the identification of the chemical composition of fine particle ranges. Using the SRS method described herein, it is possible to calculate the mass and/or volume with precise quantitative information of each chemical component species based on Raman spectroscopy. This study will report and discuss for capability of a novel quantitative classification flamework on below the hundred-micron particle in soils using model samples.

Material and Methods

Model samples were milled Normal Glass (NG) powder and Silica Sand(SS) samples used. Estimated chemical composition measuring were measured by EDXRF instruments (Epsilon 1, Malvern Panalytical Instruments, Netherlands) with a semi quantitative analysis based on a fundamental parameter method. Major elemental components on both were Si (NG=72%, SS=98%) and other alkali metals. SRS analysis

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was carried out using a Morphologi 4-ID instrument (Malvern Panalytical Instruments, UK) equipped with a dry powder sample dispersion unit (SDU) and Raman module. The laser wavelength of Raman excitation was 785nm with arbitrary intensity of laser power. Samples were dispersed using the SDU using a short duration pulse of compressed air. Measurements were made automatically using Standard Operating Procedures (SOPs) which define the software and hardware settings used. Measurement sample was dispersed on to glass plate as sample carrier which was minimized environmental exposure by the enclosed sample chamber unit. Particle identification by Raman analysis used the spectrum correlation coefficient approach.

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Keywords: Particle Mophology, Fine Partcile, Particle size analysis

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High-pressure phase relations of K-bearing NAL phase with implications to aluminosilicate inclusions in superdeep diamonds in kimberlites

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It is widely accepted that mineral inclusions in diamonds in kimberlites provide important information on mantle-constituent minerals and dynamic processes of subducted materials in the mantle, as shown by recent discovery of hydrous ringwoodite and $CaSiO_3$ perovskite as inclusions in diamonds. Walter et al. (2011) and Thomson et al. (2014) reported that some composite inclusions found in diamonds in the Juina kimberlite of Brazil had compositions close to those of hexagonal aluminous (NAL) phases which are accepted as major aluminous phases in subducted basalt in the lower mantle conditions. Experimental studies indicated that NAL phase is a candidate of K-host mineral in the deep mantle. In this study, we have examined phase relations in the system $KAlSiO_4$-$MgAl_2O_4$ at high pressure and high temperature. Based on the experimental data, we discuss stability of K-bearing NAL phase at high pressure and transport processes of the diamonds containing the mineral assemblages of the NAL phase compositions. The high-pressure and high temperature experiments were performed using multianvil apparatus. As the starting materials, mixtures of synthetic $MgAl_2O_4$ spinel and $KAlSiO_4$ gel were used. phase relation experiments were made at 5-28 GPa and 1200-1500 ˚C. The results indicate that the NAL phase is stable above 16 GPa at 1500 ˚C in a range of about 60-65 mol% $KAlSiO_4$ in the system $KAlSiO_4$-$MgAl_2O_4$. At lower pressures, $MgAl_2O_4$ spinel, corundum, pyrope and $K_2Mg_2Si_2O_7$-rich phase X are stable at ~8-16 GPa, and $KAlSiO_4$ kalsilite and $MgAl_2O_4$ spinel are stable below ~8 GPa. Based on these results, we suggest possible origin and transportation processes of the kimberlitic diamonds containing the composite inclusions of kalsilite and spinel, as follows. NAL phases with approximate compositions in the system $(K,Na)AlSiO_4$-$MgAl_2O_4$ were trapped in the diamonds during the growth in the lower mantle, then were transported to depth range of about 150-210 km where kalsilite and spinel crystalized in the diamonds, and the diamonds were finally transported rapidly to the earth’s surface by the kimberlite volcanism.

Keywords: high pressure, NAL phase, phase transition, diamond inclusion, kimberlite

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Rheology of bcc-iron at high-pressure and -temperature

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Although many hypotheses have been proposed for origin of the seismic anisotropy in the Earth’s inner core, there is no general consensus for its origin. Lasbleis and Deguen (2015) discussed that dominant mechanism of the inner core dynamics depends on the inner core age and viscosity, and there are several candidate mechanisms which includes anisotropic growth model (Yoshida et al., 1996) and thermal convection model (Jeanloz and Wenk, 1988). It had been widely accepted that the inner core consists of iron-rich alloy with hexagonal close-packed (hcp) structure. However, some recent computational mineral physics studies (e.g. Belonoshko et al., 2017) claimed that the iron-rich alloy in the inner core possibly has body-centered cubic (bcc) structure rather than hcp. Therefore, information of viscosity of bcc-iron is important for the accurate understanding of the inner core dynamics. In this study, we have studied rheology of bcc-iron based on high-pressure and high-temperature deformation experiments.

Uniaxial deformation experiments were carried out using a deformation-DIA apparatus SPEED-MkII-D installed on a beamline BL04B1 at SPring-8. Using polycrystalline iron aggregate as a starting material, deformation experiments were carried out at pressure of 2.0-6.0 GPa, temperature of 523-823 K, and strain rate of 0.8–5.7×10^{-5} s^{-1}. Stress and strain during deformation were determined based on two-dimensional X-ray diffraction and X-ray radiography, respectively, using monochromatized synchrotron X-ray with energy of 60 keV.

A preliminary analysis of the derived data suggests that power-law dislocation creep with stress exponent of ~5 and activation volume of 2-3 cm^3/mol is dominant. Extrapolation of the data to ambient pressure is generally consistent with the well-established ambient pressure rheology of this material (Frost and Ashby, 1982). When compared with rheology of hcp-iron at same deformation condition, stress value of bcc-iron is lower by ~1 order of magnitude. This means that viscosity of bcc-iron is lower by ~5 orders of magnitude than that of hcp-iron because stress exponent for the both iron polymorphs is considered to be ~5. If the inner core mostly consists of bcc-iron, the viscosity in the inner core is estimated to be significantly lower than the previous estimates where hcp-iron was assumed to be the dominant inner constituent.

Keywords: inner core, bcc-iron, rheology

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[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG56] ICDP Oman Drilling Project: Oman to Oceanic Lithosphere to Island Arc Formation and Beyond

convener:Eiichi TAKAZAWA(Department of Geology, Faculty of Science, Niigata University), Katsuyoshi Michibayashi(Department of Earth and Planetary Sciences, Nagoya University), Sayantani Chatterjee(Niigata University, Department of Geology, Faculty of Science)

The on-going Oman Drilling Project has drilled numerous hard-rock cores of ancient oceanic lithosphere and the underlying subduction zone of the Samail ophiolite in Oman, with support from ICDP, IODP, the Sloan Foundation's Deep Carbon Observatory, and Japanese, US, and European research agencies. In this session, we invite presentations on the scientific results of Oman Drilling Project. We also invite related studies of on-land geological investigations of Oman ophiolites and experimental studies. The session is intended to be interdisciplinary, including the fields of geophysics, geochemistry, petrology, engineering, and biology.

[SCG56-01] Feedback between melt percolation and deformation at Oman crust-mantle transition zone: ICDP_ Exp. 807 Holes CM1A and CM2B

★Invited Papers

*Fatma Kourim[1], Katsuyoshi Michibayashi[2], Kou-Lung Wang[1,3], Jürgen Koepke[4], Mathieu Rospabé[5], Mary-Alix Kaczmarek[6], Eiichi Takazawa[7], Damon A-H Teagle[8], Marguerite Godard[9], Mathieu Benoit[6], Peter Kelemen[10], Yuki Kakihata[2], Oman Drilling Project Phase 2 Science Party (1.Institute of Earth Sciences, Academia Sinica, 2.Nagoya University, 3.National Taiwan University, 4.Hannover University, 5.Research Institute for Marine Geodynamics, JAMSTEC, 6.Toulouse university, 7.Nigata University, 8.Southampton University, 9.University of Montpellier, 10.Columbia University)

[SCG56-02] Important role of the ultramafic layers in the lower oceanic crust and Moho

*Natsue Abe[1,2], Keishi Okazaki[3], Kohei Hatakeyama[4], Yuya Akamatsu[4], Ikuo Katayama[4], Benoit Ildefonse[5], Katsuyoshi Michibayashi[6], Eiichi TAKAZAWA[7], Damon A H Teagle[8], Peter B Kelemen[9], Science Party The Oman Drilling Project (1.Mantle Drilling Promotion Office, MarE3, Japan Agency for Marine-Earth Science and Technology , 2.Graduate School of Natural Science & Technology, Kanazawa University, 3.KCC, X-star, Japan Agency for Marine-Earth Science and Technology , 4.Hiroshima University, 5.University of Montpellier, 6.Nagoya University, 7.Niigata University, 8.University of Southampton, 9.LDEO, Columbia University)

[SCG56-03] An idea of borehole measurements at Mantle drilling: insights from the OmanDP

★Invited Papers

*Yasuhiro Yamada[1,2,3], KYAW MOE[1], Kazuya Shiraishi[1] (1.Japan Agency for Marine-Earth Science and Technology (JAMSTEC), 2.Kochi University, Japan, 3.Royal Holloway University of London, UK)

[SCG56-04] Strontium isotopic compositions of mantle peridotites in the Oman ophiolite

*Jiwon Eom[1], Shigeyuki Wakaki[2], Norikatsu Akizawa[1], Tsuyoshi Ishikawa[2], Kyoko Yamaoka[3], Eiichi TAKAZAWA[4], Hodaka Kawahata[1] (1.Atmosphere and Ocean Research Institute, The University of Tokyo, 2.Kochi Institute for Core Sample Research, JAMSTEC, 3.Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology, 4.Department of Geology, Faculty of Science, Niigata University)

[SCG56-05] Reconstruction of peridotite textures preserved within serpentinites from BA site of Oman Drilling Project Phase II

*Kakihata Yuki[1], Katsuyoshi Michibayashi[1], Laura Crispini[2], Oman Drilling Project Phase2 Science Party (1.Nagoya University Graduate School of Environmental Studies, 2.University of Genova)

[SCG56-06] Rock Magnetic Properties of Oman Drilling Project Cores BA1B, BA3A, BA4A and Its Implications on Iron Oxide Alteration

*Gilbert Hong[1], Jessica Lynn Till[2], Annika Greve[3], Sang-Mook Lee[1], Oman Drilling Project Phase 2 Science Party - (1.Seoul National University, 2.University of Iceland, 3.Utrecht University)

Feedback between melt percolation and deformation at Oman crust-mantle transition zone: ICDP_ Exp. 807 Holes CM1A and CM2B

*Fatma Kourim[1], Katsuyoshi Michibayashi[2], Kou-Lung Wang[1,3], Jürgen Koepke[4], Mathieu Rospabé[5], Mary-Alix Kaczmarek[6], Eiichi Takazawa[7], Damon A-H Teagle[8], Marguerite Godard[9], Mathieu Benoit[6], Peter Kelemen[10], Yuki Kakihata[2], Oman Drilling Project Phase 2 Science Party

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Oman ophiolite crust-mantle transition was drilled at Holes CM1A and CM2B (Wadi Tayin Massif) during Phase 2 of the Oman Drilling Project (Nov. 2017-Jan. 2018) in the Wadi Zeb of the Wadi Tayin massif. Hole CM1A (400m-long) crosses from the lowermost crust consisting of Layered gabbros, through the crust-mantle transition zone, into residual upper mantle peridotites, while Hole CM2B (300m-long) started in the crust-mantle transition zone penetrating the underlying residual mantle peridotites. The main lithological units characterized in both holes are olivine gabbro, gabbro, dunite, harzburgite and wehrlite, associated with minor gabbronorite, troctolite, websterite, anorthosite, and chromitite. During Oman-DP Phase 2 Leg 3 (ChikyuOman; July-Aug. 2018), 95 and 67 samples of core from CM1A and CM2B, respectively, were analyzed for whole-rock major and minor elements (XRF) as well as CO_2 and H_2O concentrations (CHNS). XRD measurements were performed on the 69 onsite samples. Furthermore, whole-rock (pressed powder pellets) and mineral trace element contents were determined for selected samples onboard the D/V Chikyu, using the NewWave Research UP-213 Nd: YAG deep UV (213 nm) laser ablation system coupled with an Agilent 7500ce quadrupole ICP-MS.
Samples from holes CM1A and CM2B have a large petrological and chemical variability, mainly reflecting the different rock types, especially across the crust-mantle transition. CM1A and CM2B volatile element contents reflect extensive serpentinization linked to interaction with H_2O-rich fluids, and abundant carbonate veins downhole, suggesting an association between CO_2-rich fluids and serpentinization. Whole-rock and clinopyroxene trace element abundances are similar to Oman ophiolite compositions described in previous studies. All gabbroic domains display nearly parallel REE patterns with a strong depletion in HFSE relative to REE. Dunites and harzburgites display variable trace element contents and REE patterns, negative or positive anomalies in Eu and commonly moderate to strong positive anomalies in U, Pb, Sr and Ti. The variation of REE concentrations and patterns observed in Oman dunites could be explained by melt-rock reactions leading to dunite formation, after the dissolution of orthopyroxene in harzburgite and interaction with interstitial melt.
Another way to explore melt percolation and deformation feedback at Oman crust-mantle transition zone is the analysis of detailed olivine crystallographic preferred orientations (CPO) of 36 selected samples from hole CM1A (1 olivine gabbro, 10 dunites, and 8 harzburgites) and CM2B (6 dunites, and 12 harzburgites). Olivine CPO‘s indicates that all samples from the Oman crust-mantle transition zone display well-developed olivine CPO, the three classics high temperatures olivine CPO’s symmetries (axial-[100], axial-[010] and orthorhombic) are present with an olivine J-index varying from 1.2 to 8.6. The geochemical investigations conducted onboard D/V Chikyu (Phase 2 Leg 3; July-Aug. 2018) together with the variabilities observed in olivine CPO types and strength within Oman crust-mantle transition could be explained by the localization of deformation during diffuse (crystals grains boundaries) and focused (veins, faults) melt percolation.

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Keywords: Oman crust-mantle, Melt percolation , Olivine CPO , XRF,ICP-MS, LA-ICP-MS, Oman drilling project

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Important role of the ultramafic layers in the lower oceanic crust and Moho

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ICDP Oman Drilling Project drilled several parts of the crustal section and the mantle section in the Samail ophiolite and sampled continuous cores. Onboard core logging was conducted on D/V Chikyu for 4 months in total in the summers of 2017 and 2018. We analyzed the core samples of 3200 m total length from 9 holes. The cores from the lower crustal section (Holes GT1A and GT2A) are mainly composed of olivine gabbro and gabbro, and also with small amounts of ultramafic rocks (wehrlite and dunite) and olivine-rich gabbro and troctolite. Hereafter, we call those olivine-rich rocks in the lower crust as the “ultramafic layers”. The CM holes were drilled through the crust-mantle transition, from gabbroic lower crust, through the Moho Transition Zone (MohoTZ) dunite with minor gabbros, and into residual mantle harzburgite. The lower crustal section in the Hole CM1A also includes a small number of ultramafic layers.

Whole-round data, including X-ray CT images, natural gamma radiation (NGR), gamma-ray attenuation (GRA) density, magnetic susceptibility (MS), P-wave velocity (Vp) and noncontact electrical resistivity were obtained. Split core color spectroscopy data were also collected. Magnetic susceptibility, P-wave velocity, bulk/grain density, porosity, and thermal conductivity were measured in discrete samples. Nearly 100% core recovery allowed us to take a large data set of petrophysical data on the cores from Oman ophiolite including fault zones and highly altered intervals.

Ultramafic rocks in the lower crustal section and MohoTZ show significantly higher porosity, electrical conductivity, magnetic susceptibility and thermal conductivity than gabbros. The electrical and magnetic properties of ultramafic layers also show clear correlations with the bulk density and porosity. Significant differences of the physical properties within those lithologies suggest that the ultramafic layers in the lower crust and the MohoTZ are key to understanding the seafloor structure.

Keywords: ICDP Oman Drilling Project, D/V Chikyu, Ultramafic layer, Oceanic Crust, MohoTZ, Physical Properties

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An idea of borehole measurements at Mantle drilling: insights from the OmanDP

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The ICDP Oman Drilling Project (OmanDP) brought us great experiences to realistically consider / prepare the future drilling to the mantle, i.e. drill out the Moho and the crust-mantle transition zone.

One of the most important scientific targets would be the detailed structure around the Moho, and there may be a complicated transition zone as we can seen in the Oman Ophiolite. We need two different types of information for this purpose: physical property and mineral composition. Physical property is vital to understand the mechanical architecture of the boundary and to compare with the seismic characteristics identified on the seismic profile. Among the properties, acoustic impedance is of importance defined by sonic and density, which can be measured in-situ by using geophysical logging tools. Mineral composition could be examined continuously by cuttings when riser pipes are connected, otherwise we need to run geophysical logging operation for this purpose as well. Geochemical logging, e.g. lithoscanner, was tested at the CM sites of the OmanDP and showed potential in-situ elemental measurements at every 50 cm.

Internal stress environment of oceanic plates, a basic question on how the plate moves, is another important scientific interest, which borehole images may bring key information. A possible method to extract the information would be identification of borehole failure, i.e. drilling induce tensile fractures (DITFs) for this purpose. DITFs, an indicator of the SHmax direction, may be produced by cooling of the borehole wall-rock by circulating drilling fluid.

As for geophysical logging operations, wireline tools have advantages in term of variety and accuracy of the data, comparing to the logging-while-drilling (LWD) tools. The wireline tools, however, have lower temperature limit, e.g. 260˚F (126˚C), whereas LWD tools may have less problem in temperature as far as the drill mud can be circulated. For the greater depth, we also need to consider possible pressure due to the heavy drill mud affecting on the tools.

Drilling parameter data, commonly used for operation purposes, such as WOB, ROP, RPM, TOR may be useful to draw continuous strength profile along the borehole. The data quality would be much better by using MWD, compared with the data acquired by the drilling system. MWD can be run under high temperature environments but may not be used with combination of downhole motor.

Keywords: crust-mantle boundary, Moho, geophysical logging, OmanDP

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Strontium isotopic compositions of mantle peridotites in the Oman ophiolite

*Jiwon Eom[1], Shigeyuki Wakaki[2], Norikatsu Akizawa[1], Tsuyoshi Ishikawa[2], Kyoko Yamaoka[3], Eiichi TAKAZAWA[4], Hodaka Kawahata[1]

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The Oman ophiolite is one of the best exposed and preserved ophiolites on Earth. It preserves complete oceanic stratigraphy with a mid-ocean ridge basalt (MORB) underlain by sheeted dykes, gabbros and peridotites. Although the initial stage of its formation is still controversial (at a mid-ocean ridge or in supra-subduction zone), many geochemical evidences support that the Oman ophiolite was modified by arc magmatism. Here, we report strontium isotopic compositions of mantle peridotites in the Oman ophiolite. The peridotites are harzburgite considering their modal composition (~a few volume % clinopyroxene). We collected the harzburgites from the north to south massifs, covering entire the Oman ophiolite. All the data is age-corrected to 96Ma. The harzburgites from the northern Oman ophiolite are significantly higher in $^{87}Sr/^{86}Sr$ values than Cretaceous seawater (0.7076). Particularly, northernmost samples traversing northern Fizh mantle section from basal thrust to the crust/mantle boundary are characterized by homogeneous $^{87}Sr/^{86}Sr$ values (0.7078 to 0.7086) indicating the involvement of fluids with high $^{87}Sr/^{86}Sr$ in the mantle. On the contrary, lower $^{87}Sr/^{86}Sr$ values than Cretaceous seawater are dominant to the south, implying that the mantle was insufficiently modified by the fluids. The regional variation of $^{87}Sr/^{86}Sr$ values may be relevant to the contribution of pelagic sediment with elevated $^{87}Sr/^{86}Sr$ values derived from the subducting slab. This feature is consistent with the fact that the arc magmatism is only developed in the northern Oman ophiolite, e.g. discordant dunite channels in the mantle section and arc tholeiitic and boninitic extrusive rocks in the crustal section.

Keywords: Oman ophiolite, Strontium isotope

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Reconstruction of peridotite textures preserved within serpentinites from BA site of Oman Drilling Project Phase II

*Kakihata Yuki[1], Katsuyoshi Michibayashi[1], Laura Crispini[2], Oman Drilling Project Phase2 Science Party

1. Nagoya University Graduate School of Environmental Studies, 2. University of Genova

Oman Ophiolite, which is the biggest ophiolite located in the eastern part of the Arabian Peninsula, preserves sequential structures of oceanic crust and upper mantle. The Oman Drilling Project has obtained the cores penetrating from the lower crust to the uppermost mantle including the crust–mantle transition zone. Structural characteristics of ultramafic cores in three holes at BA site have been studied in this study. We have selected 61 core samples in BA1B, BA3A and BA4A, and performed electron backscatter diffraction (EBSD) analyses in order to understand nature of the uppermost mantle flow. The ultramafic core samples consist of intensely serpentinized harzburgites and dunites. Deformation structures vary ranging from granular to protomylonite exhibited by elongated and aligned pyroxene grains. Measured dip angles of elongated pyroxene are dominantly subhorizontal in the overall core. Pyroxene and olivine grains in the protomylonitic peridotites with distinct foliations are intensely elongated and show kink bands and undulatory extinction in thin sections. In the granular peridotites, pyroxene grains have rounded shapes. In processing EBSD data, the primary textures have been reconstructed by extrapolation, when they were obscured by the intense serpentinization. Based on the reconstructed EBSD maps, grain sizes of olivine were in the range from 0.4 to 1.1 mm, suggesting that the grain size reduction occurred locally. Crystallographic preferred orientations (CPOs) of olivine were analyzed by the EBSD maps. J-index, which is the index of strength of olivine CPOs, ranges from 2 to 4. In BA1B, J-index and mean grain sizes slightly decreased, whereas olivine CPOs gradually changed from A to D type in the deeper cores. In BA3A, J-index and mean grain size decreased at around 200 m in depth, whereas olivine CPOs were fundamentally D type. In BA4A, harzburgites have constant value of J-index around 2.3 and A to D type. These results show that the ultramafic cores in the BA site would have been modified their primary peridotite textures by secondary lithospheric deformation before serpentinization.

Keywords: Oman Drilling Project, mantle peridotite, Crystallographic Preferred Orientation (CPO)

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Rock Magnetic Properties of Oman Drilling Project Cores BA1B, BA3A, BA4A and Its Implications on Iron Oxide Alteration

*Gilbert Hong[1], Jessica Lynn Till[2], Annika Greve[3], Sang-Mook Lee[1], Oman Drilling Project Phase 2 Science Party -

1. Seoul National University, 2. University of Iceland, 3. Utrecht University

The primary objective of our study is to investigate the magnetic properties of Oman Drilling Project cores BA1B, BA3A, and BA4A drilled from Wadi Lawayni, Oman; and to compare them with the mineral structure to find evidences of Iron Oxide alteration during serpentinization. The cores mainly consist of heavily serpentinized Harzburgites and Dunites with gabbroic dikes densely populated within the strata. The initial measurements, including bulk magnetic susceptibility and thin section observations, were done onboard D/V Chikyu during Oman Drilling Project phase 2. Further studies regarding natural remanent magnetism (NRM) during alternating field (AF) and thermal demagnetization were done at the University of Iceland.

In general, significant correlations are observed between the induced magnetic data and petrology of the cores. In the case of volume normalized magnetic susceptibility the magnitude remains mainly low (<0.02 SI) throughout most of the depths of all 3 cores, with dunitic areas showing higher values compared to Harzburgite dominant sections. Such behavior is perceived to be normal for serpentinized peridotite, and is considered to be because of the difference in Fayalite content. However, we have found that the bulk magnetic susceptibility is unusually high (>0.03SI) for rocks near the surface (0-50m depth) and Olivine Gabbro dikes (normally within 5m). The degree of anisotropy mostly remained low throughout all 3 cores, with occasional peaks observed near gabbroic dikes. Though it is unclear whether such phenomenon is directly related to magma contact and its resulting heat conduction, it may still reflect that the magnetic minerals and their magnetic signatures have been physically affected by magmatic intrusions.

Based on the analysis on induced magnetism onboard D/V Chikyu, further investigations on NRM were done to reveal the differences in both magnetic and mineralogical features between surface and deeper near-dike domains. NRM intensity tends to be high around magma intrusions, but remains relatively low for surface rocks. While the magnitude of both induced and remanent magnetism correlate with the magnetite content within the mineral mesh, demagnetization behaviors differ significantly between surface and lower depths. In addition, unusual positive NRM inclination was observed along the 0-50m depth range of core BA3A and some Harzburgite dominant sections of BA1B, indicating that partial remagnetization occurred along these areas. Notable differences were observed in stepwise thermal demagnetization patterns as well, showing significantly lower median destructive temperature (MDT) at the surface of BA3A core. This implies that the formation mechanism of the magnetite may vary among the BA cores, and such diversity might reflect that significant Iron Oxide mineral alterations have been induced by magma and fluid intrusions. To clarify the hypothesis, future studies will emphasize on further classification of magnetic minerals upon chemical and crystallographic attributes using SEM observations and intense geochemical investigations, aiming to specify how magnetic minerals and their magnetic signatures originated.

Keywords: rock magnetism, Iron Oxide alteration, serpentinization, magmatic intrusion

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[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG56] ICDP Oman Drilling Project: Oman to Oceanic Lithosphere to Island Arc Formation and Beyond

convener:Eiichi TAKAZAWA(Department of Geology, Faculty of Science, Niigata University), Katsuyoshi Michibayashi(Department of Earth and Planetary Sciences, Nagoya University), Sayantani Chatterjee(Niigata University, Department of Geology, Faculty of Science)

The on-going Oman Drilling Project has drilled numerous hard-rock cores of ancient oceanic lithosphere and the underlying subduction zone of the Samail ophiolite in Oman, with support from ICDP, IODP, the Sloan Foundation's Deep Carbon Observatory, and Japanese, US, and European research agencies. In this session, we invite presentations on the scientific results of Oman Drilling Project. We also invite related studies of on-land geological investigations of Oman ophiolites and experimental studies. The session is intended to be interdisciplinary, including the fields of geophysics, geochemistry, petrology, engineering, and biology.

[SCG56-07] Melt-rock interaction processes inferred from spinel-bearing layered gabbros in the Hess deep rift, East Pacific Rise

*Keita Kondo[1], Takashi Hoshide[1] (1.Faculty of International Resource Science, Akita University)

[SCG56-08] **Petrography and geochemistry of lower crustal gabbros at Oman ophiolite: Insight from Oman Drilling Project Phase 1 & 2**

*Sayantani Chatterjee[1], Eiichi Takazawa[1,2], Katsuyoshi Michibayashi[3], Oman Drilling Project Science Party (1.Department of Geology, Faculty of Science, Niigata University, 2.Volcanoes and Earth's Interior Research Center, Research Institute for Marine Geodynamics, JAMSTEC , 3.Department of Earth and Environmental Sciences, Nagoya University, Japan)

[SCG56-09] Velocity gradient in the oceanic crust layer 3 based on seismic velocity of cores drilled from the Oman ophiolite

*Kohei Hatakeyama[1], Ikuo Katayama[1], Natsue Abe[2], Keishi Okazaki[3], Katsuyoshi Michibayashi[4], The Oman Drilling Project Science Party (1.Department of earth and planetary systems science, Hiroshima University , 2.Japan Agency for Marine-Earth Science and Technology, 3.Kochi Institute for Core Sample Research, Japan Agency for Marine-Earth Science and Technology, 4.Nagoya University)

[SCG56-10] Synthesis of Oceanic Crustal Structure from Two-Dimensional Seismic Profiles
★Invited Papers

*Gail Lynn Christeson[1], John Goff[1], Robert Reece[2] (1.University of Texas at Austin, 2.Texas A&M University)

[SCG56-11] **Petrographical and chemical evolution of a troctolites rich section of oceanic crust located directly above a spreading centre, example from Wadi Mahram, Oman ophiolite**
★Invited Papers

*Marie Python[1], Mathieu Rospabe[2], Claire Charles[3], Georges Ceuleneer[4], Shoji Arai[5] (1.Hokkaido University Department of Natural History Science Division of Earth and Planetary Systems Sciences, 2.Japan Agency for Marine-Earth Science and Technology, 3.IFREMER, Université de Bretagne Loire, Brest, France, 4.Université Paul Sabatier, GET, OMP, Toulouse, 5.Department of Earth Sciences, Faculty of Science, Kanazawa University)

[SCG56-12] **The PGE and Os isotope variations of the mantle derived rocks from the ICDP Cores of the Oman Drilling Project at the Samail Ophiolite, Oman**

*Ryoko Senda[1,2], Katsuhiko Suzuki[2], Tomoaki Morishita[3], Eiichi TAKAZAWA[4], The Oman Drilling Project Science Party (1.Faculty of Social and Cultural Studies, Kyushu University, 2.Submarine Resources Research Center, Japan Agency for Marine-Earth Science and Technology, 3.School of Geoscience and Civil Engineering, College of Science and Technology, Kanazawa University, 4.Department of Geology, Faculty of Science, Niigata University)

Melt-rock interaction processes inferred from spinel-bearing layered gabbros in the Hess deep rift, East Pacific Rise

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IODP Exp.345 had drilled three main holes (U1415 I, J and P) at the Hess Deep rift, East Pacific Rise and recovered layered gabbroic rocks formed at the fast-spreading mid-ocean ridge [1]. One of the enigmas of the gabbroic rocks is that orthopyroxene occurs like an early-formed mineral (Mg# = 85~88, subhedral) in layered gabbros, even though it has been considered to appear in the late stage of crystallization of MORB melt. However, the formation mechanism of orthopyroxene is still unrevealed. Previous researches about the U1415 have clarified various occurrences of orthopyroxene; as a cumulus mineral [1], as the reaction rim around olivines, in veinlets, in the concave of anhedral olivine or as a constituent mineral in the multiphase solid inclusion in chromian-spinel [2]. The inclusions hosted by chromian-spinels had not been studied in detail. Here, we report the petrological and chemical characters of spinel-bearing layered gabbros including orthopyroxene at Hole U1415P and discuss the magma processes associated with the formation of the layered gabbros.

Hole U1415P is about 100m in length and divided into two main units based on lithology. The upper unit is called the Multi-textured Layered Gabbro Series that is composed of mainly orthopyroxene-bearing olivine gabbro or olivine gabbro and has inhomogeneous structures which exhibit the centimeter-scale variations in modal composition or grain size. In contrast, the Troctolite Series of the lower unit shows almost no lithological change and is relatively homogeneous.

Spinel-bearing olivine gabbros (U1415P 6R-1 to 6R-2) are locally distributed in the Multi-textured Layered Gabbro Series. Spinels occur in the troctolitic part of the olivine gabbro and are not included in olivine and the core of plagioclase. They are associated with orthopyroxene which occurs as the reaction rim on olivine. The occurrence and distribution of spinels are well similar to the texture reported in a troctolite sample from the ODP Site 895 (the mantle-crust transition-zone[3]), which has been interpreted as a product of an interaction between depleted peridotite and primitive MORB melt [4].

In addition, Cr_2O_3 (wt%) and Mg# in clinopyroxene do not change so much with the variation of TiO_2 (wt%) in clinopyroxene. The trend is similar to that related to the formation of the podiform chromitite [4] (Constant Cr_2O_3 regardless of TiO_2 variation) than that in layered mafic intrusions like the Bushveld complex [5] (Cr_2O_3 decrease with increasing TiO_2). The similarity in the Ti-Cr relationship for clinopyroxene suggests that the spinel-bearing layered gabbros may have been formed by some kind of interaction process.

Spinel-hosted multiphase solid inclusions consist of some of four main silicates (clinopyroxene, orthopyroxene, plagioclase, and K-phlogopite) with minor accessory minerals (chlorite, talc, titanite, Fe-Ti oxides, spinel, apatite, Fe-Ni-Cu sulfides, and zircon). On the basis of the mineral assemblage, the spinel-hosted multiphase inclusions can be divided into the following four types(Fig.1),

(1) “Cpx + Pl type” mainly composed mainly of clinopyroxene, plagioclase, and chlorite,

(2) “Opx-dominant type” consisting mainly of a large amount of orthopyroxene (up to 80 vol%) and

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minor phlogopite,

(3) “Intermediate type” including all main silicates which constitute “Cpx + Pl type” and “Opx-dominant type”,

(4) “Void type” is the tiny composite inclusion (up to 5 μm in size) which is composed of phlogopite, apatite, sulfides, and voids.

We analyzed the bulk chemical compositions of inclusions using a rastering technique on SEM-EDS. The bulk compositions of the “Cpx + Pl type” are mainly basaltic (partly picritic), ranging in SiO_2 from 45 to 48 wt% and in MgO from 7 to 23 wt%. In contrast, the “Opx-dominant type” inclusions have high-Mg basaltic andesitic to high-Mg andesitic compositions, with SiO_2 between 52 and 63 wt% and MgO between 20 and 34 wt%. Therefore, we conclude that a basaltic and a high-Mg andesitic melt may have been related to the melt-rock interaction process to form the Hess Deep spinel-bearing layered gabbro.

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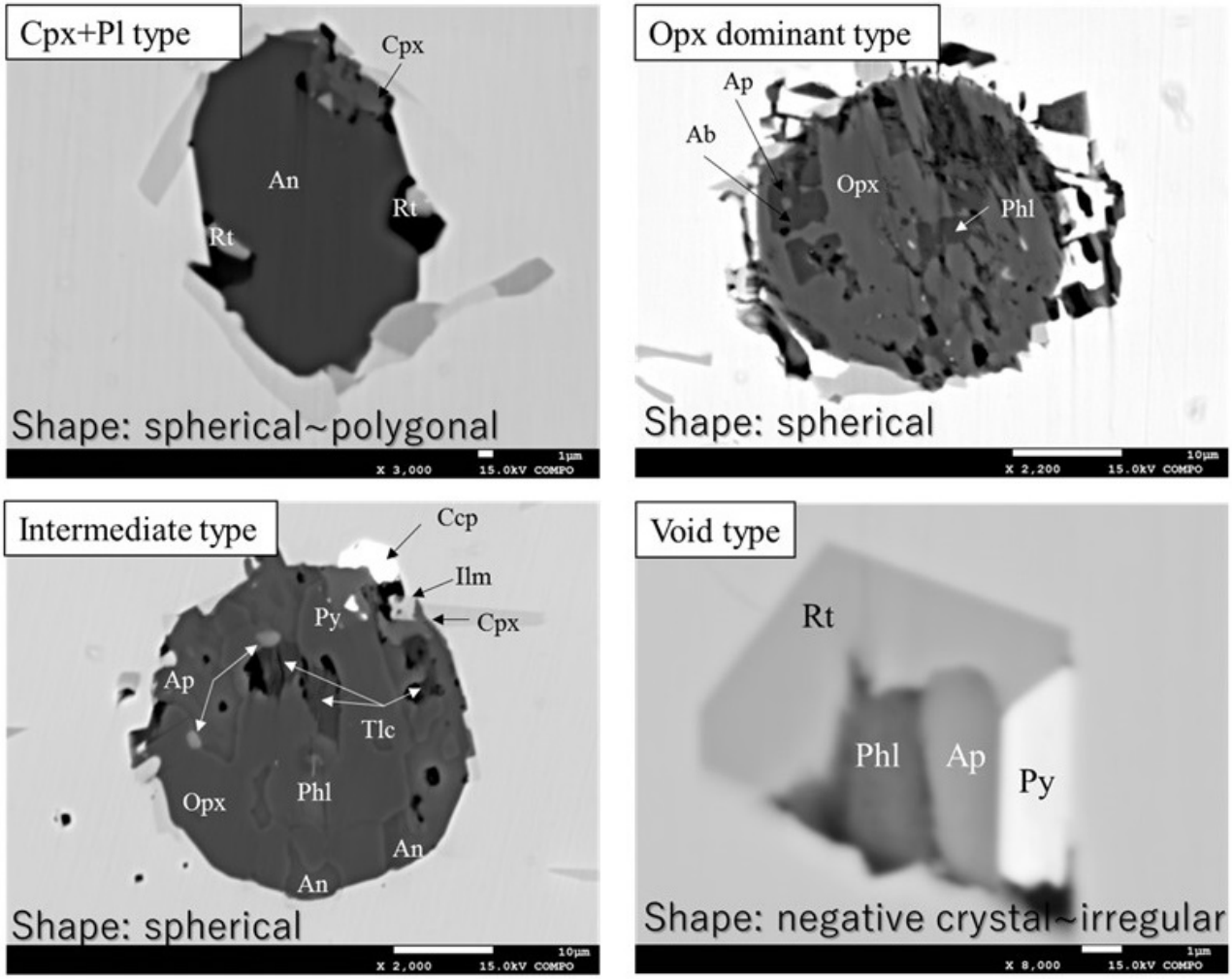

Figure 1: Backscatter-electron images of multiphase solid inclusions in spinels from the Hess Deep layered gabbros

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Petrography and geochemistry of lower crustal gabbros at Oman ophiolite: Insight from Oman Drilling Project Phase 1 & 2

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Ophiolites are the fragments of the ancient oceanic lithosphere that are exposed (mostly as dismembered) on the land surface. Magmatic processes responsible for accretion of the lower oceanic crust remain one of the least-restrained components of the global seafloor spreading system. Lack of sufficient exposures regarding the systematic representation of the oceanic lithosphere is another major hindrance in deciphering crust-mantle differentiation. In order to achieve this goal lower oceanic crust thought to be a crucial lithomember which turns out to be pretty rare in a global context to observe spatial variations in magmatic flow within in situ lower crust. In this contribution, we report recovered lower crust from Oman drilling Project Phase 1, which was drilled into Wadi Gideah of Wadi Tayin massif and Phase 2, which was drilled into Wadi Zeeb of Wadi Tayin massif in Samail Ophiolite, Oman.

In Phase 1, Hole GT1A drilled the lower crustal section (recovered 401.52 m of total cores) and Hole GT2A was mainly concentrated to recover through the transition between lower crustal foliated and layered gabbro (total depth of 406.77m). Phase 2 concentrated to drill lower crust to the mantle transition zone. Hole CM1A drilled base of crust to the mantle transition zone (total depth of 404.15 m) and CM2B drilled the mantle transition zone to the mantle (total depth of 300 m).

Petrographic observation of representative samples from both phases, we found two dominant rock types: Gabbbro and Olivine gabbro, where later dominates the lower part of the drill hole. Interlayered Troctolites in association with gabbroic rock are also noted in Phase 1 samples.

Gabbroic lithologies represented by anhedral olivine with tabular to elongate shaped. Clinopyroxenes are tabular to subequant in habit. Some thin film of orthopyroxene is present as a corona around olivine. Most of the samples have undergone alteration and obscured the igneous origin. Gabbros contain plagioclase and clinopyroxene (showing poikilitic texture) as primary minerals associated with few amounts of oxides. Clinopyroxenes are often replaced by brown amphibole along cleavages or at the rim. In olivine gabbros, olivine grains are present as subhedral to skeletal in nature. Magmatic foliation is often demarked by laths of plagioclase followed by elongated clinopyroxenes. Also, symplectitic intergrowth is present between spinel and orthopyroxene. All lithologies from different holes show the different textural relationships, which will be included in this discussion.

Downhole variations of major mineral compositions and trace element compositions in both phases indicate several cycles of crystallization history. Detailed petrographic, microstructural and geochemical studies of all the representative samples will be presented. We have also attempted to determine the oxygen fugacity of the system using oxide minerals to show the range of temperature and pressure. Oxygen fugacity provides a clue to determine the thermal evolution of the lower crust and the rate of cooling to understand the accretion process.

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Our data will be used to ascertain the hypotheses on accretion process of lower crust formation by 'The gabbro glacier' model (Nicolas et al., 1988), 'Sheeted sill' model (Kelemen et al., 1997) and maybe a hybrid model (Lissenberg et al., 2013) of both and its role to modification of composition of MORB. Moreover, assimilation-fractional crystallization and the percentage of trapped melt estimation will give the total scenario of the formation of lower crustal gabbros.

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Keywords: Lower crustal gabbros, Mid oceanic ridge, Oman ophiolite, Oman Drilling Project

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Velocity gradient in the oceanic crust layer 3 based on seismic velocity of cores drilled from the Oman ophiolite

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Seismic velocity of lower oceanic crust gently increases with the depth (seismic layer 3). Elastic wave velocity measurements of gabbro collected from ophiolite and ocean drilling suggest that velocity gradient of layer 3 is due to crack closure caused by increasing lithostatic pressure (Saito et al., 2015, Carlson and Miller, 2004). However, in the ophiolite stratigraphy, mineral assemblage of oceanic crust is heterogeneous, as the contents of olivine and pyroxene increase in the lower oceanic crust (Salisbury and Christensen, 1978; Christensen and Smewing, 1981). Therefore, it is necessary to consider the effect of crack closure and mineral assemblage with the depth of oceanic crust to understand velocity gradient of layer 3. In this study, the effects of pressure and mineral assemblage on elastic wave velocity of mafic rocks forming middle to lower oceanic crust drilled from the Oman ophiolite (Oman Drilling Project) were examined. Experimental samples were diabase and gabbro drilled from sheeted dyke-gabbro transition (Hole GT3A), foliated gabbro (Hole GT2A), layered gabbro (Hole GT1A) and crust-mantle transition (Hole CM1A). Modal analysis was performed on thin section. Intra-vessel deformation and fluid flow apparatus at Hiroshima University were used to measure elastic wave velocity under confining pressure. Elastic wave velocities (V_P and V_S) were measured from the pulse transmission method. After measurements under dry condition, measurements under wet conditions injecting pore water were performed. Pore pressure was set at 10 MPa using a syringe pump. In both experiments, confining pressure was up to 200 MPa. Experimental results showed increasing velocity with confining pressure, suggesting closing cracks. Under wet conditions, V_P of diabase increased relative to those determined under dry condition, indicating the effect of pore fluid. In contrast, the effect of pressure and pore fluid on velocity was weak in gabbro samples. We assumed that the pressure dependence of velocity is caused by closing cracks, and theoretical model of O’ Connell and Budiansky (1974) was applied to estimate crack density. Although crack density decreased with pressure, the pressure dependence of crack density was small under high pressure condition. The experimental results under high pressure were almost consistent with velocity calculated from modal composition, and samples of lower oceanic crust showed relatively high velocity. These results may reflect that the effect of mineral assemblage is predominant in the factor of velocity gradient of layer 3.

Keywords: Oman Drilling Project, Oceanic crust layer 3, Elastic wave velocity, Crack, Mineral assemblage

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Synthesis of Oceanic Crustal Structure from Two-Dimensional Seismic Profiles

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We carried out a new synthesis of oceanic crustal structure from high-quality two-dimensional seismic refraction profiles. Our compilation includes 120 velocity-depth functions from 55 publications, with ages varying from 0-171 Ma, and spreading rates from 7-102 mm/yr half-rate. Average crustal thickness in our dataset is 6.15±0.93 km. Layer 2 has an average thickness of 1.84 km, but is thicker for young slow-spreading crust (2.06 km) and thinner for superfast-spreading crust (1.36 km). The layer 2/3 boundary likely corresponds with the lithologic boundary between dikes and gabbros for young fast- and superfast-spreading crust. At slow-spreading centers the layer 2/3 boundary is well above the imaged AMC reflector, and is interpreted to mark a change in porosity with depth within the dikes. At intermediate-spreading centers the layer 2/3 boundary corresponds to different lithologies (within dikes or at dike-gabbro boundary) depending on the magma supply. Layer 3 thicknesses approximately display the opposite trend with spreading rate as layer 2 thicknesses, resulting in a similar crustal thickness across all spreading rates.

Velocities at the top of layer 2 increase rapidly from ~3.0 km/s at 0 Ma to 4.6 km/s at 10.5 Ma, with a slower increase to 5.0 km/s at 170 Ma; however, some of this velocity increase may be influenced by sediment thickness. The rapid increase in velocity at young ages is attributed to crack closure by precipitation of hydrothermal alteration products; the increase at older ages suggests that this process may continue as the oceanic crust continues to evolve. High velocities at the top of layer 2 are associated with regions of thick sediment; velocities approaching or reaching laboratory measured values of 5.8-5.9 km/s are observed with a sediment thickness of 4.0-4.3 km. Pressure from the thick sediment will close microcracks and may also collapse large-scale features such as lava tubes and fractures.

Average velocities at the top of layer 3 are substantially lower (6.12-6.19 km/s) for young (<7 Ma) slow-spreading and intermediate-spreading crust than fast-spreading and superfast-spreading crust of this age (6.50-6.67 km/s). The low velocities at the slower spreading rates for young oceanic crust are likely associated with faults and fissures that are more prevalent and extend to greater depths at these spreading rates. Average velocities at the top of layer 3 are 6.67 km/s for older (>7 Ma) oceanic crust at all spreading rates.

Keywords: ocean crust, crustal thickness, spreading rate

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Petrographical and chemical evolution of a troctolites rich section of oceanic crust located directly above a spreading centre, example from Wadi Mahram, Oman ophiolite

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The Maqsad or Sumail massif in the Oman Ophiolite is known for its well defined mantle structural diapir and other other petrographical and chemical data perfectly matching this structure. The diapir allowed us to locate the axis of the former Oman spreading centre. However, most of the studies conducted on this famous massif concerned the mantle section and published data include mantle harzburgites and mantle dykes and intrusions petrology and chemistry. The crustal section in this massif was mapped with strong details during the 90’ s but its chemistry is only locally known in its lowest part located near the mantle/crust boundary. In this study, we conducted a sequential study of the 2 km thick Wadi Mahram crustal section (from mantle-crust boundary to sheeted dyke transition) located directly above the mantle diapir, i.e. directly above the Oman spreading axis.

The crustal column above the Maqsad diapir is exceptionally rich in troctolites as this lithology represent more than the three quarters of the observed facies and is present at any level from the basis to top of the section. Troctolites are layered in the lower levels, close to the mantle-crust transition zone, intercaled with minor olivine gabbros layers, and the layering is crosscut by centimetre scale olivine gabbro dykes. From the middle to the top of the section, vary textured troctolites progressively become become isotropic at the boundary with the sheeted dyke complex. Meter scale olivine gabbros and olivine-free layers are more abundant at the top. Dolerite dyke cutting troctolite and gabbro structures are abundant near the sheeted dyke complex and probably represent its root system.

Down section mineral chemistry evolution show a considerable contrast between the troctolites and the olivine gabbros. The troctolites chemical characteristics seem to be evolving on a large scale with 2 superposed main bodies at the top and the bottom of the section, about 800 m thick, showing a regular evolution probably in relation to magmatic differentiation during fractional crystallisation. A minor block between these 2 main troctolite bodies show a strong chemical scatter in association with variable textures and mineralogies suggesting that melt mixing and melt/rock reaction were the dominant processes during its formation. Between the layers of troctolites, olivine gabbros layers show petrographical and chemical properties that could have been acquired by local magmatic processes like differentiation in small scaled trapped melt pocket or local melt/rock reaction during melt migration to the surface. As it was already shown by studies on magmatic dykes in the mantle, the presence of differentiated dykes cutting the layered structure at the section bottom show that significant differentiation degree may be reached within the mantle and differentiated melt can be injected from the mantle into the crust. These differentiated melts melt s are however injected during during the late magmatic history of the section as they cut already cooled lower troctolite. Traces of mixing with these differentiated melts are found only at 2 levels kn the crust: at the intermediate vary textured level or at the topmost level, below below the sheeted dyke complex.

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Keywords: Oman ophiolite, Troctolite, Lower ocean crust

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The PGE and Os isotope variations of the mantle derived rocks from the ICDP Cores of the Oman Drilling Project at the Samail Ophiolite, Oman

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On the Earth, the oceanic plates are formed at mid-ocean ridges and subducted into the mantle at convergent plate margins. This planetary process returns substantial surfacial materials to Earth’s interior contributing to a global recycling system. Therefore, understanding of the characteristics of between the lower oceanic crust and the underlying upper mantle and their relationships remains poor. Much of our knowledge of the construction processes of the lower oceanic crusts comes from of ophiolites; ancient blocks of oceanic lithosphere exposed on land. To generate better understanding of the oceanic crust and uppermost mantle, the Oman Drilling Project collected a suit of diamond-coded boreholes from the Samail ophiolite Oman, the world’s largest sequence of upper oceanic lithosphere exposed on land, during 2016 to 2018. The drill sites were located in the four areas with different stratiphy, Gabbro Transect (GT) sites, Crust-Mantle Transition (CM) sites, Active Alteration (BA) Sites, and Basal Thrust (BT) sites.

We focused on the lower crustal rocks and upper mantle peridotites from the GT, BA and CM sites. The GT site is located at the southward from a divide near the crust-mantle transition zone. Our samples are from the cores of the GT site which are the intact sections of lower crust, capturing the sheeted dyke - gabbro transition (GT3), middle (foliated) gabbros (GT2) and lower (layered) gabbros (GT1). The BA site is in the mantle section and the active serpentinization and carbonatization of the mantle rocks can be observed on the surface. The CM site is the place of the crust-mantle transition beautifully exposed, with mantle harzburgites in the North transitioning to dunites then gabbros. The cores from the CM site are sampled from the crust-mantle transition zone in the Samail Ophiolite and our samples from the CM cores are from the both sides of the core-mantle boundary.
Here we report the preliminary results of the PGE abundances and Os isotope ratios from the lower crustal rocks and upper mantle peridotites and compare with the data obtained for the samples from the Oman outcrops. Similar PGE patterns of the drillcore derived gabbros and outcrop samples indicate that the PGE are resistant to the surficial weathering processes in Oman. The average of the age corrected Os isotope ratios in the drillcore gabbros (0.14) at 96 Ma shows clearly higher than the mantle Os isotope ratios at the same age (CHUR: 0.127 and PUM: 0.129). This means that the Os source of the gabbroic rocks of these cores was not only the mantle and possibly the addtion of the Os from the subducted material. These data will be help us to better understand the relationships between the oceanic crust and underlying upper mantle, mechanisms of making the oceanic crust, and to plan the future Mohole projects.

Keywords: Os isotope ratio, mantle peridotite, gabbro, ICDP Oman drilling project, Platinum group elements

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[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG56] ICDP Oman Drilling Project: Oman to Oceanic Lithosphere to Island Arc Formation and Beyond

convener:Eiichi TAKAZAWA(Department of Geology, Faculty of Science, Niigata University), Katsuyoshi Michibayashi(Department of Earth and Planetary Sciences, Nagoya University), Sayantani Chatterjee(Niigata University, Department of Geology, Faculty of Science)

The on-going Oman Drilling Project has drilled numerous hard-rock cores of ancient oceanic lithosphere and the underlying subduction zone of the Samail ophiolite in Oman, with support from ICDP, IODP, the Sloan Foundation's Deep Carbon Observatory, and Japanese, US, and European research agencies. In this session, we invite presentations on the scientific results of Oman Drilling Project. We also invite related studies of on-land geological investigations of Oman ophiolites and experimental studies. The session is intended to be interdisciplinary, including the fields of geophysics, geochemistry, petrology, engineering, and biology.

[SCG56-13] Knockout seawater –basalt experiments and its implications to hydrothermal alteration in midocean ridges

★Invited Papers

*Atsushi Okamoto[1], Yusuke Netsu[1], Masaoki Uno[1], Noriyoshi Tsuchiya[1] (1.Graduate School of Environmental Studies)

[SCG56-14] Petrology of Oman listvenite (carbonated ultramafic rocks) and related serpentinite from the Hole BT1B of the Oman Drilling Project

*Toma Takahashi[1], Tomoaki Morishita[1], Akihiro Tamura[1], Yumiko Harigane[3], Tatsuhiko Kawamoto[2] (1.Kanazawa university, 2.Shizuoka university, 3.Geological survey of Japan ,National Institute of Advanced Industrial Science and Technology (AIST))

[SCG56-15] Major mineral mode of listvenite from ICDP Oman Drilling Project Hole BT1B inferred from X-ray CT core images

★Invited Papers

*Keishi Okazaki[1], Katsuyoshi Michibayashi[2], Kohei Hatakeyama[3], Natsue Abe[4], Kevin T.M. Johnson[5], Peter B Kelemen[6], Oman Drilling Project Phase I Science Party (1.Kochi Institute for Core Sample Research, Japan Agency for Marine-Earth Science and Technology, 2.Department of Earth and Planetary Sciences, Nagoya University, 3.Department of Earth and Planetary Systems Sciences, Hiroshima University, 4.Mantle Drilling Promotion Office (MDP), Japan Agency for Marine-Earth Science and Technology, 5.Department of Earth Sciences, University of Hawai‘i at Mānoa, 6.Lamont Doherty Earth Observatory, Columbia University)

[SCG56-16] Crustal structure, ophiolites and flexure beneath the Oman-UAE mountains

*Mohammed Ali[1], Anthony Watts[2], Michael Searle[2], Brook Keats[2], Simone Pilia[3], Tyler Ambrose[2] (1.Khalifa University of Science and Technology, 2.University of Oxford, 3.University of Cambridge)

[SCG56-17] *Clues to Cretaceous subduction initiation in South-East Asia - A geochronological and geochemical perspective from the Andaman Ophiolite*

*Debaditya Bandyopadhyay[1,2], Douwe J.J. van Hinsbergen[3], Alexis Plunder[3,4], Biswajit Ghosh[1], Fernando Corfu[5], Carl Guilmette[6], Eldert L. Advokaat[3,7], Pinaki C. Bandopadhyay[1] (1.Department of Geology, University of Calcutta, 35 Ballygunge Circular Road, Kolkata-700019, India, 2.Department of Geology, University of North Bengal, Darjeeling-734013, India, 3.Department of Earth Sciences, Utrecht University, Princetonlaan 8A, 3584 CB Utrecht, The Netherlands, 4.BRGM, 3 avenue Claude Guillemin, BP 36009, 45060 Orléans Cedex 2, France, 5.Department of Geosciences and CEED, University of Oslo, Oslo, Norway, 6.E4m, Département de Géologie et de Génie Géologique, Université Laval, Québec, Québec, Canada, 7.Department of Physical Geography, Utrecht University, Princetonlaan 8A, 3584 CD Utrecht, The Netherlands)

[SCG56-18] Comparison of olivine crystal-fabrics between Oman ophiolite peridotites and Supra-subduction zone peridoitites

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Knockout seawater –basalt experiments and its implications to hydrothermal alteration in midocean ridges

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Midocean ridge is one of the most active sites of water-rock interaction because of its high temperatures and high fluid flux. The hydrothermal alteration there provides significant impacts on various processes including elements exchange between hydrosphere and lithosphere, global circulation of H_2O, mineralization, and at the bottom of hydrothermal system at least reaches at supercritical conditions exceeding 400 degreeC. Seawater is characterized by high concentration of Na, Cl as well as Mg, Ca and SO_4(Antonelli et al. 2017). In spite of many experiments on basalt-seawater interaction, most of basalt-seawater experiments are limited to batch-type and/or at low temperature (<350 degreeC). Therefore, our knowledge on controls the type and extent of hydrothermal alteration of oceanic crusts is still limited. In this study, we conducted the supercritical flow-through experiments on basalt-water interaction. By Knockout seawater experiments, which uses the solutions extracting individual elements from seawater, we revealed the essential factors of seawater on the alteration of oceanic crust.

P-T conditions of the flow-through experiments are 400-410 degreeC and 38-39 MPa and with flow rate of 0.025 –0.1 ml/min. Four series of experiments were conducted with different starting solutions; (1) distilled water, (2) NaCl aqueous solution, (3) NaCl + $MgCl_2$aqueous solution, (4) analogue sulfate-precipitated seawater (hereafter, analogue seawater). The composition of the analogue seawater was set based on the fact that CaSO4 precipitates during the heating of seawater above 150 degreeC. We enclosed the power of basalt taken from Iceland. The contrasting behaviors in the evolution of solution chemistry and product minerals were found between experiments with distilled water and analogue seawater system. In the basalt-distilled water experiments, the concentrations of Si, Na and Al increased and pH (room T) increased from 6 to 9. The plagioclase grains (An60-80) is replaced by anorthite (An100) with abundant pores preferentially near inlet, and a small amount of chlorite formed downstream. These features indicates that preferential leaching of albite components occurred, and the other elements are small. In contrast, basalt-analogue seawater experiments, the Mg concentration decreased and Fe, Ca and Si increased, and pH decreased from 8 to to 3. In this experiments, Mg-chlorite replaced pyroxene and plagioclase throughout the reaction tube, and Fe-Ti oxide precipitates at downstream. The extensive chloritization is similar to those found in chloritites in Oman ophiolites. The PC scores plot based on the principal component analyses of the solutions of four types of Knockout experiments reveal that NaCl,aq is similar to distilled water, but NaCl+MgCl2,aq is similar to seawater. These features means that Mg, not NaCl, is a key factor controlling the extent of hydration and element budget during the hydrothermal alteration of midocean ridges.

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Keywords: basalt-seawater experiments, hydrothermal alteration of midocean ridge, chloritization

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Petrology of Oman listvenite (carbonated ultramafic rocks) and related serpentinite from the Hole BT1B of the Oman Drilling Project

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In recent years, carbon sequestration by minerals has attracted attention as one of the solutions to reduce carbon dioxide emmision in the atmosphere. Serpentinized and carbonated peridotites are formed when peridotite reacts with H_2O and CO_2 near the surface of the Earth. Temperature conditions of carbonated peridotites (listvenite) were investigated from fluid inclusions, oxygen isotope analysis, and mineral paragenesis (e.g., Belogub et al., 2017, Falk and Kelemen, 2015). Carbonation of peridotite for the formation of listvenite is estimated at 80 to 360 ℃. However, some fundamental questions are still unresolved: how peridotite is converted to listvenite, and elemental mobilization on carbonation of peridotite.

Listvenite occurs locally at the boundary of the mantle section of the Samail ophiolite and the metamorphic sole below the mantle section. Hole BT1B of the Oman Drilling Project sampled listvenites, 2 carbonate-veined serpentinite bands at 80-100 and 180-185 m depth, and 70 cm of fault gouge at 197 m depth, followed by 103 m metamorphic sole. The serpentinite bands were originally dunite and harzburgite. The listvenite mainly consists of magnesite and quartz/chalcedony ±fuchsite (Cr-mica). Dolomite veins often cut early structures and rarely contain fluid inclusions. Dolomite also occurs as matrix of the listvenite. Dolomite-rich listvenite bands are found from near the upper serpentinite band and just above the metamorphic sole. The frequent occurrence of dolomite in the core suggests that calcium was supplied to the core at a later stage. The occurrence of hematite in some parts of the dolomite-listvenite are similar to the occurrence of magnetite in the serpentinite bands.

Trace elements compositions of magnesite vein and dolomite vein were measured. Both of magnesite and dolomite vein have high Ba and Sr contents, wheras only dolomite vein contents high Pb contents. Dolomite could be play a important role as Pb host in carbonated peridotite.

Keywords: Listvenite, Carbonated rocks, Ophiolite

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Major mineral mode of listvenite from ICDP Oman Drilling Project Hole BT1B inferred from X-ray CT core images

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To understand the global cycle of fluid flow from the surface to the deep of the Earth, it is important to constrain how and how much fluid is captured and released by metamorphic reactions following hydration/dehydration and carbonation/decarbonation. In the Oman Ophiolite, a fossil of an oceanic plate is widely exposed. Continuous drilling from the bottom of the ophiolite through the basal thrust to the footwall metamorphic sole was conducted in Hole BT1B by the ICDP Oman Drilling Project. Listvenite, completely carbonated former peridotite, is the main lithology in Hole BT1B also found in other ophiolite bodies. Listvenite is mainly composed of magnesite, quartz, dolomite and Fe-hydroxide with minor chromian spinel and chromian mica (fuchsite). Two serpentinite and ophicarbonate intervals were also found above the basal thrust. Below the basal thrust, the metamorphic sole composed by the greenschist/greenstone is the main lithology.

We evaluated the mineral mode of listvenite in BT1B from the X-ray Computed Tomography (XCT) images. XCT images was continuously obtained with a spacing of 0.625 mm along the Z-axis on all 401 whole-round core sections recovered from Hole BT1B. The X-Y resolution of XCT image is 0.125mm and an intensity of X-ray attenuation, “XCT number”, are computed for each voxel. The XCT number of a material depends on several factors such as density, element (e.g., atomic number), porosity, sample shape and sample volume. All listvenite and serpentinite core sections are nearly the same dimensions (~63.5 mm in diameter) and thus same volume, therefore, the XCT number provides information of physical and chemical properties of the core samples.

Each XCT number in XCT images and chemical mapping data of Mg, Si, Ca and Fe from the XRF core scanner in the same location as XCT images are compared for 27 sections including 9289 data points for each element. Multiple linear regression for XCT number and XRF quantified that XCT numbers of pure magnesite ($MgCO_3$), quartz (SiO_2), and dolomite ($CaMg(CO_3)_2$) grains in the cores are 3037+/−143 , 2999+/−140 and 3514+/−102, respectively. Using these values, histograms of XCT number of each slice in each section is fitted assuming that the CT histogram (CT number >2500) of a slice is composed of three peaks with Gaussian distribution.

In most core sections, XCT data indicates that the matrix of listvenite is mainly composed of magnesite and quartz, and minor dolomite, consistent with discrete XRD and XRF data. Veins usually show high CT number (~3400), while the CT number in veins is fitted well with dolomite. Dolomite abundance in each core section is highly dependent on the intensity of veins. Dolomite abundance in most core sections within 15 m from the basal thrust is higher than 50%. This is consistent with higher vein intensity close to the basal thrust and could indicate that significant amounts of Ca were supplied from Ca- and CO_2-rich fluids along the basal thrust. Total MgO/SiO_2 ratio in BT1B is ~1.2. This value is smaller than that

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estimated from the geochemical analysis of the Oman peridotite and XRF data from the BT1B. This suggest that Si enrichment or Mg loss during carbonation and/or following serpentinization of the ophiolite. Fe contents may also have significant effect on evaluating the modal abundance of minerals in listvenite and further investigation of compositional effects, especially Fe solid solutions in carbonate and hematite on the XCT number would be needed for an accurate assessment of the mineralogy in listvenite.

Keywords: Ophiolite, Carbonate, X-ray CT

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Crustal structure, ophiolites and flexure beneath the Oman-UAE mountains

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Previous work suggest the Oman-UAE mountains formed in the Late Cretaceous by obduction of a largely intact thrust sheet of Late Cretaceous oceanic crust and upper mantle (Semail ophiolite), and Tethyan oceanic sedimentary and volcanic rocks onto the eastern margin of the Arabian plate. The geometry of the ophiolite, its extension into the Gulf of Oman and the nature of the underlying crust are, however, unknown.

In this paper we report on the results of an onshore/offshore seismic experiment that addresses these questions by a combination of active and passive seismic techniques, as well as potential field modelling and surface geological mapping. We use the data acquired to constrain the geometry of the ophiolite, the nature of the crust that underlies it and the role that it has played in deforming a pre-existing rifted margin and initiating basin subsidence.

Here we show that the Semail ophiolite forms a high *P* wave velocity, high density, >15 km thick east-dipping body that during obduction flexed a highly extended rifted continental margin downwards by up to ~10 km, thereby contributing to subsidence of flanking sedimentary basins. The western limit of the ophiolite is defined onshore by the Semail thrust while the eastern limit extends several km offshore, where it is defined seismically by a ~40º, east-dipping, normal fault. We interpret the fault as the margin of an incipient suture zone that currently separates the Arabian plate from *in situ* Gulf of Oman oceanic crust and mantle presently subducting northwards beneath the Eurasian plate at the Makran trench.

Keywords: Oman-UAE mountains, Semail ophiolite, obduction

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Clues to Cretaceous subduction initiation in South-East Asia - A geochronological and geochemical perspective from the Andaman Ophiolite

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Magmatic and mantle rocks of suprasubduction zone ophiolites record the evolutionary history of intra-oceanic subduction, from the juvenile stages to subduction maturation. This study presents an integrated geochemical and geochronological synthesis from the Andaman Ophiolite in order to reconstruct the subduction initiation history. The Andaman Ophiolite Suite is exposed on the Andaman and Nicobar Islands in the outer arc ridge of the Sunda trench of the India-Eurasia subduction system. The Ophiolite Suite is made up of incoherent Penrose sequence including contrasting crustal (especially volcanic) and mantle rocks along with underlying metamorphic sole and mélange, and an overlying Palaeogene and younger forearc sedimentary sequence. Comparing our geochemical and geochronological data of igneous rocks to published data, two distinct geodynamic environments have been inferred for their origin. One indicates an arc magmatism with agglomerates and cogenetic plagiogranites-diorites, with U/Pb ages ranging from 98-93 Ma whereas another group clinches towards a back-arc origin. Similar geochemical and accordingly geodynamic diversity has been documented for Andaman mantle peridotites. So far, the ~95 Ma age derived from Andaman plagiogranite was correlated to ophiolites in the western Neotethyan realm. However, one U/Pb analysis (from gabbro) suggests inheritance of a ~105 Ma age, which coincides with recent Ar/Ar ages of the Andaman metamorphic sole, and with an inherited K-feldspar age from the nearby Barren island volcanics. Our new field, geochemical, and geochronological findings thus led us to speculate that intra-oceanic subduction started within the back-arc basin behind the Woyla arc, that collided in the mid-Cretaceous with Sumatra.

Keywords: Andaman Ophiolite, Agglomerate, Plagiogranite, U-Pb Zircon age, Tectonic discrimination, Subduction initiation

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Comparison of olivine crystal-fabrics between Oman ophiolite peridotites and Supra-subduction zone peridoitites

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The origin of Oman ophiolite is still in debate between the mid-ocean ridge model and the supra-subduction zone model. For the last two decades, we have collected peridotite samples from both ophiolites and the ocean floor and have shown how to quantify CPOs in Vp-Flinn diagram (Michibayashi et al., 2016 EPSL), since olivine crystallographic preferred orientations (CPOs) are key factors to identify the nature of the uppermost lithospheric mantle. In this study, we show similarities and differences of olivine CPOs between the Oman ophiolite peridotites and the others such as Yakuno ophiolites and IBM trench peridotites. The Oman ophiolite peridotites are unique to have axial[100] (AG type) along with typical (010)[100] (A type) and {0kl}[100] (D type) olivine fabrics, whereas the trench peridotites are locally characterized by (001)[100] (E type) and (010)[001] (B type) olivine fabrics.

Keywords: mantle, peridotite, Oman

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[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG57] New perspectives of subduction zone earthquake dynamics through experiments across-scales

convener:Masataka Kinoshita(Earthquake Research Institute, University of Tokyo), Yoshio Kono(Geodynamics Research Center, Ehime University), Eiichiro Araki(Japan Agency for Marine-Earth Science and Technology), Hiroko Kitajima(Texas A&M University College Station)

Introduction

[SCG57-01] Combined X-ray microtomography and elastic wave velocity measurements of porous material at in situ high pressures

*Yoshio Kono[1], Brendan Anzures[2], Heather Watson[3], Tony Yu[4], Yanbin Wang[4] (1.Geodynamics Research Center, Ehime University, 2.Brown University, 3.Union College, 4.University of Chicago)

[SCG57-02] A consideration on friction experiments with synchrotron radiation towards unveiling earthquake generation processes

*Takehiro Hirose[1], Yoshio Kono[2] (1.Kochi Institute for Core Sample Research, Japan Agency for Marine-Earth Science and Technology, 2.Geodynamics Research Center, Ehime, University)

[SCG57-03] Riserless contingency operations during IODP NanTroSEIZE Expedition 358

*Asuka Yamaguchi[1], Matt Ikari[2], Gaku Kimura[3], Lena Maeda[4], Toczko Sean[4], Scientists IODP Expedition 358 (1.Atomosphere and Ocean Research Institute, The University of Tokyo, 2.Marum, University of Bremen, 3.Tokyo University of Marine Science and Technology, 4.JAMSTEC)

[SCG57-04] Overpressured underthrust sediment in the Nankai Trough forearc revealed by high-frequency receiver function inversion

*Takeshi Akuhara[1], Takeshi Tsuji[2], Takashi Tonegawa[3] (1.Earthquake Research Institute, The University of Tokyo, 2.Kyushu University, 3.Research and Development center for Earthquake and Tsunami, JAMSTEC)

[SCG57-05] **Regional imaging of the Nankai subduction zone from decades' worth of active and passive seismic data.**

★Invited Papers

*Adrien F Arnulf[1], Dan Bassett[2], Alistair Harding[3], Shuichi Kodaira[4], Ayako Nakanishi[4] (1.Institute for Geophysics, University of Texas at Austin, 2.GNS Science, 3.IGPP, Scripps Institution of Oceanography, University of California San Diego, 4.Japan Agency for Marine-Earth Science and Technology)

Combined X-ray microtomography and elastic wave velocity measurements of porous material at in situ high pressures

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Elastic wave velocity is ubiquitously used as seismic probes in a variety of geologic settings including subduction zones, and it is an integral tool for seismologists to understand not only the mineral constituents but also the conditions, such as porosity, pore structure and permeability in the subduction zones. Therefore, an important but complicated question considers what information about the porosity, pore structure and permeability can be gleaned from seismic probes. There are many theoretical models for the effect of porosity and/or pore geometry on elastic wave velocity, but coupling this theoretical framework with directly measured pore structures has not been experimentally tested. The complexity of natural rock samples and the observations involving many parameters such as mineral constituents, volume fraction of the constituents, grain size, lattice orientation, etc. make it difficult to isolate the effect of pore structure on elastic wave velocity.

In this study, we introduce a new approach, which combines in situ high pressure experimental observations on elastic wave velocity and X-ray microtomography measurements with lattice-Boltzmann analysis to understand the connection between elastic wave velocity and structural properties such as porosity and permeability. Combined X-ray microtomography and elastic wave velocity measurements were carried out in a 250-ton press with a rotation anvil apparatus at beamline 13-BM-D (GSECARS) of the Advanced Photon Source, USA. Experiment was conducted on a simple analog material, porous aluminum, in a Paris-Edinburgh-type high-pressure cell at pressure conditions between 0.14 and 1.36 GPa. Porosity was observed to have a strong inverse dependence on pressure up to ~0.9 GPa, while permeability has an anisotropic dependence on pressure. Elastic wave velocity and Poisson’s ratio all increase with pressure, with P-wave velocity agreeing well with the Hashin–Shtrikman upper bound under high porosity conditions. These results demonstrate a new methodology combining experimental tools of X-ray microtomography and elastic wave velocity measurements and analytical method to provide cross-property links between microscopic structure and macroscopic elastic wave velocities. Future investigations on more complex rock samples may have important implications for our understanding of the nature of subduction zones.

Keywords: X-ray microtomography, elastic wave velocity, high pressure

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A consideration on friction experiments with synchrotron radiation towards unveiling earthquake generation processes

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During large earthquakes, a fault moves with high velocity (>m/s), inevitably leading to generation of frictional heat on fault plane. The heat triggers a number of thermally-activated physico-chemical processes (gelification, melting, dehydration, and so on), whose products are responsible for coseismic fault lubrication (Di Toro et al., 2011). The products are likely formed instantaneously at the onset of coseismic faulting by non-equilibrium reactions. For example, Lee et al. (2017) observe that quartz undergoing coseismic faulting could melt at substantially lower temperatures than expected. They then suggest that the depression of the melting temperature is caused by metastable melting of β-quartz that could be transformed from α-quartz during the faulting. However, such a metastable phase which appears at moving micro-contacts with high temperature and pressure (i.e. asperity) are hardly confirmed without in-situ observation.

In order to confirm metastable micro-products formed during coseismic faulting and its mechanical impacts of fault, it is necessary to establish a high-velocity friction apparatus that allows to reproducing coseismic faulting at a synchrotron beamline. The friction apparatus for synchrotron micro tomography and X-ray diffraction studies of geomaterials will enable us to better understand the earthquake generation processes. In the presentation, we' d like to review the previous reports on dynamic processes in coseismic fault zones and introduce our thoughts of the future apparatus with synchrotron radiation.

Keywords: Earthquake, Friction, synchrotron

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Riserless contingency operations during IODP NanTroSEIZE Expedition 358

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The International Ocean Discovery Program (IODP) Expedition 358 in the NankaiTrough was carried out from October 10, 2018 to March 31, 2019. The original plan of this expedition was to deepen the existing cased borehole at Site C0002 in the Kumano Basin, and to reach the plate boundary fault lying below a high velocity zone by using logging while drilling (LWD). However, due to operational difficulties, drilling at Site C0002 was ended by the end of February 2019, with new depth records in scientific ocean drilling: LWD reached 3262.5 meters below sea floor (mbsf), and core samples were recovered from 2836.5 to 2848.5 mbsf.

After finishing riser operations at Site C0002, riserless contingency drilling was conducted at two sites until March 31, 2019. Site C0024 is located at the toe region of Nankai Trough, while Site C0025 is in the Kumano Basin. Site C0024 was selected to reveal fast/slow earthquakes and their history along the shallow plate boundary, with relation to core/log/long-term monitoring data from Sites C0006 and C0007. Site C0025 was chosen for understanding the background of geological evolution for the onset of seismogenic zone of the Nankai Trough.

LWD at Hole C0024A penetrated the probable plate boundary fault zone, and reached 869 mbsf. At shallow holes (C0024B/C/D/G), cores were retrieved down to 319.5 mbsf. Trench-wedge facies dominated by turbidites with volcanic ash layers was found in shallow holes. Sediments at C0024 are expected to record seismicity and fault activity in the frontal thrust system. Preliminary age data suggest that the top part of this site is missing due to surface erosion. At a deep hole (C0024E), cores record the trench-wedge to Shikoku Basin transition.

Coring at Hole C0025A started from 400 mbsf, and continued down to 580.5 mbsf. The early phase of sedimentation history of the Kumano Basin is expected to be recorded in the retrieved core. Description and measurement of the cores was performed in Chikyu at Shimizu Port in July 2019.

Despite limited shiptime, riserless contingency drilling during Exp. 358 operated efficiently. Upcoming data from Sites C0024 and C0025, together with previous data from other NanTroSEIZE drillsites, will help our understanding of spatial and temporal aspects of seismogenesis in the Nankai Trough.

Keywords: IODP, Nankai Trough, Expedition 358

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Overpressured underthrust sediment in the Nankai Trough forearc revealed by high-frequency receiver function inversion

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Active-source seismic surveys have resolved the fine-scale P-wave velocity (Vp) of the subsurface structure in subduction forearcs. In contrast, the S-wave velocity (Vs) structure is poorly resolved despite its usefulness in understanding rock properties (e.g., pore fluid pressure). Passive-source analyses are sensitive to Vs, but the low-spatial resolution hampers a direct comparison to the Vp model obtained by active-source surveys.

This study performs the receiver function inversion for stations from the seafloor cabled network (DONET1) deployed at the Kumano-nada in the central Nankai subduction zone. First, we calculate high-frequency receiver functions using the multichannel deconvolution method. Then, the resultant receiver functions are inverted for the one-dimensional seismic velocity structure beneath each station using a transdimensional Markov-chain Monte Carlo sampler. Since the receiver functions are less sensitive to the absolute values of Vs (but sensitive to Vs contrast), we employ the exiting Vs models from Rayleigh wave admittance as prior constraints.

The resulting high-resolution velocity structures show a thin (~1 km) low-velocity zone, or high Vp/Vs zone, beneath the outer ridge: It is located ~6 km below sea level and exhibits Vs ~1.2 km/s and Vp/Vs ~2.3. By comparing the results to the established Vp models based on active-source surveys, we conclude that this low-velocity zone reflects a high pore pressure zone within the underthrust sediment. We infer that this overpressured underthrust sediment hosts slow earthquake activities and that the accompanying strain release helps impede coseismic rupture propagation further updip.

Keywords: Nankai Trough, receiver function, ocean-bottom seismometer, subduction zone

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Regional imaging of the Nankai subduction zone from decades' worth of active and passive seismic data.

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Subduction zones are the sites of the world' s largest and some of its most hazardous earthquakes, either through extended ground shaking or through the generation of tsunamis. Knowledge of the structure and geometry of both the overriding and subducting plates, and of conditions at the interface can contribute significantly to our understanding of subduction zones, potentially revealing controls on rupture area, slip behavior, and spatial variations in the width of the seismogenic zone. However, it is difficult to obtain a detailed synoptic view of subduction zones from seismic methods over areas comparable to those of the largest ruptures, ~100s km. Earthquake tomography studies provide 3-D images but at low resolution, ~30-50 km, while individual onshore-offshore experiments provide higher resolution but are often limited to 2-D profiles and shallower depths.

Here, we bridge this imaging gap for the entire Nankai subduction zone by making use of the largest onshore-offshore and ocean-bottom seismometers (OBSs) dataset ever recorded: air gun sources from multiple offshore experiments recorded by the dense set of permanent stations of the Japanese F-net and Hi-net networks, augmented by large 3-D OBS experiments and carefully selected Earthquake events from existing Japanese agencies catalogs. This dataset has been accumulating over two-decades and potentially includes over 45+ million source-receiver pairs with coverage of the entire Nankai subduction zone. This region has different patterns of seismic rupture and of largely aseismic slip that are only partially understood and have analogs around the world.

Here, we obtain refined 3-D constraints on the width and properties of the frontal prism, the thickness and geological architecture of the forearc crust, and the geometry of the subduction interface. Our tomographic model also places broad constraints on the crustal structure and geometry of the subducting Philippine Sea plate to 50 km depth. We integrate our tomographic model with residual gravity anomalies, regional seismicity, geological observations and seafloor geodetic constraints on slip rate deficits to describe the relationship between crustal structure and fault-slip behavior along the Nankai trough.

Keywords: subduction zone, Nankai trench, traveltime tomography, crustal structure, Kumano pluton, fault-slip processes

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[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG57] New perspectives of subduction zone earthquake dynamics through experiments across-scales

convener:Masataka Kinoshita(Earthquake Research Institute, University of Tokyo), Yoshio Kono(Geodynamics Research Center, Ehime University), Eiichiro Araki(Japan Agency for Marine-Earth Science and Technology), Hiroko Kitajima(Texas A&M University College Station)

Knowledge on subduction zone earthquake phenomena has considerably increased in the last decade. On the other hand, there are limits to seismological approach alone to comprehensively elucidate the earthquake mechanism in which phenomena that differ by 10 orders of magnitude in space and time, from earthquake nucleation/growth processes to its driving force. Steps to enable scientific earthquake forecasting should include; monitoring regional seismic/tectonic activity using networked observatories, sampling of and insitu measurement in seismogenic faults and plate materials through ultra-deep drilling, and reproduction/insitu-observation of fracture nucleation processes by high-pressure quantum-beam experiments. Through a close collaboration, we challenge a dynamic imaging of earthquake processes. Based on the proposal submitted as a Large Research Master Plan 2020 of the Science Council of Japan, we will deepen the interdisciplinary discussion on subduction-zone earthquakes and the state & property of lithosphere. We welcome, but not limited to, presentations from fields of ocean and land networks observation, seismogenic zone drilling, rock mechanical & quantum beam experiments, fracture process theory, etc.

[SCG57-06] Thermal conductivity under high-pressure conditions of core samples from IODP NanTroSEIZE input site C0012

*Weiren Lin[1], Osamu Tadai[2], Takehiro Hirose[3], Wataru Tanikawa[3], Xiaoqiu Yang[4] (1.Graduate School of Engineering, Kyoto University, 2.Marin Works Japan LTD, 3.Kochi Institute for Core Sample research, Japan Agency for Marine-Earth Science and Technology, 4.South China Sea Institute of Oceanology, Chinese Academy of Sciences)

[SCG57-07] Pilot seafloor borehole tilt observation in the Nankai Trough seismogenic zone: development for future array network observation for slow slip events.

*Eiichiro Araki[1], Takashi Yokobiki[1], Toshinori Kimura[1], Shuhei Nishida[1], Shuichi Kodaira[1] (1.Japan Agency for Marine-Earth Science and Technology)

[SCG57-08] Comparison of active seismic signals collected from DAS along seafloor cable and conventional OBS

*Toshinori Kimura[1], Eiichiro Araki[1], Hiroyuki Matsumoto[1], Takashi Yokobiki[1], Gou Fujie[1], Shuichi Kodaira[1], Takashi Tonegawa[1], Kazuya Shiraishi[1], Koichiro Obana[1], Ryuta Arai[1], Yuka Kaiho[1], Yasuyuki Nakamura[1], Martin Horst Karrenbach[2], Robert Ellwood[2], Victor Yartsev[2] (1.Japan Agency for Marine-Earth Science and Technology, 2.Optasense)

[SCG57-09] Seafloor geodetic observation network using seafloor pressure gauges for monitoring of real-time plate coupling strength in the Nankai trough seismogenic zone

*Yuya Machida[1], Shuhei Nishida[1], Toshinori Kimura[1], Hiroyuki Matsumoto[1], Eiichiro Araki[1] (1.Japan Agency for Marine-Earth Science and Technology)

[SCG57-10] Hydroacoustic signals detected by distributed acoustic sensing (DAS) using submarine cable

*Hiroyuki Matsumoto[1], Eiichiro Araki[1], Toshinori Kimura[1], Takashi Yokobiki[1], Gou Fujie[1], Shuichi Kodaira[1], Takashi Tonegawa[1], Kazuya Shiraishi[1], Koichiro Obana[1], Ryuta Arai[1], Yuka Kaiho[1], Yasuyuki Nakamura[1], Narumi Takahashi[1,2], Martin Karrenbach[3], Robert Ellwood[3], Victor Yartsev[3] (1.Japan Agency for Marine-Earth Science and Technology, 2.National Research Institute for Earth Science and Disaster Resilience, 3.OptaSense Ltd.)

[SCG57-11] Crustal deformation observations and monitoring using a seafloor optical fiber strainmeter on the DONET seafloor cabled network

*Matthew James Cook[1], Eiichiro Araki[1], Mark Zumberge[2], Takashi Yokobiki[1], Toshinori Kimura[1], Shuhei Nishida[1], Shuichi Kodaira[1] (1.JAMSTEC Japan Agency for Marine-Earth Science and Technology, 2.University of California San Diego)

Thermal conductivity under high-pressure conditions of core samples from IODP NanTroSEIZE input site C0012

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Knowledge of rock thermal conductivity is necessary to understand thermal structure in active seismogenic zones such as the Nankai Trough subduction zone, SW Japan. If the drill core samples of the subduction zone are available, their thermal conductivities may be easily determined by thermal conductivity measurements using the samples. However, drill core samples at great depths more than ~3 km below seafloor in Nankai Trough subduction zone have not obtained by the Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) scientific drilling program yet. Thus, thermal conductivity depth profile in the accretionary prism of the Nankai Trough subduction zone is not available.
The in-situ thermal conductivity of sediments in a deep part of the accretionary prism of the seismogenic zone may mainly depend on the solid grain components and in-situ porosity of the sediments. Based on this consideration, we have conducted laboratory experimental study aimed to figure out quantitative relationship between thermal conductivity of core samples and their porosity. For the experiments, we must use the core samples with the same/similar solid grain components as those from the great depths. Because sediments from sedimentary formations overlaying the in-coming subducting oceanic basement will subduct in the accretionary prism, they may have the same/similar solid grain components. Therefore, we collected whole-round sediment core samples retrieved from sedimentary formations at the NanTroSEIZE input site C0012; and then measured their thermal conductivity change with increasing confining pressure, i.e., to change the core samples' porosity to simulate the subduction process. We have successfully measured the thermal conductivities of six core samples from a depth range from ~144 to ~ 518 meters below seafloor at IODP site C0012 under high pressure conditions up to a maximum effective pressure of ~50 MPa. Consequently, an empirical equation between thermal conductivity and porosity for the Nankai Trough accretionary prism was obtained. The equation enables us to estimate thermal conductivity from in-situ porosity estimated from log data.

Keywords: NanTroSEIZE, Thermal Conductivity, High-Pressure

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Pilot seafloor borehole tilt observation in the Nankai Trough seismogenic zone: development for future array network observation for slow slip events.

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Monitoring seismogenic zone under the seafloor in the Nankai Trough with seafloor cable observation network has been practical after the development of DONET (Dense Oceanfloor Network for Earthquake and Tsunamis). The seafloor observation sensor for DONET is a broadband seismometer (Guralp CMG3T), a strong motion accelerometer (Metrozet TSA100) to monitor earthquakes and slow earthquakes in broadband and wide dynamic range, as well as pressure sensors to monitor Tsunami and vertical seafloor movement associated with earthquakes. The DONET also has an ability to expand seafloor network for new sensors with its underwater connections, and new sensors has been connected since 2013. Current DONET systems have 96 seafloor sensor connectors and only 51 has been occupied by the original DONET seafloor sensors. Connection of sensors installed in three deep boreholes at IODP Sites C0002, C0010, C0006 drilled in International Ocean Discovery Program, to the DONET further expanded our sensitivity to slower events such as slow slip events of a few weeks period (Araki et al., 2017). Our current effort to expand the ability of the seafloor cabled network DONET is to develop seafloor sensor system that has ability to detect such slow slip events as detected by deep borehole observatories.

The sensor system which we conceived consists of a tiltmeter in shallow (5-20 m deep) borehole to monitor tilt change of the crust, fiber optic strainmeters to monitor seafloor horizontal deformation, as well as a pressure gauge to monitor vertical seafloor movement in long-term. The borehole tiltmeter in shallow seafloor borehole is one of the key sensors and we started a pilot long-term observation since February 2019. The location of the pilot tiltmeter installation is in 1B-S1 site south of DONET 1B node where splay fault is branched from the subducting plate boundary where Tonankai earthquakes occurred in the history. Long-term observation by DONET recorded slow earthquakes near the 1B-S1 site, where our interest is what slow slip associate with slow earthquakes in the splay fault system. In the pilot tilt observation, we drilled 8.6 m deep borehole of 104 mm diameter hole with BMS (seafloor drill by Cellula Robotics) by JAMSTEC R/V Kaimei in November 2018. We installed a Lily tiltmeter from Jewell Instruments in the borehole and packed the borehole by sand to the seafloor. To connect the tiltmeter to DONET to start continuous observation with the borehole tiltmeter, we used a DONET borehole interface which has been used to connect the IODP boreholes to DONET. We continue the observation since February 2019.

The first 1 year pilot observation exhibited the process of the hole and installed tiltmeter gets stable over time. First a half year data showed significant saw tooth trend of tiltmeter record in both x and y components and relatively large long-term drift. After a half year, such trend became much smaller and smooth. As of January 2020, long-term drift of the tiltmeter is ~-1 and ~5 microrad/month for x and y components respectively. The records showed clear and relatively large response in tidal frequencies with peak-to-peak amplitude of ~1 and ~ 2 microradians for x and y components (Figure). The response has good correlation with ocean tide measured by seafloor pressure gauges near the 1B-S1 site. We consider the large tidal response represents surface deformation of sediment layer to ocean tidal pressure loading, but further investigation is needed to clarify the origin of such tidal response, reported also in other seafloor observations (Davis et al, 2017, Araki et al., 2017).

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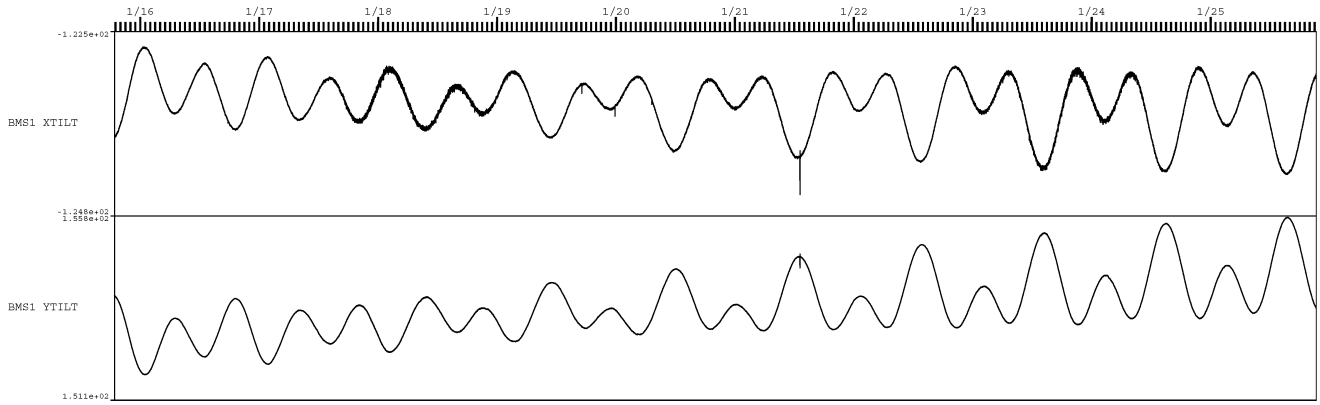
We are planning another tiltmeter installation in deeper (~20 m planned) borehole to establish technique to observe tilt change in the seafloor environment with enough stability to recognize slow slip occurrence at depth. The planned installation also includes use of a laser interferometric long-arm tiltmeter and cementing the instrument at the bottom of the hole to enhance maximum stability.

Keywords: Nankai Trough, seafloor tilt observation, slow slip events



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Comparison of active seismic signals collected from DAS along seafloor cable and conventional OBS

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Distributed acoustic sensing (DAS), which can observe distributed strain by measuring Rayleigh scattering along optical fiber cable. DAS technology was first developed for Oil and gas exploration and reservoir monitoring. Recently, this technology is becoming new approach to observe seismic signal for earth science field (e. g. Lindsey et al., 2019). DAS technology has some advantages over conventional observation method. High spatial density is one of the most significant advantages. DAS technology allow us to measure seismic signal with spatial intervals of less than 10 m. Also, DAS technology can be easily applied to seismic monitoring / time-lapse survey by using existing optical fiber cables. However, to evaluate seismic records observed by DAS, quantitative analysis and discussion is still needed.

To evaluate seismic records observed by DAS, we conducted a field test with DAS acquisition using an existing seafloor cable, controlled seismic source and conventional seafloor seismometers. We used existing seafloor optical fiber cable installed in off-Muroto Cape, Japan. The cable is originally installed as a part of Long-Term Deep Sea Floor Observatory off Muroto Cape project in 1997 and now is not under operation. 2 conventional pup-up type ocean bottom seismometers (OBSs) were installed near the off Muroto cable and the arigun shooting line before the survey to observe airgun signal which could be used for comparison with DAS data directly. The distance between the cable and OBSs were less than 200 meters. We connected DAS acquisition system to the off Muroto cable for 6 days, from 30 Nov. to 5 Dec. 2019. In the same period and the same region, R/V Kaimei was firing airgun shooting with interval of 200m along a survey line near off Muroto cable. 50 km length of the cable from shore station was used for DAS acquisition, and seismic signals were observed every 10 m. Maximum water depth is around 1000 m.

We compared common receiver gathers of DAS and OBS of airgun shooting line, MROBS1, performed near the off Muroto cable for direct comparison DAS and OBS records. The maximum offset between receiver and shooting point of MROBS1 is 128 km and total number of shot points was 671 shots with shooting intervals of 200 m. Shot records of MROBS1 confirmed that the closest point of the cable to the OBS was around 21 km from the shore station. Seismic records observed by DAS along 21.2-21.4 km (21 receiver points) were stacked to generate DAS common receiver gather used for direct comparison with OBS common receiver gather. The direction of the off Muroto cable around 21 km is almost north-south direction. We rotated OBS horizontal record to the same direction of the cable direction. Initial results of the comparison DAS and OBS records are as follows: 1) Overall, OBS records have better S/N ratio than DAS records. In OBS records, seismic signal including refraction waves propagating deep boundaries are visible in long offset more than 120 km. In DAS records, the seismic signals are visible with shot-receiver offset of less than 70 km. 2) DAS records and horizontal component of OBS record are very similar with offset of less than 70 km. Results suggest that DAS observed down-going and refraction waves propagating along boundaries as P-wave and up-going as converted S-wave, which are also observed by horizontal component of OBS. S-wave refraction waves are not clearly visible in DAS records. 3) Time derivative waveform of DAS is in better agreement with OBS records better than raw waveform of DAS.

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For further analysis and discussion, we have to perform quantitative analysis using DAS and OBS seismic records converted to physical values. However, initial results of comparison of DAS and OBS records suggest that DAS records include actual seismic signal including information of deep structure, and that DAS technology can be applied to seismic survey and monitoring in seismogenic subduction zone.

Keywords: Distributed acoustic sensing (DAS), Seafloor optical fiber cable, Ocean bottom seismometer (OBS), Airgun shooting, Seismic signal

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Seafloor geodetic observation network using seafloor pressure gauges for monitoring of real-time plate coupling strength in the Nankai trough seismogenic zone

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Long-term and precise pressure measurements on the seafloor has been a key to understand geophysical phenomena such as occurrences of large inter plate earthquakes. However long-term pressure measurements contain inherent instrument drift up to 10 hPa/year (equivalent to 10 cm/year) in addition to the seafloor displacements. As the expected vertical displacements rate on the seafloor are less than 1 hPa/year (i.e., = 1cm seawater height/year), a correction of the inherent drift component using an absolute calibration system with a resolution better than 1 hPa is necessary when measuring long-term precise pressure on the seafloor. Machida et al. (2018) has developed a mobile pressure calibrator (MPC) for calibration of seafloor pressure gauges. A concept of the MPC is to carry a reference pressure from laboratory to the seafloor, and calibrate the seafloor pressure gauge with the reference pressure via the MPC. In the nankai trough seismogenic zone, a dense ocean-floor network system for earthquakes and tsunamis (DONET) was installed. The system has a total of 51 observatories, and each observatory has a pressure gauge for monitoring of tsunami activity. We have repeatedly carried out an in situ calibrations of the DONET pressure gauges which were installed in the stations of MRC10 and KMB08 in Oct. 2018, Feb. 2019, and May 2019. The drift components of each observatories including inherent instrument drift components and seafloor displacements for the last two years are 5.2 hPa/year and 1.3 hPa/year for the MRC10 and KMB08, respectively. The inherent drift component estimated by the repeatedly calibration using the MPC were 4.4 hPa/year and 0.56 hPa/year for the MRC10 and KMB08, respectively. The results indicate that the long-term vertical displacements are 0.81 hPa/year and 0.74 hPa/year for the MRC10 and KMB08, respectively. We will continue to carry out in situ calibrations of the DONET pressure gauges to increase measurement accuracies by repeatedly measuring at the same observatories and to increase number of observatories to understand high-dense and broad area of deformations on the seafloor. The results would contribute to understand a real-time plate coupling strength on the subducting oceanic plate in the nankai trough seismogenic zone.

Keywords: DONET, seafloor pressure gauge calibration, long-term crustal deformation on the seafloor, subduction zone, the Nankai trough seismogenic zone

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Hydroacoustic signals detected by distributed acoustic sensing (DAS) using submarine cable

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1. Japan Agency for Marine-Earth Science and Technology, 2. National Research Institute for Earth Science and Disaster Resilience, 3. OptaSense Ltd.

Ship-based seismic survey was conducted close to the non-operational submarine cable in December 2019, and the DONET observatories were operational alternatively at the same region. We obtained the distributed acoustic sensing (DAS) recordings along the non-operational submarine cable down to 50 km from the landing station during the seismic survey. We examine the acquired DAS dataset together with the DONET observations to investigate the detectability of the underwater acoustic (hydroacoustic) signals. Raw data of DAS measurement is associated with the strain dimension of the fiber optic cable, while hydroacoustic signals originated from the air-gun (predominant frequency range > 1 Hz) is proportional to velocity of the source. Therefore, we process the DAS dataset so that the direct comparison with the DONET sensors can be performed. Our analysis suggests that DAS can be sensitive at the frequency range between a few of Hz and a few tens of Hz, in which the power spectral density (PSD) follows the frequency contents recorded by the DONET seismometer and pressure sensors nearby. DAS can identify ocean microseismic background noise at the appropriate frequency range, i.e. between 0.1 Hz and 0.2 Hz. However, PSD of DAS suggests that noise level is somewhat different at the frequency range less than 0.1 Hz compared to the DONET observations. Since hydroacoustic signals originated from geodynamic sources such as submarine volcanic eruptions or submarine earthquakes have predominant frequency between 1 and 10 Hz, the present unique opportunity has proved that DAS is capable to detect hydroacoustic events occurred in the ocean.

Acknowledgements: The DONET dataset used in the present study were provided by the National Research Institute for Earth Science and Disaster Resilience (NIED).

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Crustal deformation observations and monitoring using a seafloor optical fiber strainmeter on the DONET seafloor cabled network

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Optical fiber instruments can provide high-fidelity measurements of solid earth signals across a broad dynamic ranging from seismic, microseismic, and infragravity activity to episodic tremor and slow slip to interseismic secular strain accumulation. Fiber optic instruments such as strainmeters, distributed temperature sensing, and distributed acoustic sensing, have gained considerable momentum in the last decade. A 200-m long optical fiber strainmeter was installed on the seafloor and connected to DONET Node 2F in June 2019. Since then, it continues to provide real-time in situ measurements for seismic and tectonic monitoring in the Nankai Trough, Japan.

We tested two configurations to assess the best installation and measurement practices for future deployments: (1) on 03 June 2019 the instrument fiber was nearly completely buried under several cm of sediment along the length of the fiber, and (2) on 08 October 2020, the fiber was lifted out of the sediment and laid across the bare seafloor with a small additional amount of tension.

Initial data and results were used to determine the thermal response and performance of the instrument and revealed signals possibly attributed to drift, initial loading and/or sediment settling effects. Nearby instruments including seafloor pressure gauges and broadband seismometers provide valuable data for comparison. We present results and insights addressing the following: (1) thermal response and behavior, (2) ocean tides and ocean tidal loading signals, (3) teleseismic events, such as the February 2020 M6.9 Kuril earthquake, and (4) performance comparisons based on the initial and adjusted instrument installation configurations and conditions.

Keywords: Fiber optic cable, Strainmeter, Seafloor crustal deformation, Marine geodesy

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[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG58] Science of slow earthquakes: Toward unified understandings of whole earthquake process

convener:Satoshi Ide(Department of Earth an Planetary Science, University of Tokyo), Hitoshi Hirose(Research Center for Urban Safety and Security, Kobe University), Kohtaro Ujiie(Graduate School of Life and Environmental Sciences, University of Tsukuba), Takahiro Hatano(Department of Earth and Space Science, Osaka University)

Accumulating observational studies on various types of slow deformation events, such as tectonic tremors, very low frequency events, and slow slip events, portrays some universal characteristics in generally complex behavior, including interaction among events and influence by various outer loadings. Some of these phenomena seem to have causal relation with the occurrence of very large earthquakes. A unified understanding of these slow and fast earthquake processes requires an approach integrating geophysics, seismology, geodesy, geology, and non-equilibrium statistical physics. We welcome presentations based on, but not limited to, geophysical observation, data analysis, analytical theory, numerical simulation, field study, and laboratory experiments.

[SCG58-01] Characteristic activities of deep low frequency tremor in Cascadia and southwest Japan based on energy information

*Kazushige Obara[1], Kenneth C. Creager[2] (1.Earthquake Research Institute, The University of Tokyo, 2.University of Washington)

[SCG58-02] Seismic energy estimation for shallow tremors in the Nankai trough and Japan trench

*Suguru Yabe[1], Masaru Nakano[2], Takashi Tonegawa[2], Satoru Baba[3], Shunsuke Takemura[3] (1.National Institute of Advanced Industrial Science and Technology, 2.Japan Agency for Marine-Earth Science and Technology, 3.Earthquake Research Institute, UTokyo)

[SCG58-03] Triggering of deep low-frequency earthquakes along the Parkfield-Cholame section of the San Andreas Fault by local and regional earthquakes

★Invited Papers

*Zhigang Peng[1], David R Shelly[2], Taka'aki Taira[3] (1.Georgia Institute of Technology Main Campus, 2.United States Geological Survey, 3.University of California Berkeley)

[SCG58-04] Characteristics of tectonic tremors in the northern Mexican subduction zone remotely triggered by the 2017 Mw8.2 Tehuantepec earthquake

*Masatoshi Miyazawa[1], Miguel A Santoyo[2] (1.Disaster Prevention Research Institute, Kyoto University, 2.Instituto de Geofísica, Universidad Nacional Autónoma de México)

[SCG58-05] **Tectonic tremors in southern Chile, observed in three space-time windows**

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Characteristic activities of deep low frequency tremor in Cascadia and southwest Japan based on energy information

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Episodic tremor and slip (ETS) composed of three types of slow earthquakes; deep low frequency tremor, deep very low frequency earthquake and short-term slow slip event actively occur at the downdip side of the seismogenic zone along the subducting plate interface in Cascadia and southwest Japan subduction zones. ETS indicates some characteristic activities including segmentation, periodicity, migration, triggering and so on, similar to those of regular earthquake activities. Among these phenomena, tremor may be able to considered to be a representative to illuminate detailed spatiotemporal slip behavior and interplate condition. At the beginning of discovery of tremor, the tremor catalog did not include energy information (e.g., Obara, 2002); however, recently constructed tremor catalogs including radiation energy of tremor (e.g., Annoura et al., 2016) is expected to evaluate inhomogeneous properties of tremor source (e.g., Kano et al., 2018). In Cascadia, Pacific Northwest Seismic Network (PNSN) has been producing the tremor catalog for many years based on the method developed by Wech and Creager (2008) and the system has been improved to include the radiation energy of tremor from 2018. In this paper, the tremor activity in Cascadia is reinvestigated from the point of view for radiation energy of tremor and compared to southwest Japan.

Tremor activity in Cascadia is mainly separated into three large segments as pointed by previous studies (e.g., Brudzinski and Allen, 2007); north (47N~), middle (44~47N), and south (~44N) segments. Among these segments, the radiation energy of tremor is the largest in the north segment although the number of tremor event is the largest in the south segment. The tremor activity is the lowest in the middle segment as for both of number and energy of tremor. On the other hand, the radiation energy per tremor event is almost the same in middle and south segments although it is the largest in the north segment. This suggests that the strength of each tremor patch is similar in the middle and south segments however the population of weak tremor patches is larger in the south segment.
By using energy information, spatiotemporal variation of tremor activity is well clarified. During major tremor episodes associated with migration and SSE, the number of tremor event seems to be constant with time; however, the radiation energy changes with time including rise and fall at every several days. Such long-period temporal variation of tremor energy might be correlated with rapid change in migration pattern of tremor. Radiation energy of tremor seems to large when the migration direction and/or velocity significantly change. This is well consistent with the relationship between energy and migration speed of tremor obtained in western Shikoku, Japan (Kano et al., 2018).

Keywords: Slow earthquake, Tremor, Episodic tremor and slip, Subduction zone

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Seismic energy estimation for shallow tremors in the Nankai trough and Japan trench

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After the deployment of wide ocean bottom seismometer networks in the Pacific off Japan, it has been revealed that tectonic tremors have repeatedly occurred on the shallow plate interface. As studies of deep slow earthquakes have shown that characteristics of tremor activities vary along the fault, spatial variations are expected for shallow slow earthquakes as well. As shallow seismic structure can be imaged in detail by seismic reflection surveys compared with deep structure, this study aims to clarify spatial variations of shallow tectonic tremor activities and to compare them with shallow seismic structures. We estimate seismic energy of tectonic tremors in order to characterize their sizes. We also compare the estimated seismic energy of tectonic tremors with the seismic moment of accompanying very low frequency earthquakes (VLFEs) to evaluate scaled energy of slow earthquakes.

Yabe et al. (2019, doi: 10.1029/2018JB016815) estimated seismic energy of shallow tectonic tremors in Kumano region off Kii Peninsula. We applied the same method to the entire Nankai trough (DONET) and Japan trench (S-net). In the Nankai trough, we refer shallow VLFE catalog by Nakano et al. (2018, doi:10.1038/s41467-018-03431-5) and estimate seismic energy of shallow tremors accompanying VLFEs. In the Japan trench, we refer tremor catalog by Nishikawa et al. (2019, doi:10.1126/science.aax5618) and estimate seismic energy of those tremors. In addition, we also estimate seismic moment of VLFEs accompanying tectonic tremors with large seismic energy, which can be observed using onshore F-net stations. We will report the spatial variations of the estimated seismic energy of shallow tremors and the scaled energy of shallow slow earthquakes.

This study used data from NIED F-net (doi:10.17598/NIED.0005), DONET (doi:10.17598/NIED.0008), and S-net (doi:10.17598/NIED.0007).

Keywords: Shallow slow earthquakes, seismic energy, Scaled energy

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Triggering of deep low-frequency earthquakes along the Parkfield-Cholame section of the San Andreas Fault by local and regional earthquakes

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Long-period surface waves from large distant earthquakes are capable of triggering deep tectonic tremor along major plate boundary faults. However, it is relatively challenging to observe such triggering following local or regional earthquakes, mainly because the frequency band of tremor overlaps with those of triggering earthquakes. Our recent studies have shown that moderate to large-size earthquakes can trigger tremor and slow-slip events at regional distances. Here we examine tremor triggering behavior along the Parkfield-Cholame section of the San Andreas Fault following local and regional earthquakes in California and surrounding regions. We primarily use the deep low-frequency earthquake (LFE) catalog detected by the 88 LFE template families with a matched filter technique, as well as visual inspection of high-frequency (> 20 Hz) waveforms during and immediately following earthquakes. We find that the 2019/07/06 M7.1 Ridgecrest mainshock triggered a few high-frequency tremor events at Parkfield during the first few cycles of its surface waves. However, the 2019 Ridgecrest mainshock was not followed by a prolonged major tremor sequence in Cholame, unlike the 2014 M6.0 South Napa earthquake (Peng et al., 2015). This is likely because a major tremor sequence just occurred a few days ago before the Ridgecrest mainshock. Hence, the region may not be ready to be triggered by the Ridgecrest event. In addition, we find that a M4.3 local earthquake near Parkfield on 2019/12/17 triggered a one-hour episode of migrating tremor north of Parkfield, but it apparently did not trigger tremor in the Cholame region. Our next step is to examine the 19-year LFE catalog since 2001 to identify how tremor behaviors in Parkfield change following local and regional earthquakes in California, and use them to better understand the physical mechanism of tremor generation.

Keywords: Tremor, Parkfield, Triggering

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Characteristics of tectonic tremors in the northern Mexican subduction zone remotely triggered by the 2017 Mw8.2 Tehuantepec earthquake

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Surface waves from the 2017 Mw8.2 Tehuantepec earthquake, Mexico, on September 8th, 2017 (UTC), remotely triggered tectonic tremors in the Jalisco region, approximately 1000 km WNW in the northern Mexican subduction zone, where no triggered tremor has been found previously. While prior studies found tectonic tremors triggered by teleseismic waves in subduction zones and plate boundaries, further investigation of tremor triggering is crucially important for understanding the causative mechanism. Given that the relatively low spatial coverage of the seismic network prevented the location of the triggered tremors, we calculate the stress and strain changes across the three-dimensional plate interface attributable to seismic waves from the 2017 Tehuantepec earthquake by full wavefield simulation. The maximum magnitude of the dynamic strain tensor eigenvalues on the plate interface, where tremors likely occur, is approximately 10^{-6}. The subducting slab geometry effectively amplifies triggering waves. The triggering Coulomb failure stress changes resolved for a thrust fault plane consistent with the geometry are estimated at 10-50 kPa. The relationship between the triggering stress and triggered tremor amplitude may indicate that the $A\sigma$ of the rate-state-dependent friction law is 10-100 kPa.

Keywords: 2017 Tehuantepec earthquake, tectonic tremor, dynamic triggering

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Tectonic tremors in southern Chile, observed in three space-time windows

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In southern Chile, tectonic tremors occur along the subduction interface between the Nazca and South American Plates. While several studies investigated this phenomena, the whole picture of tremor activity is yet unclear because of the lack of wide and continuous observation networks. So far, three space-time windows are available for tremor observation.

The first is a temporary observation by the Chile Ridge Subduction project 2004-2007 (Gallego et al., 2010). Thousands of tremors were detected and located beneath the Chonos Archipelago, using an envelope correlation method (Ide, 2012; Idehara et al., 2013). The southern limit of tremor distribution delineated by a potential slab window suggested in this region (Russo et al., 2010) and gradually increasing tremor depths (20-40 km) to the north support tremors occurrence on the upper surface of very young Nazca Plate. Tremor often migrated at ~10 m/s in the subduction direction and at ~0.1 m/s in the along-trench direction, which are similar to observations in various tremor regions worldwide. The sensitivity to tidal shear stress in the subduction direction is very high, and the tremor rate is proportional to an exponential function of shear traction.

The second window was open in 2009, by a joint observation of ocean bottom seismometers (Abe, 2009) and a temporary land network. The ocean bottom network detected tremors near the subducting ridge (Sáez et al., 2019) and the land network captured the southern part of the tremor distribution studied with 2004-2007 data. These two distributions of tremors and the plate boundary between the Nazca and Antarctica Plates probably demarcate the locked region in this subduction zone, where the rupture of the 1960 Valdivia earthquake was arrested.
Despite a rapid improvement of seismic observation in Chile in this decade, these tremor zones cannot be monitored well by current permanent observation networks. The only exception is a seismic array deployed around Aysen volcanic region. We can monitor some tremor activity near the northern end of the deep tremor region, with a little more extension to the north. The northern limit of this tremor zone, especially the occurrence of tremors beneath Chiloe Island has not determined yet.

Keywords: Tectonic tremor, Chile, subduction zone

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[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG58] Science of slow earthquakes: Toward unified understandings of whole earthquake process

convener:Satoshi Ide(Department of Earth an Planetary Science, University of Tokyo), Hitoshi Hirose(Research Center for Urban Safety and Security, Kobe University), Kohtaro Ujiie(Graduate School of Life and Environmental Sciences, University of Tsukuba), Takahiro Hatano(Department of Earth and Space Science, Osaka University)

Accumulating observational studies on various types of slow deformation events, such as tectonic tremors, very low frequency events, and slow slip events, portrays some universal characteristics in generally complex behavior, including interaction among events and influence by various outer loadings. Some of these phenomena seem to have causal relation with the occurrence of very large earthquakes. A unified understanding of these slow and fast earthquake processes requires an approach integrating geophysics, seismology, geodesy, geology, and non-equilibrium statistical physics. We welcome presentations based on, but not limited to, geophysical observation, data analysis, analytical theory, numerical simulation, field study, and laboratory experiments.

[SCG58-06] Calibration of portable relative gravimeters toward the detection of gravity signals accompanied by slow slip events

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[SCG58-07] Long-lasting afterslip associated with the 2016 moderate earthquakes along the Chaman fault, Pakistan

Fumiko Matsumoto[1], *Masato Furuya[1] (1.Department of Earth and Planetary Sciences Hokkaido University)

[SCG58-08] Detection of short-term slow slip events and estimation of their duration by using three components of GNSS data in the Nankai subduction zone, southwest Japan

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[SCG58-09] Slow slip events in the Kanto region, central Japan detected from 25-years-long GNSS data

*Takuya NISHIMURA[1] (1.Disaster Prevention Research Institute, Kyoto University)

[SCG58-10] Afterslip in the ETS zone at Nankai trough, SW Japan, and implications for rheology

★Invited Papers

*Kaj M Johnson[1] (1.Indiana University Bloomington)

Calibration of portable relative gravimeters toward the detection of gravity signals accompanied by slow slip events

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During these two decades, slow slip events (SSEs) have been found with crustal deformation monitoring around the Pacific Rim. These observations have revealed the diverse spatiotemporal behaviors of the slip distribution on the plate interface. However, the obtained kinematic slip distributions do not necessarily give information about a possible interaction between slip and high-pressure fluids which are suggested by laboratory experiments and numerical simulations. Revealing the interaction is important to understand the generation of SSEs. Recently, gravity changes of a few microGals associated with the long-term SSEs in the Tokai area have been detected for the first time, by annual absolute gravity observations over a time span of 20 years. This result suggests that high-pressure fluids migrate upward along the plate interface. The duration of the Tokai SSEs are long (4-5 years), but those in other areas are generally shorter (e.g. 1 month in Ishigaki Island in the Ryukyu Trench). So, in order to confirm such a gravity change can be seen in other slow slip areas, the temporal resolution of the observation must be improved. For this purpose, we use a portable g-Phone X relative gravimeter which is suitable for continuous observation. To evaluate its instrumental characteristics, we made a test measurement in the Mizusawa VLBI observatory in NE Japan, where the superconducting gravimeter (SG) with a higher precision is in operation. The comparison for 3 months shows that the transient gravity changes observed by both gravimeters agree with each other within approximately 1 microGal in standard deviation. The gravity changes with amplitude of a few microGals and durations of about 1 month were detected by the g-Phone and the SG, reflecting the groundwater level change. This implies that, if similar gravity changes are caused by SSEs, they are detectable by the portable gravimeter. We initiated the observation in the Ishigaki Island Local Meteorological Observatory from January 2020 to detect biannual SSEs.

Keywords: slow slip events, gravity, fluid, groundwater, slow earthquakes, geodesy

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Long-lasting afterslip associated with the 2016 moderate earthquakes along the Chaman fault, Pakistan

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The Chaman fault system forms a ~900 km long major sinistral strike-slip fault, and is a transform boundary between Indian and Eurasian plates in Pakistan and Afghanistan. Previous geological surveys find the relative velocity of the Indian plate to the Eurasian plate at about 40 mm/yr. However, no large earthquakes (M>7) have been observed along the fault (Lawrence, 1992). Low seismicity results from either a long recurrence interval or aseismic creeping (Ambrasseys and Bilham, 2003). Recent geodetic studies reveal a heterogeneous distribution of locked and creeping segments along the Chaman fault (Fattahi and Amelung, 2016; Barnhalt, 2016).Meanwhile, Furuya and Satyabala (2008) showed a long lasting and spreading afterslip following a moderate earthquake (M5.0) in 2005 on the fault , where no creeping signals were detected prior to the earthquake.
We focus on the two moderate earthquakes occurred on May 13 and July 10 in 2016 on the fault, which were the first M5-class events since the 2005 M5.0 event examined by Furuya and Satyabala (2008). Ascending 11 SAR data of C-band Sentinel-1 from 2015 to 2017 are used to generate 55 interferograms. To separate deformation signals from other temporally random errors, we perform InSAR time series analysis based on a linear least squares inversion, which translates the set of interferograms into a range change time series. We use Small Baseline Subset (SBAS) method, following Schmidt and Bürgmann (2003), to detect cumulative LOS displacements. Our results indicate long-lasting afterslip for both of the two events. In particular, the second event has a sharper phase discontinuity across the fault, whereas the LOS changes are smaller than the first event.

Based on the cumulative LOS changes derived by SBAS, we estimate fault source models in an elastic half-space. We use Triangular Dislocation Element (TDE) to build non-planar fault. Our model indicates cumulative slip distribution which expands(?)on the fault plane. The maximum slip for the first event increased from 0.12 m to 0.53 m at a depth of 4-5 km during the 293 days after the event, while that for the second event increased from 0.11 m to 0.26 m at a depth of 2 km during the 235 days after the event.

Keywords: Chaman fault, afterslip, Interferometric synthetic aperture radar, Sentinel-1

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Detection of short-term slow slip events and estimation of their duration by using three components of GNSS data in the Nankai subduction zone, southwest Japan

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Several methods have been developed to detect short-term slow slip events (S-SSEs) by using Global Navigation Satellite System (GNSS) data in a subduction zone (e.g., Nishimura et al., 2013; Frank, 2016; Rousset et al., 2017). In these methods, a vertical component of GNSS data hasn't been generally used because of its worse positioning accuracy than horizontal components. However, it helps determine the location of S-SSEs to use a vertical component. Therefore, we attempt to detect S-SSEs and estimate their durations by using three components of GNSS data in the Nankai subduction zone, known as one of the most active regions of slow earthquake activities including S-SSEs.

We use daily coordinates time series at ~ 800 GNSS stations operated by the Geospatial Information Authority of Japan, Japan Coast Gard, universities, and International GNSS services, located around the Nankai subduction zone in the period from April 1, 1997, to December 31, 2019. The coordinates were estimated using GIPSY Ver 6.4 software with a strategy of precise point positioning. As preprocess of GNSS data, we first remove coseismic and postseismic effects and long-term trends including annual and semiannual oscillations. Next, to estimate candidate date and locations for S-SSEs, we improve the Geodetic Matched Filter (Rousset at al., 2017) and apply it to both vertical and horizontal coordinate data by shifting a 121-day time window. And then, we estimate rectangular fault models by applying the nonlinear inversion method (Matsu'ura and Hasegawa, 1987) to displacements estimated around the candidate date. Finally, we calculate the weighted averages of time series around the candidate date and estimate the duration by fitting a logistic function. In this step, we use the surface displacements predicted from the estimated fault as a weight.

As a preliminary result, we detected 70 S-SSEs in the Shikoku region which is a part of the Nankai subduction zone. Most of them accompanied deep low-frequency tremor activities (Maeda and Obara, 2009; Obara et al., 2010). We also detected several S-SSEs at a shallower part of the subduction zone near the trough axis. Although we cannot completely exclude a possible misdetection, the existence of such a shallow S-SSE may be supported by the spatial-temporal proximity of shallow very low frequency earthquakes (Takemura et al., 2019) and the shallow SSE (Yokota and Ishikawa, 2020). In addition, we discuss the regional difference of slow-slip activities including long-term trends of the cumulative moment, duration, and recurrence interval.

Acknowledgment
We thank the Geospatial Information Authority of Japan, Japan Coast Guard, Japan Crustal Activity Science Consortium, and International GNSS Service for providing GNSS RINEX data.

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Keywords: southwest Japan, GNSS, short-term slow slip event

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Slow slip events in the Kanto region, central Japan detected from 25-years-long GNSS data

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The Kanto region, central Japan situated in the complex tectonic region where two oceanic plates subducts from the Japan trench and Sagami trough. Although many previous studies clarified repeated M_w ~6.6 Slow Slip Events (SSEs) with a duration of a week in an offshore region of the Boso Peninsula along the Sagami trough, the number of the detected SSEs are limited and overall activity of SSEs have not been fully understood in these regions. We, here, applied our SSE detection in these regions to the whole available GNSS dataset for a quarter century spanning from 1994 to 2019 and clarify the relation between SSE and tremor distribution.

We use daily coordinates at 291 GNSS stations using a precise point positioning strategy of the GIPSY 6.4 software. We apply the method of Nishimura et al. (2013) and Nishimura (2014) to detect a jump associated with short-term SSEs in GNSS time-series and estimate their fault models from observed displacements. A rectangular fault on the Philippine Sea or the Pacific plates is assumed for each SSE. The stacking of GNSS time-series based on the displacement predicted by the fault model [Miyaoka and Yokota, 2012] enable us to estimate duration of SSEs.

We detected >= 150 possible SSEs along both the Japan trench and Sagami trough but we here focus on SSEs along the southernmost part of the Japan trench. Total slip distribution of the detected possible SSEs shows that large slip (>= 0.3 m) is limited near the trench. A comparison with low-frequency tremors (LFTs) along the Japan trench (Nishikawa et al., 2019) suggests SSEs occur in the same depth range (10-20 km) of LFTs but their distribution is rather complimentary whereas a minor tremor activity exists at the edge of the SSE total slip. This complimentary distribution is contrast to overlapping distribution of SSEs and LFTs observed in a deep episodic and tremor region in the other subduction zones including southwest Japan. Another distinctive feature is that SSEs continuously occur from the trench to a depth of ~60 km only at ~35.50N. Because the subducted seamounts locate at this latitude, geometry of plate interface may control a genesis of SSEs in these regions.

Keywords: Slow slip event, GNSS, Kanto region, subduction zone

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Afterslip in the ETS zone at Nankai trough, SW Japan, and implications for rheology

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Postseismic and interseismic deformation at the Nankai subduction zone in southwestern Japan following 1944 M8.1 Tonankai and 1946 M8.4 Nankai earthquakes was recorded with GPS, leveling and tide gauge data. Using this data, we have estimated the vertical velocity field of southwestern Japan from immediately after the 1944/46 events until near present day. Analysis of these data with 2D and 3D postseismic and interseismic deformation models show that observed inland postseismic subsidence pattern is diagnostic of about 50 years of viscoelastic mantle flow uplift along the southern coastline is diagnostic of afterslip on the subduction interface. Furthermore, both kinematic inversions and forward models with rate-strengthening afterslip show that afterslip overlaps the zone of Episodic Tremor and Slip (ETS) on the subduction interface. This gives us the opportunity to probe physical conditions within the ETS zone that will permit creep manifesting as both afterslip and spontaneous episodic slow slip events. Nearly all models for ETS require very low effective normal stress of order 1-10 MPa and rate-weakening friction conditions, however our rate-strengthening afterslip simulations as well as kinematic afterslip inversions suggest much higher effective normal stresses of order 100-300 MPa at Nankai. In this study, we examine several hypotheses for reconciling this apparent discrepancy in physical conditions using 2D earthquake cycle models with rate-state friction, fault zone dilatancy, and pore pressure evolution. We find that afterslip can be generated in the ETS zone on if there is a rate-strengthening gap between the bottom edge of the locked zone and the top of the ETS zone.

Keywords: friction, slow slip

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[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG58] Science of slow earthquakes: Toward unified understandings of whole earthquake process

convener:Satoshi Ide(Department of Earth an Planetary Science, University of Tokyo), Hitoshi Hirose(Research Center for Urban Safety and Security, Kobe University), Kohtaro Ujiie(Graduate School of Life and Environmental Sciences, University of Tsukuba), Takahiro Hatano(Department of Earth and Space Science, Osaka University)

Accumulating observational studies on various types of slow deformation events, such as tectonic tremors, very low frequency events, and slow slip events, portrays some universal characteristics in generally complex behavior, including interaction among events and influence by various outer loadings. Some of these phenomena seem to have causal relation with the occurrence of very large earthquakes. A unified understanding of these slow and fast earthquake processes requires an approach integrating geophysics, seismology, geodesy, geology, and non-equilibrium statistical physics. We welcome presentations based on, but not limited to, geophysical observation, data analysis, analytical theory, numerical simulation, field study, and laboratory experiments.

[SCG58-11] Slow slip events and temporal changes of coupling condition on the shallow side of the Nankai Trough

★Invited Papers

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[SCG58-12] Slow slips with durations between VLF and short-term SSE

*Akio Katsumata[1], Kazuki Miyaoka[2], Takahiro Tsuyuki[1], Satoshi Itaba[4], Masayuki Tanaka[1], Takeo Ito[5], Akiteru Takamori[3], Akito Araya[3] (1.Meteorological Research Institute, Japan Meteorological Agency, 2.Seismology and Volcanology Department, Japan Meteorological Agency, 3.Earthquake Research Institute, The University of Tokyo, 4.The National Institute of Advanced Industrial Science and Technology, 5.Nagoya University)

[SCG58-13] Seismic heterogeneity changes before and during slow earthquakes

*Takashi Tonegawa[1], Shunsuke Takemura[2], Suguru Yabe[3], Kiyoshi Yomogida[4] (1.Research and Development center for Earthquake and Tsunami, Japan Agency for Marine-Earth Science and Technology, 2.Earthquake Research Institute, The University of Tokyo, 3.National Institute of Advanced Industrial Science and Technology, 4.Hokkaido University)

[SCG58-14] Multi-band Receiver Function Analysis Including Local Deep-focus Events in Northeastern Kii

*Yasunori Sawaki[1], Yoshihiro Ito[2], Kazuaki Ohta[3], Takuo Shibutani[2], Tomotaka Iwata[2] (1.Graduate School of Science, Kyoto University , 2.Disaster Prevention Research Institute, Kyoto University, 3.National Research Institute for Earth Science and Disaster Resilience)

[SCG58-15] The relationship between slow earthquake activity and frictional property on the plate boundaries around Japan islands

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Slow slip events and temporal changes of coupling condition on the shallow side of the Nankai Trough

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GNSS-A was developed to capture slow seafloor crustal deformation on the seafloor. At present, it is the most generalized seafloor geodetic observation technology. Our research group estimated inter-plate slip deficit rate of Nankai Trough subduction zone using GNSS-A seafloor geodetic data obtained from 2006 (partially 2012) to June 2015 (Yokota et al., 2016). Then, we revealed spatial heterogeneity of slip defect rates which was not clearly detected from onshore GNSS data only. Using the same data, Nishimura et al. (2018) estimated slip deficit rate and plate coupling rate from advanced model considering block motion of micro plate.

We have been developing the GNSS-A technology to extract the temporal change of coupling condition including slow slip events (SSE). Recently, Yokota and Ishikawa (2020) analyzed GNSS-A data up to 2018 statistically and revealed the existence of the SSE around the shallow side of strong coupling regions estimated in Nishimura et al. (2018).

The temporal resolution of GNSS-A is extremely low, and the year-scale resolution is the limit. Neither the coupling nor the SSE introduced in above section can accurately determine the time constant. In other words, it is not possible to discuss in detail whether there is a time when the coupling is weakened or there is a time when the strain is completely released as the SSE without the coupling. In this presentation, we discuss the temporal change of the coupling and the SSE to the extent possible from the data so far, and explain the mystery of the SSE in the Nankai Trough that should be elucidated.

Keywords: GNSS-A, Nankai Trough, SSE, coupling condition

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Slow slips with durations between VLF and short-term SSE

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Various types of slow earthquakes have been observed so far. Their durations vary from 0.1 s to about one year. However, there have been no report on slow earthquakes with durations between those of VLE (very low frequency earthquake) and short-term slow slip event (SSE). VLFs have characteristic periods of about a few tens of seconds. Short-term SSEs have durations of a few days to a week. We searched for slow earthquakes with durations from minutes to one day with data obtained with laser extensometers and bore-hole strain meters, and found slow slips with one hour duration.

We calculated correlation coefficients between ramp functions of various rise time with observed strain data with shifting time. Polarity of the ramp function was set based on calculated strain assuming slip directions. Then we accumulated the correlation coefficients from each strain channel. The time series of accumulated correlation function showed some peaks. Many of them seems to be due to some noise. However, some of them were consistent with plate boundary slip. Slow slips of one hour duration were found while a short-term slow slip was proceeding in February, 2019 (upper panel of the figure). The slip corresponded to moment magnitude of about 5.0. In the figure, the red line indicates calculated strain. It is considered that this is a temporary speed-up of the short term slow slip event. This is similar to occurrence of deep low-frequency earthquakes and VLF during a short-term SSE. We found similar events during SSEs since 2015. Ide et al. (2007) pointed out existence of a scaling relationship among slow earthquakes (lower panel of the figure). The newly found one-hour duration slow slip (the star in the lower panel graph) is consistent with the scaling relationship by Ide et al. (2007).

Keywords: slow earthquake, strainmeter data, one-hour duration SSE

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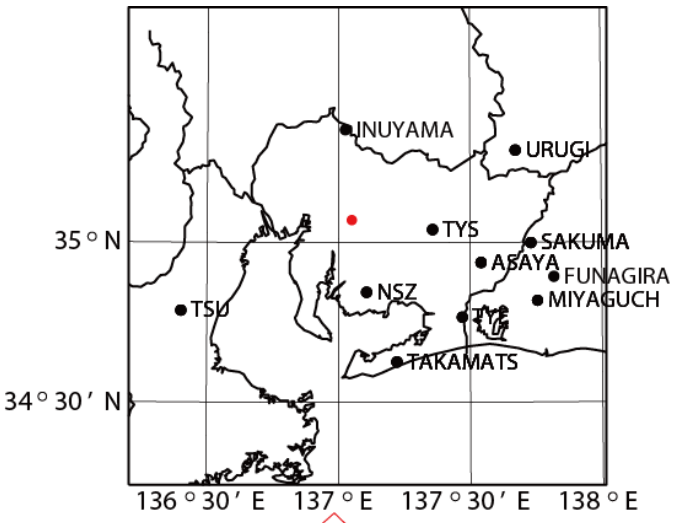

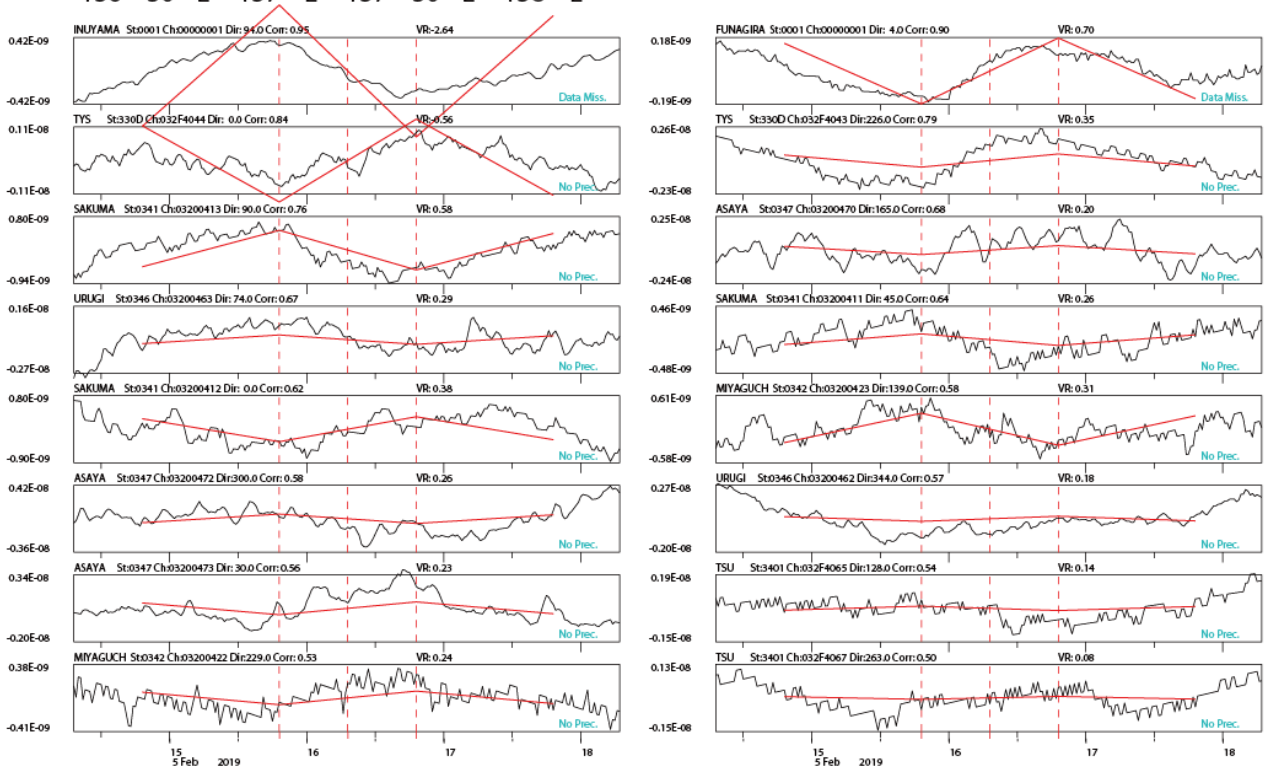

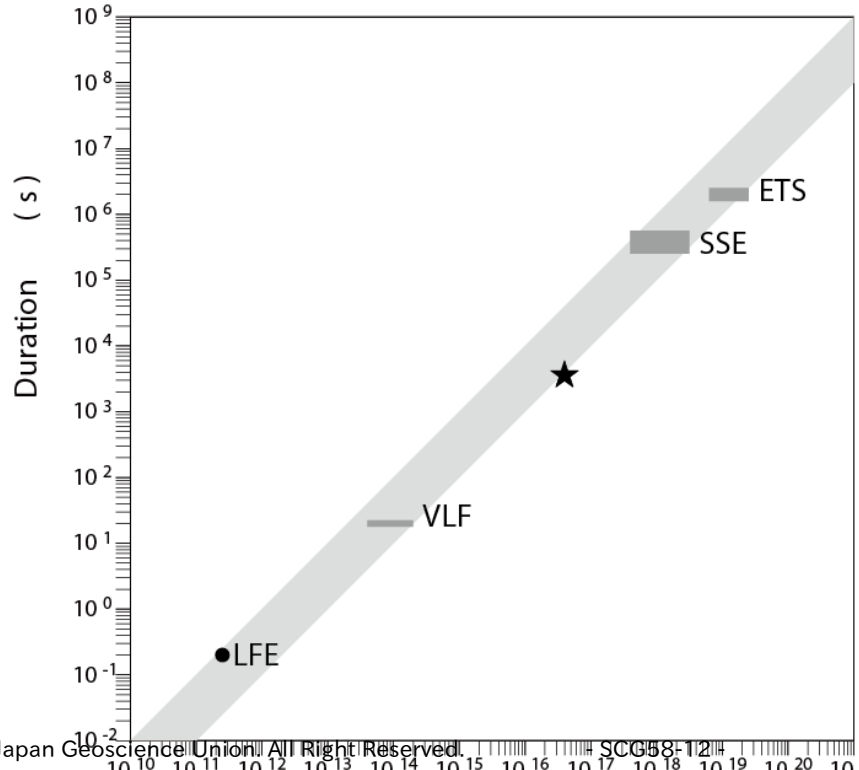

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Seismic heterogeneity changes before and during slow earthquakes

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Slow earthquakes at the shallow plate interface in the Nankai subduction zone, Japan, have been detected by seafloor seismic observations. The activations of the slow earthquakes are potentially related to fluids around the plate boundary, but whether fluids are linked to the activations is still under debate. If fluid migration occurs, it is expected to observe seismic velocity changes associated with slow earthquakes. In the Nankai subduction zone, a cabled-network, named DONET (Dense Oceanfloor Network system for Earthquakes and Tsunamis) have been constructed since 2011. We applied an ambient noise analysis to the continuous records obtained by DONET, in order to investigate whether seismic velocity changes associated with slow earthquakes occur or not.

We calculated cross-correlation functions (CCFs) of ambient noise records in the vertical component with a time window of 400 s and a frequency band of 0.5–2.0 Hz, and stacked the CCFs over 30 days. At this frequency band, ocean acoustic coupled Rayleigh (ACR) waves are dominant in the CCFs. We prepared the reference CCFs by stacking CCFs for the first 1-year in the observation period. Using the reference CCFs and individual 30-day averaged CCFs, the stretching method was applied to a time window of 10–90 s of the CCFs, which contains direct and coda waves, to measure seismic velocity change (dv/v) around pairs of stations. After stretching the individual CCFs using the estimated dv/v, we calculated the cross correlation coefficients (CC) between the reference CCFs and individual corrected CCFs. This processing allows us to estimate temporal variation of seismic heterogeneities.

Our results show (1) gradual seismic velocity increase in the accretionary prism toe and (2) rapid reduction of CC prior to slow earthquakes. On (1), seismic velocities in the southern part of DONET1 was increased 0.1–0.15 % (Fig. 1), while such phenomena were not observed in the northern part of DONET1 and DONET2. The observation in DONET1 is consistent with the result of Ikeda and Tsuji (2018). It is considered that fluids are gradually expelled by sediment compaction in this region. On (2), we observed CC reductions in the southern part of DONET1 before slow slip events that were detected by borehole pore pressures (Araki et al. 2017) (Fig. 1). Although we observed CC reduction in DONET2, this reduction started at the activity timing of very low frequency earthquakes (Takemura et al. 2019). The CC reductions are presumably caused by fluid supply. We consider that if structure near the plate boundary is not saturated with fluids, slow earthquakes occur after fluid saturation and thereby increasing pore fluid pressure. If it is already saturated with fluids and has a pore fluid pressure, slow earthquakes occur after fluid supply.

Acknowledgement: We thank NIED for providing us DONET records. This study is supported by MEXT Grant-in-Aid for Scientific Research on Innovative Areas "Science of Slow Earthquakes" (19H04632).

Keywords: Seismic heterogeneity, Temporal variation, Slow earthquake

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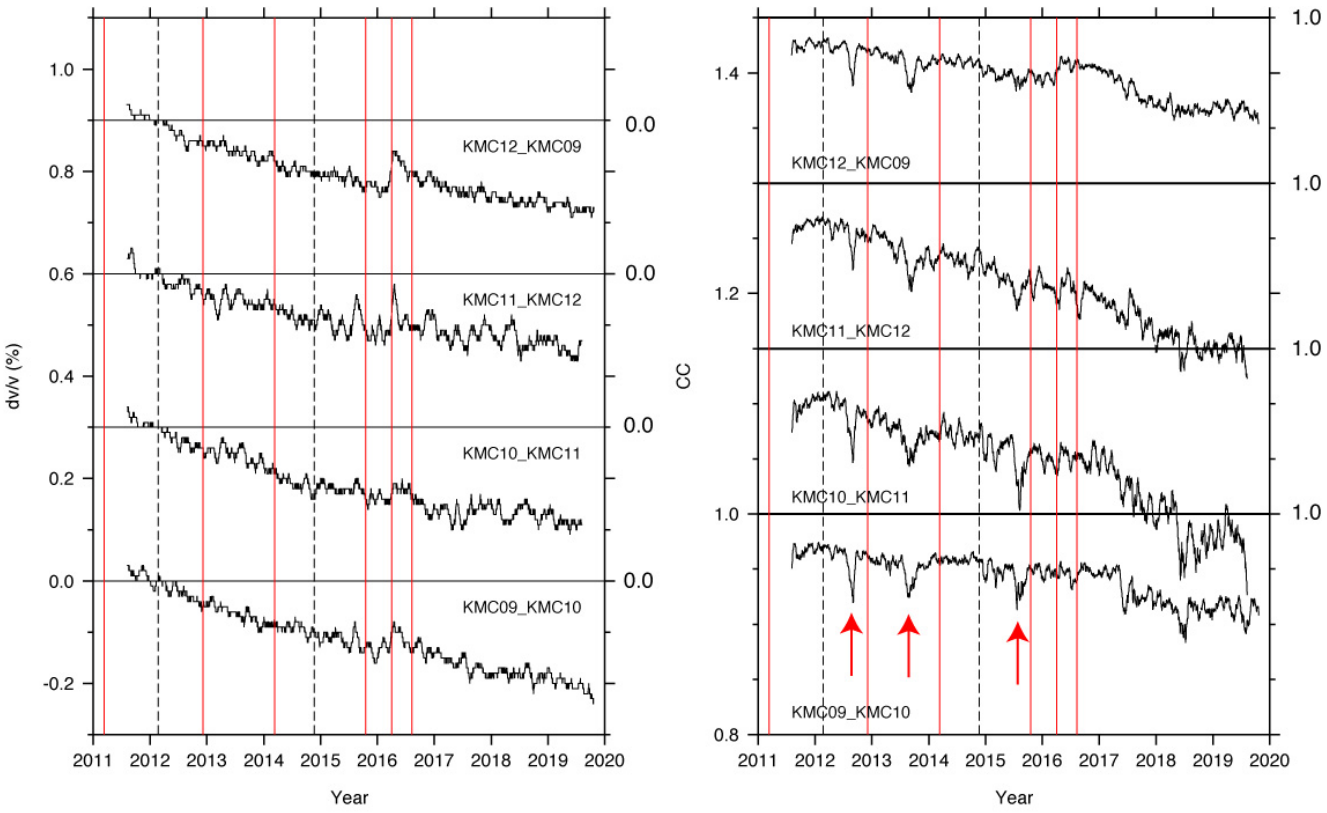

Fig. 1 (left) Seismic velocity changes at the node KMC in DONET1. Red and dashed lines represent slow slip events (SSEs) in which pore pressure variation greater than 0.5 kPa and smaller than 0.5 kPa were observed, respectively (Araki et al. 2017). (right) CC changes at the node KMC in DONET1. Red arrows indicate CC reductions before SSEs.

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Multi-band Receiver Function Analysis Including Local Deep-focus Events in Northeastern Kii

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Slow earthquakes play important roles in the occurrence of megathrust earthquakes in subduction zones. It is still unclear what sort of seismological structures exhibits each slow earthquake activity, although an increasing number of seismic networks have contributed to significant findings and the detection of slow earthquake activities. We have developed the multi-band receiver function (RF) method, in which the RFs are composed of different higher-frequency contents. We, here, calculate the multi-band RFs using records both of tele-seismic events and local deep-focus events that occurred in the Pacific slab. We also reveal smaller-scale structures around the Philippine Sea plate boundary in Southwestern Japan, where numerous slow earthquakes have been detected (e.g., Obara, 2002; Ito et al., 2007; Nishimura et al., 2013).

The records of deep-focus earthquakes, frequently occurring in the Pacific slab below Southwestern Japan, can apply to the multi-band RF analysis because the local deep events and tele-seismic events have similar slowness of the first-arrival phases. Local deep-focus events, however, have different variations in back azimuths from tele-seismic events, which enables us to estimate seismological structures in a wider range of azimuths by stacking traces from both events. We carefully select the deep-focus events with S-P time longer than 40 sec and exclude triplication phases from mantle transition zones. Here we apply the method to short-period 3-component seismograms of Hi-net (NIED, Japan) in the Northeastern Kii Peninsula, where short-term slow slip events (SSEs) and episodic tremors are very active (e.g., Obara et al., 2010; Nishimura et al., 2013; Yabe & Ide, 2014).

Cross-sections of higher-frequency RFs (up to 2 Hz) show large and narrow negative phases from the plate interface shallower than 35 km depth, which is one of the most active regions of episodic tremors (Obara et al., 2010). This suggests that the velocity steeply decreases from the lower continental crust to the low-velocity oceanic crust. The basaltic oceanic crust releases much amount of fluid by dehydration (e.g., Hyndman & Peacock, 2003). This indicates that the low permeable continental crust (Katayama et al., 2012) is in contact with the oceanic crust and the released fluid is building up there. We conclude that episodic tremors, accompanied by short-term SSEs, occur on the interface between the continental crust and the oceanic crust. On the other hand, the higher-frequency RF at the deeper portion of the plate interface shows the mantle-wedge structure and the negative phases are relatively small and broad, suggesting that a hydrous mantle wedge stably exists with gradual velocity change from plate interface to the bottom of the continental crust. The minor and continual tremors, reported by Obara et al. (2010), may occur the plate interface between the oceanic crust and the wedge mantle. These results indicate overriding materials above the area of tectonic tremors is possibly one of the components to control their activities.

Keywords: Receiver function, Tectonic tremor, Deep-focus earthquake

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The relationship between slow earthquake activity and frictional property on the plate boundaries around Japan islands

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On the subducting plate boundaries, slow earthquakes are distributed mainly in the downdip and updip vicinities of seismogenic zones of megathrust earthquakes and we expect some relationships between both earthquakes. The relationships could be revealed by spatial variation of slow earthquake activity reflecting the heterogeneity of the frictional condition on the plate boundary. We focus on very low frequency earthquakes (VLFEs) which are one type of slow earthquakes and whose signal has a predominant period of 20-50 s, because they have the potential to clarify detailed spatiotemporal slip behaviors in the updip and downdip sides of the seismogenic zone.

Around Japan, the Philippine sea plate and the Pacific plate subducts from the Nankai Trough and the Japan and Kuril Trenches, respectively. Along the Japan and Kuril Trenches, Baba et al. (2020) detected VLFEs comprehensively by the matched-filter technique. They used synthetic waveforms from virtual sources on the plate boundary using a three-dimensional velocity model as templates. In this study, to compare all VLFE activities across Japan, we detected VLFEs along the Nankai Trough by the same method as Baba et al. (2020) by using continuous NIED F-net seismograms from January 2003 to June 2019.

We detected 1,925 deep VLFEs and 18,298 shallow VLFEs. Deep VLFE activity in the depth range of 30-40 km accompanies with short-term SSEs, which occur in the interval of several months (Nishimura et al., 2013). Shallow VLFEs in the depth range of 5-10 km activated episodically in the interval of several months to several years and the interval of the activation of shallow VLFEs is longer and more various than that of deep VLFEs. Shallow VLFE activity off the Kii peninsula had been high during the period of shallow SSEs in 2009 and 2017-2018 (Yokota and Ishikawa, 2020).

The distribution of shallow VLFE activity rate is more heterogeneous along trench axes and clearly shows an anti-correlation relationship with the spatial distribution of interplate coupling rate (Hashimoto et al., 2012, GJI; Noda et al., 2018, JGR), whereas the variation of deep VLFE activity rate is small and deep VLFEs are distributed only in weak coupled areas. This suggests that the along-strike heterogeneity of frictional property is stronger in the shallow part than in the deep part. Temporal changes in shallow VLFE activity synchronized with the interplate coupling change after huge earthquakes. Furthermore, shallow VLFEs are mainly hosted within low seismic velocity anomalies, thus slow earthquakes can be encouraged by decreased effective stress due to high pore fluid pressure within regions with weak interplate coupling. Our results suggest that slow earthquake activity is an indicator illuminating interplate slip behavior surrounding the seismogenic zone.

Keywords: Slow Earthquakes, Very low frequency earthquakes, Slip deficit rate

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[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG58] Science of slow earthquakes: Toward unified understandings of whole earthquake process

convener:Satoshi Ide(Department of Earth an Planetary Science, University of Tokyo), Hitoshi Hirose(Research Center for Urban Safety and Security, Kobe University), Kohtaro Ujiie(Graduate School of Life and Environmental Sciences, University of Tsukuba), Takahiro Hatano(Department of Earth and Space Science, Osaka University)

Accumulating observational studies on various types of slow deformation events, such as tectonic tremors, very low frequency events, and slow slip events, portrays some universal characteristics in generally complex behavior, including interaction among events and influence by various outer loadings. Some of these phenomena seem to have causal relation with the occurrence of very large earthquakes. A unified understanding of these slow and fast earthquake processes requires an approach integrating geophysics, seismology, geodesy, geology, and non-equilibrium statistical physics. We welcome presentations based on, but not limited to, geophysical observation, data analysis, analytical theory, numerical simulation, field study, and laboratory experiments.

[SCG58-17] Seismic evidence for fault-bound anisotropy and its implications on fault structure in the northern Hikurangi subduction zone

*Ryuta Arai[1], Shuichi Kodaira[1], Stuart Henrys[2], Nathan Bangs[3], Koichiro Obana[1], Gou Fujie[1], Seiichi Miura[1], Dan Barker[2], Dan Bassett[2], Rebecca Bell[4], Kimihiro Mochizuki[5], Richard Kellett[2], Valerie Stucker[2], Fry Bill[2], NZ3D Team (1.Japan Agency Marine-Earth Science and Technology, 2.GNS Science, 3.University of Texas, Institute for Geophysics, 4.Imperial College London, 5.Earthquake Research Institute, University of Tokyo)

[SCG58-18] Marine observations of slow earthquakes using ocean bottom seismometers in the northern part of the Hikurangi subduction zone, NZ

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[SCG58-19] **Seismic evidence for megathrust fault-valve behavior during episodic tremor and slip**

★Invited Papers

Jeremy M Gosselin[1], *Pascal Audet[1], Clement Esteve[1], Morgan McLellan[1], Stephen G Mosher[1], Andrew J Schaeffer[2] (1.University of Ottawa, 2.Geological Survey of Canada)

Seismic evidence for fault-bound anisotropy and its implications on fault structure in the northern Hikurangi subduction zone

*Ryuta Arai[1], Shuichi Kodaira[1], Stuart Henrys[2], Nathan Bangs[3], Koichiro Obana[1], Gou Fujie[1], Seiichi Miura[1], Dan Barker[2], Dan Bassett[2], Rebecca Bell[4], Kimihiro Mochizuki[5], Richard Kellett[2], Valerie Stucker[2], Fry Bill[2], NZ3D Team

1. Japan Agency Marine-Earth Science and Technology, 2. GNS Science, 3. University of Texas, Institute for Geophysics, 4. Imperial College London, 5. Earthquake Research Institute, University of Tokyo

We present a three-dimensional anisotropic P-wave velocity model in the northern Hikurangi subduction zone offshore Gisborne, New Zealand, constructed by a tomographic inversion using over 380,000 travel times of refracted seismic waves from the NZ3D seismic experiment. The study area covers a region with active slow slip events at the shallow plate boundary (Wallace et al., 2016) and provides an ideal location to understand the relationship between the structural and hydrogeologic properties along the megathrust faults and shallow slow earthquakes. The obtained P-wave velocity model reveals a ~30-km-wide low-velocity (P-wave velocity of 1.8-4.0 km/s) accretionary wedge in the frontal part of the overriding plate, in which the previous multi-channel seismic reflection study suggests that several active thrust faults branching from the plate interface are developed (Barker et al., 2018). We found some locations with large azimuthal anisotropy over 4% spatially correlate with the distribution of the backstop interface, branching faults and deformation front. The fast axes of the P-wave anisotropy are mostly oriented to the trench-normal direction (i.e., plate convergence direction) within the accretionary prism, but become trench-parallel on the seaward side of the trough and within the landward old backstop crust.

Seismic anisotropy around the shallow plate interface is often interpreted to be caused by preferentially-oriented cracks in a compressional stress regime associated with plate subduction. Our findings suggest that the anisotropic features are not ubiquitous and homogeneous within the overriding plate but more localized along the active thrust faults. We also found that the magnitude of anisotropy is roughly equivalent to the values reported in the spreading centers where the ridge-perpendicular extensional stress regime is dominant and thus aligned fractures, or cracks, are primary controls on crustal anisotropy (e.g. Dunn, 2015). In the case of subduction zones, the porosity along the faults is not expected to increase significantly due to the compressional stress regime as implied by the core samples from the splay fault in our study area (Fagereng et al., 2019). These considerations may indicate that both the orientation of cracks and the foliation structure, related to fault slip, contribute to seismic anisotropy.

Keywords: Subduction zone, Seismic anisotropy, Fault structure

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Marine observations of slow earthquakes using ocean bottom seismometers in the northern part of the Hikurangi subduction zone, NZ

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1. Earthquake Prediction Research Center, Earthquake Research Institute, University of Tokyo, 2. Disaster Prevention Institute, Kyoto University, 3. Veictoria University of Wellington, 4. GNS Science

The Pacific Plate subducts beneath the Australian Plate at a rate of ~5 cm/year along the northern Hikurangi trough off the North Island, New Zealand, and the seismic activity is very high. In addition to regular earthquakes, slow earthquakes including slow slip events (SSEs) and tremor have been observed offshore on the shallow plate interface. SSEs are relatively frequent in the northern part of the Hikurangi subduction margin, occurring every 1-2 years. Therefore, this frequent, repeating occurrence offers an excellent chance to capture accompanying seismicity as well as the SSE itself using temporary deployments of ocean bottom instruments directly overlying the shallow (<10 km) SSE source.

We conducted an international collaborative observation from May, 2014, through June, 2015, using 15 ocean bottom seismometers (OBSs) and 24 ocean bottom pressure gauges (OBPs). We were successful in capturing an SSE directly beneath the network, and obtained a precise slip distribution of the event. The slip reached near the trough axis, and that the slip was reduced in the area of subducted seamounts. The tremor activity initiated near the end of the SSE and it lasted for more than two weeks, within a limited region over one of the subducted seamounts. Stress inversions from focal mechanisms of earthquakes during the SSE cycle revealed temporal variations in stress orientations suggestive of an increase in pore fluid pressure within the slab and along the plate interface during the period prior to SSEs in the area, and a subsequent reduction of pore fluid pressure following SSEs. Furthermore, variations of shear wave splitting delay times and Vp/Vs suggested that filling and emptying of cracks and pore spaces accompanied the fluid pressure changes. These observations of long-lasting tremor activity and temporal variation of focal mechanisms and cracks in tandem with the occurrence of SSEs suggest a potential role of fault-valving in the generation of slow earthquakes.
We conducted another temporary OBS deployment from Oct. 2018 through Oct. 2019 using 5 OBSs in the same region of the 2014-2015 observation spanning the subducted seamount where we recorded offshore tremor activity previously. A large SSE occurred during the observation period in April-May 2019 around our OBS network, and we were successful in capturing seismic activity accompanying the SSE. The seismicity increased around the start of the SSE and continued throughout the event. Some of the activity shows a large low frequency component, and it is likely that tremors were activated. We are conducting further investigations.

Keywords: Hikurangi subduction zone, marine seismic observation, tremor, plate interface geometry

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Seismic evidence for megathrust fault-valve behavior during episodic tremor and slip

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The periodic occurrence of slow earthquakes, including episodic tremor and slip (ETS), has been observed in several subduction zones and is believed to be related to cyclic fluid processes. The ETS source region is characterized by a layer of anomalously-low seismic-wave velocities (LVL) interpreted as subducting oceanic crust and/or shear zone material, which require near-lithostatic pore-fluid pressures and a weak megathrust fault. Hydro-mechanical models describe fluid motion during fault slip as ‘fault valving’, wherein fluids are able to migrate within and through faults when low-permeability barriers are ruptured during fault motion. Such models necessitate fluctuations in pore-fluid pressures near the fault. However, evidence for cyclic fluid processes during ETS is limited and indirect. Here we use repeated seismic scattering observations in the Cascadia subduction zone to show a change in the seismic velocity structure of the LVL following ETS. We interpret this velocity change as a response to a temporary reduction in pore-fluid pressure of approximately 1-10 MPa, which is comparable with recent observations of stress-switching within the shallow slow earthquake source region in Hikurangi. The observed change in seismic velocity structure is limited to stations located above the intersection of the slab with the hydrous mantle wedge corner, suggesting a link between slow fault slip and fluid storage within the overlying continental margin. Our results provide direct evidence of a change in the mechanical properties of the megathrust and fluid flow following ETS, and support models of fault-valve control on deep episodic slow earthquakes.

Keywords: Subduction zone structure, Slow earthquakes, Fluid pressure cycling

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[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG58] Science of slow earthquakes: Toward unified understandings of whole earthquake process

convener:Satoshi Ide(Department of Earth an Planetary Science, University of Tokyo), Hitoshi Hirose(Research Center for Urban Safety and Security, Kobe University), Kohtaro Ujiie(Graduate School of Life and Environmental Sciences, University of Tsukuba), Takahiro Hatano(Department of Earth and Space Science, Osaka University)

Accumulating observational studies on various types of slow deformation events, such as tectonic tremors, very low frequency events, and slow slip events, portrays some universal characteristics in generally complex behavior, including interaction among events and influence by various outer loadings. Some of these phenomena seem to have causal relation with the occurrence of very large earthquakes. A unified understanding of these slow and fast earthquake processes requires an approach integrating geophysics, seismology, geodesy, geology, and non-equilibrium statistical physics. We welcome presentations based on, but not limited to, geophysical observation, data analysis, analytical theory, numerical simulation, field study, and laboratory experiments.

[SCG58-20] Deformation of antigorite serpentinite in the base of the shallow wedge mantle and relationship to slow earthquakes

*Kazuyuki Yoshida[1], Takayoshi Nagaya[1], Simon Richard Wallis[1] (1.Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo)

[SCG58-21] Serpentinized shear zones with low frictional strength by grain-boundary sliding of antigorite at the depth of deep SSEs

*Takayoshi Nagaya[1], Simon Richard Wallis[1] (1.Graduate School of Science, The University of Tokyo)

[SCG58-23] Role of metasomatic reactions on plate-boundary shear localization near mantle wedge corner

*Naoki Nishiyama[1], Kohtaro Ujiie[1], Kazuya Noro[1], Yasushi Mori[2], Haruna MASUYAMA[1] (1.University of Tsukuba, 2.Kitakyusyu Museum of Natural History & Human History)

[SCG58-24] Stress heterogeneity on shallow decollement controls property of sediments and Very Low Frequency Earthquakes in Nankai Trough

*Yoshitaka Hashimoto[1], Haruki Kuchimoto[1], Shigeyuki Sato[1], Gaku Kimura[2], Masataka Kinoshita[3], Ayumu Miyakawa[4], Gregory F Moore[5], Masaru Nakano[6], Kazuya Shiraishi[6], Yasuhiro Yamada[6] (1.Kochi University, 2.TUMSAT, 3.ERI, University of Tokyo, 4.AIST, 5.Hawaii University, 6.JAMSTEC)

[SCG58-25] Rheology of the fluid oversaturated simulated quartz shear zone at the brittle-ductile transition

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Deformation of antigorite serpentinite in the base of the shallow wedge mantle and relationship to slow earthquakes

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Slow slip events (SSE) in SW Japan detected by geodetic and seismic studies develop at depths of 30–40 km. This domain is thought to consist of serpentinite with antigorite as the dominant serpentine mineral. The physical properties of antigorite and serpentinite, and in particular the anisotropic properties of foliated serpentinite, have been highlighted as important in controlling the nature of fluid flow, the times scales for relaxation after slip, and the seismic anisotropy in the plate boundary domain. The properties of foliated serpentinite are closely linked to the crystallographic preferred orientation (CPO) patterns and the most commonly recognized natural examples of antigorite CPO have c-axis maxima perpendicular to the foliation, thought to be roughly parallel to the subduction boundary, and b-axis maxima parallel to the extension direction, which approximates the subduction direction. However, the antigorite CPO of natural examples may not preserve the conditions at the depth because some antigorite may recrystallize and/or deform during exhumation of the serpentinite to the earth’ s surface.

Here we report on the kilometer-scale Shiragayama serpentinite body derived from the mantle wedge and exposed in the subduction-type Sanbagawa belt of Shikoku. Previous work has shown that there is an extensive antigorite shear zone in the base of this serpentinite body parallel to the boundary with slab-derived subducted metapelite units. This shear zone is potentially an important source of information on the state of the subduction boundary beneath the mantle wedge. However, it remains to be shown that this shear zone was present at depth or if it developed during exhumation. Previous petrological studies have shown that most of the Shiragayama serpentinite body originally consisted of both antigorite and up to 20 vol% of brucite. In addition, shortly before the onset of exhumation there was a regional rise in temperature that resulted in the reaction of brucite with adjacent antigorite to form olivine. All the observed olivine is metamorphic in origin. The growth of the olivine took place without deformation at peak pressure and this olivine can be used as a marker to look for evidence of post-olivine, exhumation-related growth and deformation of antigorite. Our microstructural observations show that aligned antigorite is locally overgrown by olivine. The CPO characteristics of this antigorite are indistinguishable from those of the shear zone. These features show that the foliated antigorite domain reflects features formed at depth in the subduction zone. A second line of evidence in favour of this interpretation comes from observations of a separate serpentinite body in the Sanbagawa belt, the Kamabuseyama body. The Kamabuseyama body consist dominantly of antigorite serpentinite and the outermost boundary is strongly deformed. However, the foliated serpentinite domain is largely defined by the presence of aligned chrysotile, which is the a low-T type of serpentine. A similar development of a foliation defined by chrysotile is not observed in the Shiragayama area supporting the idea that the antigorite shear zone reflects the state of the subduction boundary at depths of 30–40 km.

Keywords: Antigorite serpentinite, Slow slip event, Crystallographic preferred orientation, Sambagawa metamorphic belt

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Serpentinized shear zones with low frictional strength by grain-boundary sliding of antigorite at the depth of deep SSEs

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Deep slow slip events (SSEs) commonly occur around the plate interface between the subducting slab and the shallow wedge mantle at depths of ~30–50km. At these depths it is thought to be difficult to sustain large porous channels capable of transporting large volumes of fluids derived from the subducting slab, the main exception being water released by metamorphic reactions along plate interfaces (Abers et al., 2017, Nat. Geosci.). In addition, it is proposed that slow-slip behaviours arise near the threshold between stable and unstable failure related to frictional instabilities in hydrous silicates (Leeman et al., 2016, Nat. Comm.). For these reasons, the frictional properties of hydrous silicates are likely to be important in understanding SSE phenomena.

The shallow forearc wedge mantle is thought to contain significant amounts of hydrated peridotite in the form of high-temperature serpentine, antigorite (Atg). However, previous experimental studies have focused on gouge samples of the low-temperature serpentine minerals lizardite and chrysotile, and proposed the importance of both low effective normal stresses developed due to influence of pore fluids and the low frictional strength of the low-temperature serpentine (μ values from 0.7–0.5) to explain the slow rupture velocities of the short-term SSEs observed in nature (Hirauchi & Muto, 2015, EPS). Therefore, there are the gaps between the understanding of slow slip based on experimental frictional studies and the expected distribution of serpentinite minerals based on their thermodynamic stabilities in the region of deep SSEs.

Here we focus on the frictional property of antigorite as a key to deepen our understanding of the material properties relevant to deep SSEs. Atg is a highly anisotropic sheet silicate mineral and alignment of this mineral can result in strong frictional and permeability anisotropies in the forearc wedge mantle. However, several different types of crystal preferred orientation (CPO) patterns of Atg and the different CPO formation mechanisms have been proposed and the conditions under which these different types are likely to develop are not well known. In this study, we examine progressive development of Atg CPO by using EBSD analysis applied to strain gradients preserved in natural serpentinite shear zones. In addition, EBSD maps provided aspect ratios of individual grains and changes in shape preferred orientation. We also compared chemical composition with the observed geometric changes in Atg grains, using the results of EPMA analyses.

CPO analysis shows a clear rotation of the (001) basal plane of Atg towards parallel to the shear zone with increasing strain. The Atg CPO within the shear zone shows the B-type Atg CPOwhere a strong concentration of *b*-axes of Atg is parallel to the shear direction. There are only limited mis-orientations in individual Atg grains within the shear zone that could indicate internal plastic deformation. In addition, there are no significant differences seen in the size, aspect ratios and major element chemical compositions of the Atg grains within and outside of the shear zones. Finite strain ellipses estimated using March’s model for passive rotation of elongate shapes show increasing strain ratios associated with progressive rotation of the maximum stretching direction towards the shear plane of the shear zone. The above observations suggest reorientation of Atg grains occurred with increasing strain but without internal deformation or grain size reduction. Therefore, we propose the B-type Atg CPO formed by mechanical

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rotation of grains associated with grain-boundary sliding.

The association of grain-boundary sliding with the formation of B-type Atg CPO in the present shear zones is in agreement with the experimental observation that the low-friction direction of Atg is parallel to the *b* -axis. This implies that serpentinized shear zones that develop B-type Atg CPO along the slab-mantle boundary in subduction zones have a lower frictional strength than expected from experimental studies using the gouge sample of Atg and may be comparable to low-temperature serpentines, and could develop aseismic frictional sliding in deep SSEs domains.

Keywords: B-type antigorite CPO, Shallow wedge mantle, Grain boundary sliding, Deep slow slip events, Serpentinized shear zones, Friction

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Role of metasomatic reactions on plate-boundary shear localization near mantle wedge corner

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Geophysical observations have shown that fluids play an important role on the generation of slow earthquakes along the subduction plate boundary near the mantle wedge corner. However, the plate boundary processes remain poorly understood. We examined the subduction mélanges in the Nishisonogi metamorphic rocks, Kyushu Island, Japan, which were deformed at depths of ~25–30 km and temperatures of ~520 ˚C, comparable to environments of deep slow earthquakes. The subduction mé langes are composed of metabasite, pelitic schist, serpentinite, and chlorite-actinolite schist (CAS). The shear deformation is localized along the 0.02–5 m-thick CAS, resulting in the composite planar fabric defined by strong shape and crystallographic preferred orientations of actinolite and chlorite. The localized shear along CAS is accompanied with ~0.1–2 m-thick metasomatized metabasite. The metasomatic reactions between metabasite and CAS are characterized by decreased calcium (Ca) associated with consumption of actinolite and epidote and water release. The coexistence of metasomatized metabasite and localized shear zone suggest that the Ca-metasomatism and associated dehydration may lubricate the plate boundary fault by reaction-enhanced shear, resulting in the shear localization along CAS.

Keywords: metasomatic reaction, dehydration reaction, shear localization

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Stress heterogeneity on shallow decollement controls property of sediments and Very Low Frequency Earthquakes in Nankai Trough

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Variable slips from slow to fast have been observed in subduction plate interfaces. Recently, slow slips and tremor, and very low frequency earthquakes (VLFEs) are observed in shallow portion of subduction plate interface in Nankai Trough. Such variation of slips can be controlled by a rheological heterogeneity, which will be expressed by both heterogeneities in stress and/or physical properties of sediments. Stress heterogeneity could be archived due to the roughness of plate interface reacted with the regional stress. Material heterogeneity could be expressed by the heterogenetic distribution of porosity or abnormal fluid pressure. This study investigates stress and material heterogeneities on the shallow decollement in Nankai Trough to see the relationship between the heterogeneities and its relation to the VLFEs' occurrences.

We used 3D seismic profiles acquired for IODP NanTroSEIZE in the Nankai Trough off Kii peninsula and produced a 3D surface of the shallow decollement. Dip angle and dip azimuth for each 50 m X 50 m patch of the 3D surface were obtained. With focal mechanisms of the VLFEs in the region, regional stress orientations and stress ratio were estimated. Normal and shear stresses normalized by differential stress on each patch were calculated by the relationship between patch orientations and the regional stress. Slip tendency (*Ts*) and dilation tendency (*Td*) were also calculated.

The decollement dips in the convergent direction with low angle 0–5 degree in average. Patches with slightly larger dip (10–25 degree) are identified, distributing in NE-SW direction. The regional stress estimated shows relatively horizontal NW σ_1 and relatively vertical σ_3 with 0.65 of stress ratio. *Ts* ranges 0.4–0.6 and high or low *Ts* areas distribute in NE-SW directions repeatedly. *Td* ranges 0.3–0.7 and the distribution of *Td* shows a good agreement with that of *Ts*.

In the reprocessing on the 3D seismic profiles, the velocity model was also improved using the up-dated technics. Velocity distribution on the shallow decollement was also examined. Velocity ranges 1500-3500 m/s increasing from shallow to deep in broad sense. It is, however, not a simple increase with depth but some high and low velocity areas with NE-SW directions are identified. Using the velocity-porosity-effective pressure relationship from laboratory experiments on the sediments from IODP NantoSEIZE expeditions, the velocity could be converted to porosity and to effective pressure. Porosity ranges from 0.5-5% and effective pressure ranges from 1600-2600 kPa on the decollement. Because the conversion from velocity to others is a kind of linear conversion, the distributions of porosity and effective pressure are the same with that of velocity; NE-SW trend in high and low values. Although the absolute values of these properties could have multiple errors in many procedures, the relative values in spatial relationships can be discussed.

The spatial relationship between *Ts* and *Td*, and porosity or effective pressure also represent a consistent distribution. High *Ts* and *Td* areas correspond to the areas with low porosity and high effective pressure (relatively low fluid pressure at a depth). Slips tend to concentrate in the area with high *Ts*. High *Td* area corresponds to that with high *Ts*, which implies that the slip zone could be a fluid conduit. Oppositely, low *Ts* area has low *Td* where the fault could be a barrier of fluid migration. In the area with low porosity and

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high effective pressure, the sediments are relatively lithified than the sediments in the other area. In high *Ts*and *Td*areas enhance the fluid escape to make sediments lithified. The NE-SW directions of the distribution of high *Ts*and *Td*areas shows a good agreement with the direction of VLFEs' elongated distributions. This suggests that the *Ts*and *Td,*determined by the regional stress and the geomorphic features on decollement, may have close relation to VLFEs' occurrences.

Keywords: Slip and dilation tendencies, physical property of sediments, very low frequency earthquake, Nankai Trough

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Rheology of the fluid oversaturated simulated quartz shear zone at the brittle-ductile transition

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At the plate boundary, large earthquakes as well as slow earthquakes are typically nucleated around the depth limit of the seismogenic zone. At hot subduction zones, below the seismogenic zone, slow earthquakes and high V_p/V_s ratios indicating the presence of aqueous fluid are commonly observed. Thus, it is important to understand how the water content and the pore structure affect the rheology of polycrystalline materials at these conditions.

We conducted deformation experiments on quartz aggregates using a Griggs-type deformation apparatus. Silica gel was used as the starting material; quartz samples synthesized from “as-is” silica gel contain a fluid-filled porosity of ~22%; we prepared samples with lower fluid-filled porosity by pre-drying the gel at 120 degC (~15% porosity), 450 degC (~16%), and 900 deg (~7%). The average grain size is about 12 um, the grain shape is equigranular, and no crystallographic preferred orientation (CPO) is observed.

The measured stress from general shear experiments on porous quartz aggregates at an equivalent strain rate of 1.5 x 10^{-4} 1/s, pressures of 1.1 and 1.5 GPa and temperatures of 800–900 deg is significantly lower than predicted by the wet quartzite flow laws (e.g., Tokle et al., 2019), and shear stress decreases with increasing porosity. The stress exponent *n* at 800–900 deg is 2.8–5.2, suggesting that the dislocation creep of quartz controls the overall rate-behavior in the quartz shear zone. The stress exponent at 500–700 deg is 4.7–19, indicating a transition to brittle fracture/friction and/or semi-brittle flow.

S-C’ mylonitic structures characterized by the CPO and water segregation are observed in recovered samples deformed at 800–900 deg. A-axes of quartz align parallel to the P direction. We also found evidence for strain localization along R_1riedel shears, structure that are characterized by high porosity. In contrast, deformation experiments on cores of quartzite show homogeneous dislocation creep at this pressure/temperature condition.

The low flow stress and R1 reidel shear zones suggest that a stress enhancement process promoted by the high volume fraction of water, similar to observations on partially molten samples (e.g., Hirth and Kohlstedt, 1995). At low temperature conditions, sample strength may decrease owing to the influence of the effective pressure law in frictional deformation, in which case the effective fluid pressure increases with increasing porosity. The strength of the water-saturated high-porosity quartz shear zones can be explained by the combination of quartz flow law (e.g., Tokle et al., 2019) and the frictional strength of quartzite (Hirth and Tullis, 1994) including the effect of porosity on both the effective pressure law in the brittle regime and plastic strengths (Cooper et al., 1989) and a BPT constitutive law (Shimamoto and Noda, 2014). Our mechanical data is well explained by the combination of those theoretical and empirical equations.

Our result suggests that a few % of porosity causes drastic weakening in the quartz shear zone from a brittle to fully plastic regime. These rheology of fluid oversaturated shear zones could explain the weakness and the spectrum of slip behavior along the plate boundary.

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Keywords: Rheology, Fault, Brittle-plastic transition

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[S-CG58] Science of slow earthquakes: Toward unified understandings of whole earthquake process

convener:Satoshi Ide(Department of Earth an Planetary Science, University of Tokyo), Hitoshi Hirose(Research Center for Urban Safety and Security, Kobe University), Kohtaro Ujiie(Graduate School of Life and Environmental Sciences, University of Tsukuba), Takahiro Hatano(Department of Earth and Space Science, Osaka University)

Accumulating observational studies on various types of slow deformation events, such as tectonic tremors, very low frequency events, and slow slip events, portrays some universal characteristics in generally complex behavior, including interaction among events and influence by various outer loadings. Some of these phenomena seem to have causal relation with the occurrence of very large earthquakes. A unified understanding of these slow and fast earthquake processes requires an approach integrating geophysics, seismology, geodesy, geology, and non-equilibrium statistical physics. We welcome presentations based on, but not limited to, geophysical observation, data analysis, analytical theory, numerical simulation, field study, and laboratory experiments.

[SCG58-26] Slow slip prior to runaway slip in laboratory

*Miki Takahashi[1] (1.Institute of Earthquake and Volcano Geology, Geological Survey of Japan, AIST)

[SCG58-28] Slow slip and transition to fast rupture in friction of gels

*Tetsuo Yamaguchi[1] (1.Graduate school of Engineering, Kyushu University)

[SCG58-29] Experiments simulating the subduction of seamounts beneath a viscoelastic crust

*Atsuko Namiki[1] (1. School of Integrated Arts and Sciences, Hiroshima University)

[SCG58-30] Episodic fluid pressure cycling controls the interplay between Slow Slip Events and Large Megathrust Earthquakes

★Invited Papers

*Luca Dal Zilio[1], Claudio Petrini[2], Taras Gerya[2] (1.Seismological Laboratory, California Institute of Technology, Pasadena, CA, 2.Department of Earth Sciences, ETH Zürich, Zürich, Switzerland)

Slow slip prior to runaway slip in laboratory

*Miki Takahashi[1]

1. Institute of Earthquake and Volcano Geology, Geological Survey of Japan, AIST

Earthquake nucleation and propagation involves the acceleration of slip on a fault from a background, quasi-static, low-velocity state towards meter-per-second values. Following e.g. Niemeijer & Spiers, [2007, JGR], Takahashi et al., [2017, G-cubed] recently conducted shear experiments on brine-saturated simulated gouge composed of 80:20 wt.% mixtures of halite and muscovite at 5 MPa in normal stress and room-temperature and reported that the strength of the gouge shows the maximum at 1 mm/sec in the slip velocity. This boundary velocity of 1 micron/sec divides into velocity-strengthening regime controlled by pressure solution creep under low velocity condition and velocity-weakening regime characterized by cataclastic deformation, such as dilation, comminution and shear localization under high velocity condition. The mixtures of halite and muscovite could be a good analogue material to simulate the fault behaviors at around the brittle-ductile transition. Moreover, Takahashi et al., [2017] observed the direct effect disappears when the velocity exceeds another boundary velocity, V_c (~20 mm/sec). This means the fault slip easily accelerates towards “a runaway slip” once the velocity exceeds V_c. Therefore, to measure these boundary velocities in nature is very importance to understand the earthquake nucleation and propagation processes.

Takahashi et al., [2017] evoked a question, thus --- How does the fault at around brittle-ductile transition respond against a perturbation of the stress? Generally, in recognizing the fault slip stability, we use a sign of the velocity dependence of frictional strength, *so-called* a-b, under velocity-controlling boundary condition experiments. However, as long as we are adopting the velocity-controlling boundary condition experiments, spontaneous behavior of slip acceleration/decoration won’t be observable. Shear stress step change tests will be required to observe spontaneous evolution of the slip velocity. Excess stress over the maximum strength will be expected to induce unstable and runaway slip. On the other hand, at relatively low-velocity state, pressure solution creep will be expected to play a role to suppress the slip acceleration. Therefore, we have a potential to catch the fault behaviors of both slow slip and runaway slip in laboratory by adopting stress-controlling boundary condition experiments.

I performed rotary shear experiments with step changes in shear stress on the brine-saturated, 80:20 (wt %) mixture of halite (grain size < 75 mm) and muscovite (grain size < 30 mm) gouge. Approximately 1.65 g of the mixed gouge was then sandwiched between two teethed steel piston rings, having a size of 38 mm in inner diameter and 50 mm in outer diameter, which formed a 1 mm thick layer initially. I use a high-velocity rotary shear apparatus settled at GSJ, which has been developed by Toshi Shimamoto [e.g., Togo and Shimamoto, 2012, JSG]. I modified this apparatus to enable a torque control with an accuracy of 0.002 in the friction coefficient at 5 MPa in the normal stress. I measured rotation displacement using a potentiometer set near the piston ring at a rotation side. I obtained well-reproducible relationship between steady-state friction coefficient and steady-state velocity, comparing with the results from both Takahashi et al., [2017] and Niemeijer and Spiers [2007].

We obtained slow slip behaviors, spontaneous acceleration followed by deceleration, when the stress was nearly equal to but lower than the maximum strength of the simulated gouge. Once the velocity excessed ≈1 mm /sec, the runaway slip occurred followed by dynamic weakening at V ≈Vc = 20 μm/sec. However, the shear stress was sustained for 2~3 hours before the dynamic weakening occurred, even after the

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velocity exceeded 1 mm /sec. This delay of the onset of dynamic weakening could be explained by that the simulated gouge earned strength temporary due to the direct effect.

Keywords: slow slip, pressure solution creep, direct effect

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Slow slip and transition to fast rupture in friction of gels

*Tetsuo Yamaguchi[1]

1. Graduate school of Engineering, Kyushu University

It is an essential question of whether a slow slip completes as an isolated event or it accompanies a fast rupture, to predict a giant earthquake and to understand the underlying processes. In this study, we reproduced the above two cases in our laboratory experiments and compared them by measuring slip velocities and stress fields. As a result, we found that the heterogeneous stress distributions strongly effects the nucleation processes and the transition to fast rupture. In our talk, we will discuss our experimental results by comparing with numerical simulations.

Keywords: slow earthquake, giant earthquake, laboratory experiment , gel

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Experiments simulating the subduction of seamounts beneath a viscoelastic crust

*Atsuko Namiki[1]

1. School of Integrated Arts and Sciences, Hiroshima University

Topographies on a subducting plate changes the frictional force between the hanging wall and the foot wall. Indeed, the subducting seamounts seem to regulate the source locations of slow earthquakes. However, the quantitative evaluation of the effects of seamounts has not yet understood. Here, we performed a series of experiments of subducting seamounts beneath a viscoelastic rock analog. Associate with the increase of displacement of the slider as an analog of the subducting slab, the stress accumulates on the downdip edge, while in the updip, space appears between the hanging wall and seamount to be friction-free. We also found that, when there are topographies on the surface of the foot wall, topographies develops on the surface of the deformable hanging wall. The interlock of the topographies on the facing surfaces alters the temporal and spatial friction. Our results suggest that a unimodal topography on the subducting plate is the most efficient way to cause a repeating earthquake.

Keywords: earthquake, seamount

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Episodic fluid pressure cycling controls the interplay between Slow Slip Events and Large Megathrust Earthquakes

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1. Seismological Laboratory, California Institute of Technology, Pasadena, CA, 2. Department of Earth Sciences, ETH Zürich, Zürich, Switzerland

Slow slip events (SSEs) are part of a spectrum of aseismic processes that relieve tectonic stress on faults. Their occurrence in subduction zones have been suggested to trigger megathrust earthquakes due to perturbations in fluid pressure. However, examples to date have been poorly recorded and physical observations of temporal fluid pressure fluctuations through slow slip cycles remain elusive. Here, we use a newly developed two-phase flow numerical model —which couples solid rock deformation and pervasive fluid flow —to show how crustal stresses and fluid pressures within subducting megathrust evolve before and during slow slip and regular (fast) events. This unified 2D numerical framework couples inertial mechanical deformation and fluid flow by using finite difference methods, marker-in-cell technique, and poro-visco-elasto-plastic rheologies. Furthermore, an adaptive time stepping allows the correct resolution of both long- and short-time scales, ranging from years to milliseconds during the dynamic propagation of earthquake rupture.

Results show how permeability and its spatial distribution control the degree of locking along the megathrust interface and the interplay between seismic and aseismic slip. While a constant permeability leads to more regular seismic cycles, a depth dependent permeability contributes substantially to the development of two distinct megathrust zones: a shallow, locked seismogenic zone and a deep, narrow aseismic segment characterized by SSEs. Furthermore, we show that without requiring any specific friction law, our model shows that permeability, episodic stress transfer and fluid pressure cycling control the predominant slip mode along the subduction megathrust. Specifically, we find that the up-dip propagation of episodic SSEs systematically decreases the fault strength due to a continuous accumulation and release of fluid pressure within overpressured subducting interface, thus affecting the timing of large megathrust earthquakes. These results contribute to improve our understanding of the physical driving forces underlying the interplay between seismic and aseismic slip, and demonstrate that slow slip events may prove useful for short-term earthquake forecasts.

Keywords: Slow-slip events, fluids, Numerical modeling, Large megathrust earthquakes, Subduction zones

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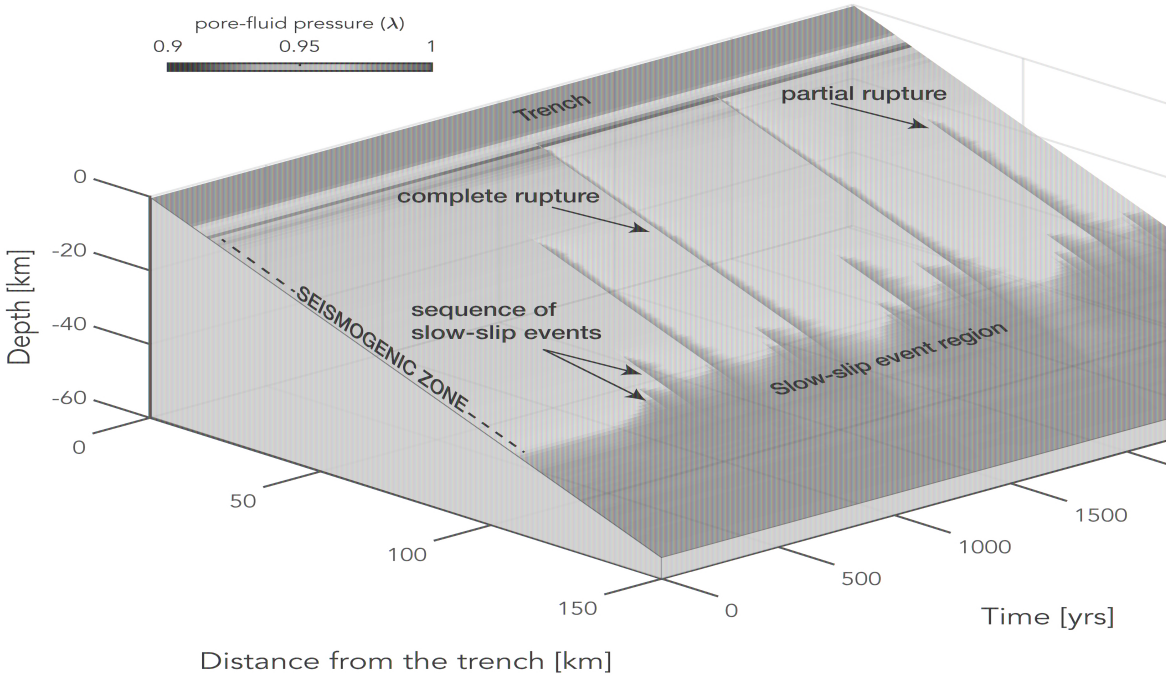

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[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG58] Science of slow earthquakes: Toward unified understandings of whole earthquake process

convener:Satoshi Ide(Department of Earth an Planetary Science, University of Tokyo), Hitoshi Hirose(Research Center for Urban Safety and Security, Kobe University), Kohtaro Ujiie(Graduate School of Life and Environmental Sciences, University of Tsukuba), Takahiro Hatano(Department of Earth and Space Science, Osaka University)

Accumulating observational studies on various types of slow deformation events, such as tectonic tremors, very low frequency events, and slow slip events, portrays some universal characteristics in generally complex behavior, including interaction among events and influence by various outer loadings. Some of these phenomena seem to have causal relation with the occurrence of very large earthquakes. A unified understanding of these slow and fast earthquake processes requires an approach integrating geophysics, seismology, geodesy, geology, and non-equilibrium statistical physics. We welcome presentations based on, but not limited to, geophysical observation, data analysis, analytical theory, numerical simulation, field study, and laboratory experiments.

[SCG58-31] Slip-front-propagation velocity with non-vanishing friction stress at infinitely large slip velocity

*Takehito Suzuki[1], Hiroshi Matsukawa [1] (1.Department of Physics and Mathematics, Aoyama Gakuin University)

[SCG58-32] Modeling tremor with cellular automaton

*Kota Fukuda[1], Takahiro Hatano[2], Kimihiro Mochizuki[1] (1.Earthquake Research Institute The University of Tokyo, 2.Department of Earth and Space Science The Osaka University)

[SCG58-33] **Continuum model for interacting many faults: emergence of main fault and Gutenberg-Richter's law**

*Akio ISHII[1], Takahiro Hatano[1], Tomoaki Niiyama[2] (1.Osaka University, 2.Kanazawa Univesity)

[SCG58-34] New atomistic mechanism for velocity-weakening friction

*Takahiro Hatano[1], Akio Ishii[2], Tomoaki Niiyama[3], Tomotsugu Shimokawa[3], Shigenobu Ogata[2] (1.Department of Earth and Space Science, Osaka University, 2.Department of Mechanical Science and Bioengineering, Osaka University, 3.Department of Mechanical Engineering, Kanazawa University)

[SCG58-35] Reduction of mathematical model for slip behavior of one dimensional elastic layer with rate and state friction

*Yutaka Sumino[1], Takuya Saito[2], Tetsuo Yamaguchi[3], Takahiro Hatano[4], Satoshi Ide[5] (1.Tokyo University of Science, 2.Aoyama Gakuin University, 3.Graduate School of Engneering, Kyushu University, 4.Department of Earth and Space Science, Osaka University, 5.Department of Earth and Planetary Science, Tokyo University of Science)

[SCG58-36] Effects of periodic stress perturbations on earthquake nucleation

*Takuya Saito[1], Takahiro Hatano[2] (1.Aoyama Gakuin University, 2.Osaka University)

Slip-front-propagation velocity with non-vanishing friction stress at infinitely large slip velocity

*Takehito Suzuki[1], Hiroshi Matsukawa [1]

1. Department of Physics and Mathematics, Aoyama Gakuin University

Ordinary and slow earthquakes are different in many perspectives such as slip velocity. Among those differences, rupture velocity is important; the rupture velocities for ordinary earthquakes are usually larger than those for slow earthquakes. We aim to explain the difference observed in the rupture velocities by assuming a simple 1D end-loading model.

We consider a visco-elastic block on a rigid and fixed substrate, and apply the loading stress acting on the left end in the direction tangential to the substrate. We assume that the friction stress tau is given by $tau = a \dot{u}(2b-\dot{u})[H(\dot{u})-H(\dot{u}-2b)]= a \dot{u}(v_{van}-\dot{u})[H(\dot{u})-H(\dot{u}-v_{van})]$, where u is the slip, $\dot{u}$ is the slip velocity, H is the unit Heaviside function, a and b are positive constants, and $v_{van}=2b$. We refer to this friction law as the quadratic-form (q-form) friction law. It should be noted that this friction law gives vanishing friction with $\dot{u} > v_{van}$. Based on this model setup, we already obtained the analytical value of the smallest steady slip-front-propagation velocity. This value has been interpreted as the smallest propagation velocity for ordinary earthquakes. However, we should investigate the case where the friction stress does not vanish with infinitely large slip velocity regime. We therefore assume the friction law with the form $tau = a\ b\ \dot{u} \exp(-\dot{u}^2/2b^2+1/2)$ here. This friction law will be referred to as the non-vanishing (NV) friction law below.

To compare the slip behavior with NV friction law to that with q-form friction law, we calculated the slip persistent time. We define the slip persistent time as the time at which the normalized slip velocity at all points on the slip plane becomes smaller than 0.1 $|p_{left}|$ as measured from the onset of end-loading, where $|p_{left}|$ is the normalized stress applied at the left-end point. Actually, the slip persistent time diverges with negligible $||p_{left}|-|p_c||$, where p_c is a constant, with the q-form friction law because the steady propagation emerges for $|p_{left}|>|p_c|$. On the other hand, the slip persistent time never diverges with the NV friction law, since the steady state does not emerge as shown in our previous treatments. However, the numerical result shows the power law between the persistent time and $||p_{left}|-|p_c||$ within the time range investigated, and distinction between the q-form and NV friction laws is impossible within the computational limit. This result clearly shows that apparent critical behavior emerges with the NV friction law. We can conclude that implications based on the q-form friction law is qualitatively applicable to the law where the friction stress decreases with increasing slip velocity in the large slip velocity regime, but never vanishes. In particular, the smallest propagation velocity for ordinary earthquakes can be robustly applicable. Moreover, we can imply that the slip-front-propagation velocity for slow earthquakes does not exceed such a velocity.

Keywords: slip-front-propagation velocity, 1D model, slip-velocity-dependent friction stress law

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Modeling tremor with cellular automaton

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1. Earthquake Research Institute The University of Tokyo, 2. Department of Earth and Space Science The Osaka University

Bak, Tang, and Wiesenfeld introduced the concept of self-organized criticality. In this concept, the OFC model was introduced by Olami, Frder, and Christensen as a further simplification of the Burridge and Knopoff model(BK model) and as a nonconservative sandpile model. The Olami-Frder-Christensen model(OFC model) is cellular automaton model which exhibits critical properties such as the Gutenberg-Richter law or the Omori law. In the conventional OFC model, stress doesn’t accumulate during rupture propagation because the rupture propagation time scale is assumed to be much smaller than the loading time scale in the regular earthquakes. If we consider tremor’s model that more sensitive than regular earthquakes, we should consider that rupture propagation time scale and loading time scale is close. Tremor’s loading time scale may be shorter because tremor’s stress drop is smaller. Therefore we introduced a new parameter which represents a degree of balance between rupture propagation time scale and loading time scale into the OFC model. This parameter is defined as the amount of stress that accumulate until one cell finishes sliding. We can think the new OFC model represent tremors when this parameter is large.

The new OFC model can explain the several observational properties of tremors. 1: Tremor can be explained as a swarm of low-frequency earthquakes(LFE). 2:The seismic displacement waveform power spectrum density is lorentzian spectrum. 3: The seismic moment is proportional to the duration. 4: The size distribution power or exponential depends on the new parameter dimensionless loading rate. These results suggest that the dimensionless loading rate is an important parameter to represent tremors and LFE.

Keywords: tremor, cellular automaton, Gutenberg-Richter law

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Continuum model for interacting many faults: emergence of main fault and Gutenberg-Richter's law

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1. Osaka University, 2. Kanazawa Univesity

Although the origin of the Gutenberg-Richter's (GR) law has long been discussed, we are still far from the decisive conclusion. Historically, the Burridge-Knopoff model and similar discrete models have played a certain role in understanding the origin of the GR law. However, they are essentially discrete models and therefore the relation to continuum (i.e., the Earth's crust) has not been clear. Additionally, the large-scale morphology of many faults, such as the emergence of strain concentration zones and tectonic lines, lacks any physical models, although such geological structure has long been discussed in geodesy and geology.

To address the above questions, here we construct a large-scale continuum model for seismicity based on the elasticity theory and the micromechanics theory for defects in solids [1]. In our model, earthquake faults are regarded as point sources, and the seismic moment of a point source is translated into the "eigenstrain" in the context of micromechanics. Then the local stress and released energies of individual earthquake are calculated based on micromechanics, and these earthquakes interact each other via the elastic continuum. We adopt the Mohr-Coulomb failure criterion as the earthquake occurrence condition. Our simulation reproduces a clear band structure, in which the seismic moment accumulates. The GR law is also reproduced with a range of b-value that is consistent with the observations. We discuss how the b-value depends on the pressure and other physical conditions.

[1] T. Mura, Micromechanics of defects in solids (Springer Science & Business Media, 2013).

Keywords: earthquake model, simulation, micromechanics, point source

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New atomistic mechanism for velocity-weakening friction

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The extent of slip acceleration is crucial to the understanding of “science of slow earthquakes”, and it is mainly determined by the law of friction. A necessary condition for slip acceleration is the negative velocity-dependence of friction force: i.e., the frictional force decreases as the slip velocity increases.

To the current popular belief, the physics behind the negative velocity-dependence of friction is the time-dependent growth of the real contact area. This has been actually verified in laboratory experiments on brittle, dry, and transparent materials.

In actual seismogenic zones, however, such experimental conditions may not be so relevant due to the existence of gouges, fluid, and high pressure. For instance, at the depth of 40 km, the pressure is expected to be 1 GPa. Even if the fluid may support the pressure in part, the nominal normal stress may exceed the compression strength of quartz, and therefore one can expect that the real contact area may equal the nominal contact area. In such cases, the time-dependent growth of the real contact area is less likely.

Here we propose a completely different mechanism for negative velocity-dependence of friction by assuming a time-dependent process at the atomic scale. Namely, the atomistic rearrangement (or a plastic event) by the shear “activates” the system and therefore a subsequent plastic event can occur more easily. This is effectively described by introducing the time-dependent activation energy for plastic events. The activation energy decreases immediately after an atomistic plastic event and slowly relaxes to the original value unless another plastic event occurs. We show that the negative velocity dependence is derived if the relaxation time of the time-dependent activation energy has a certain distribution width. Since this velocity-weakening mechanism does not require any concepts on real contact area, this may be applicable to a wider class of earthquakes, such as intermediate depth earthquakes.

Keywords: friction law, hysteresis

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Reduction of mathematical model for slip behavior of one dimensional elastic layer with rate and state friction

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1. Tokyo University of Science, 2. Aoyama Gakuin University, 3. Graduate School of Engneering, Kyushu University, 4. Department of Earth and Space Science, Osaka University, 5. Department of Earth and Planetary Science, Tokyo University of Science

It is already accepted notion that slow earthquake occurs at the region between steady sliding and seismogenic zones[1]. Inspired from such observation, in this study, we explore the mathematical model of one-dimensional thin elastic layer incorporating a rate and state friction model, especially focused near the Hopf-bifurcation point. Hopf-bifurcation is a bifurcation from steady sliding state to oscillatory state. Intuitively, the behavior near such bifurcation point should be related with slow earthquake which occurs at the region between steady sliding to seismogenic zones.

Our model starts from one-dimensional thin elastic layer sheared between two parallel solid plates which moves perpendicular to the spatial dimension at the constant relative velocity. This situation is reduced to be one-dimensinal wave equation incorporating the effect of the friction at the bottom plate[2]. As a friction, we used rate and state friction model, which is introduced by Dietrich[3]. These situation lead to partial differential equations with three variables, displacement, speed and state. Despite of extremely simplified situation, there still remains ten parameters to be determined. However, our concerns are limited to the behaviors near the Hopf bifurcation point of our mathematical model. By focusing near the bifurcation point, we can reduce the equation into complex Ginzburg Landau equation, which has only one complex variable with three complex parameters. The reduced equation also predicts that the model exhibits spatio-temporal chaos due to Benjamin-Feir instability as shown in Fig. (a) by the spatio-temporal diagram. By applying the threshold value of the slip velocity, we can discretize the obtained slip data as in Fig. (b). In this way, we found that the statics of the slip shows exponential distribution in the spatio-temporal chaos regime as in Fig. (c).

The size of such slip can be also deduced from physical parameters analytically. Some engineering circumstances and room analogue experiments, we can show that the current model can be applied successfully. Unfortunately, however, our prediction, the duration and the spatial size of slip, are NOT consistent with geophysical observations. Thus, we conclude that slow earthquake can NOT be simplified as spatio-temporal chaos observed in one dimensional elastic layer. In this talk, we will show the detail of the mathematical model, as well as the result of reduction. In addition, we show the observed spatio-temporal chaos regime and their inconsistency with geophysical observation.

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[1] K. Obara, *Science* **296** 1679 (2002).
[2] I. Clancy and D. Corcoran, *Phys. Rev. E* **73**, 046115 (2006).
[3] J. H. Dietrich, *J. Geophys. Res.* **84**, 2161 (1979), J. R. Rice, A. L. Ruina, *J. Appl. Mech.* **50** 343 (1983).

Keywords: rate and state friction, reduction of mathematical model, Benjamin-Feir instability

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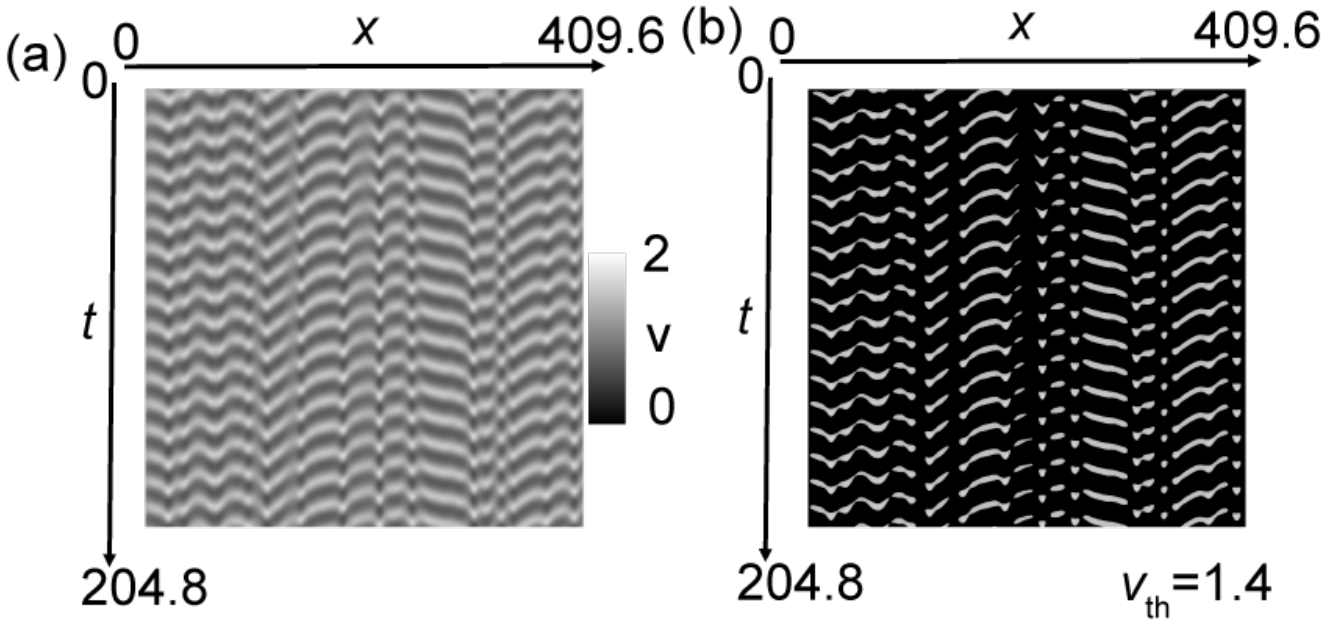

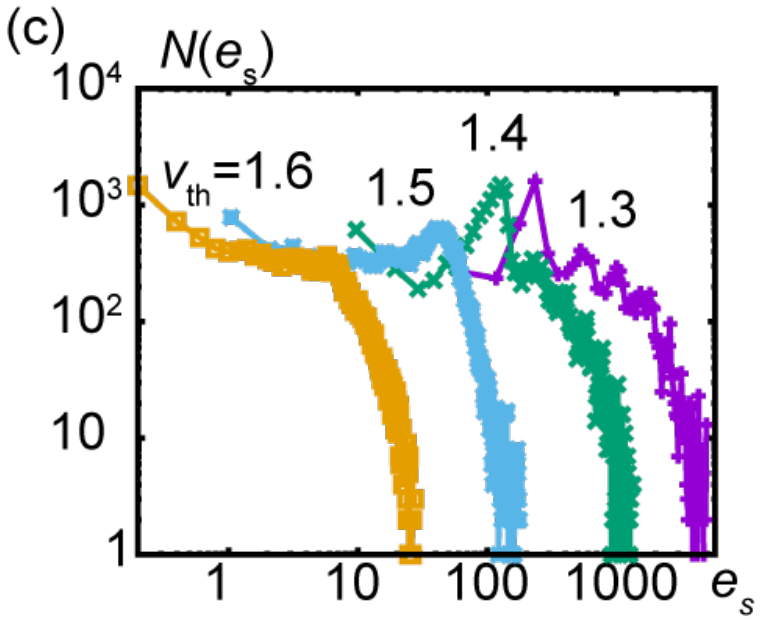

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Effects of periodic stress perturbations on earthquake nucleation

*Takuya Saito[1], Takahiro Hatano[2]

1. Aoyama Gakuin University, 2. Osaka University

One of the important approaches to find underlying physics is to investigate a mechanical response. This idea is inherent not only in laboratory scale, but applicable to a kilometer-scale fault [1]. Recent studies have been showing a high susceptibility of tremors in slow earthquake [2], which may be sorted into an issue of the mechanical response. This study numerically investigates effects on earthquake nucleation growths of periodic stress perturbations like ocean tides. By assuming the rate- and state-dependent friction law on a flat fault embedded in an elastic continuum, we compute the earthquake occurrence rate as functions of the stress or the phase of stress perturbation.
The remarkable points in the results are as follows:
(1) The phase distributions do not show a large phase shift.
(2) The earthquake occurrence is defined as the moment when the slip rate exceed a given threshold value. The occurrences are represented by the normal or shear stress imposed at that moment.
(3) The dependences of earthquake rate on the shear or the normal stress appear to be exponential. This indicates existence of a characteristic stress.
(4) According to the rock experiments conducted by Linker and Dieterich [3], variation of the normal stress additionally alters the frictional condition on the interface. The Linker-Dieterich effect suppresses a gap between top and bottom on the phase distributions, and furthermore, if the effect is very large, we observe antiphase distribution (see fig. 1).

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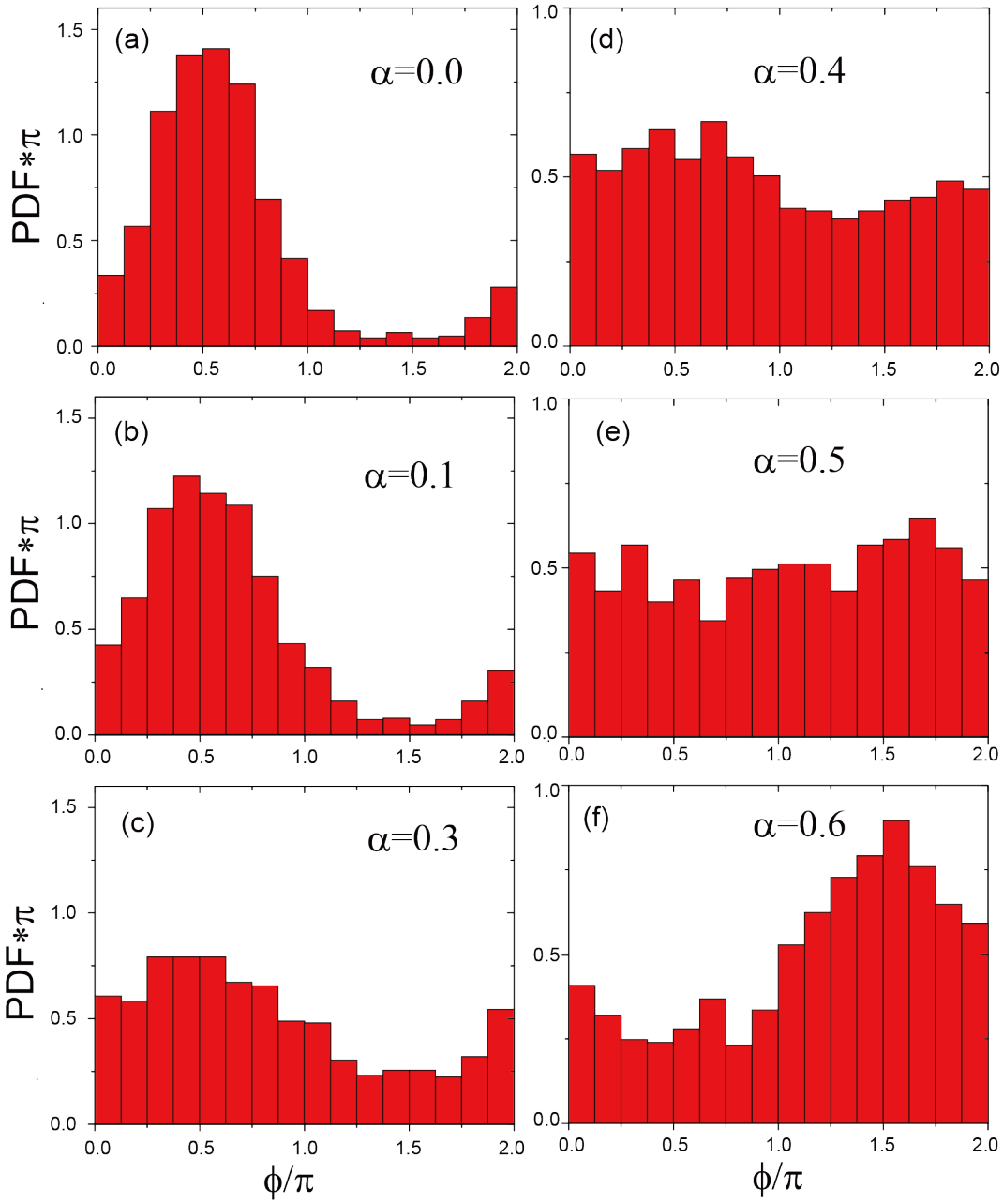

FIG. 1: Distributions of the normal-stress phase at the moment when the nucleation velocity reaches the threshold, which is regarded as the onset of seismic wave. As an increase of the Linker-Dieterich parameter α, a gap between the top and the bottom on the distribution becomes small, and then the phase distribution is eventually inverted.

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[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG59] Evolution and movement of the crustal surface and application of geo- and thermochronology

convener:Noriko Hasebe(Institute of Nature and Environmental Technology, Kanazawa University), Shigeru Sueoka(Japan Atomic Energy Agency), Frederic Herman(University of Lausanne), Takahiro Tagami(Graduate School of Science, Kyoto University)

The terrestrial earth surface is the habitat of humans and undergoes drastic changes caused by endogenic and exogenic processes. Establishing the chronology of the past changes/episodes is a key to understanding ongoing processes and to predict future physical environments. This session aims at comprehensive understanding of dynamics of the earth's surface, including crustal movements, uplift-denudation processes, and subsequent landform development occurred in various spatio-temporal scales. In addition to the thermochronological approach, it welcomes interdisciplinary studies based on, e.g., tectonic geomorphology, structural geology, geodetic observation, cosmogenic nuclides, numerical calculations, and analogue experiments.

[SCG59-01] Overview of geo- and thermo-chronology applicable to unravel the earth's surface evolution

*Takahiro Tagami[1], Shigeru Sueoka[2], Noriko Hasebe[3], Frederic Herman[4] (1.Graduate School of Science, Kyoto University, 2.Japan Atomic Energy Agency, 3.Institute of Nature and Environmental Technology, Kanazawa University, 4.University of Lausanne)

[SCG59-02] **Direct dating of faults by luminescence and ESR: Case studies from Japan and Switzerland**

★Invited Papers

*Sumiko Tsukamoto[1], Benny Guralnik[2], Kiyokazu Oohashi[3], Makoto Otsubo[4], David Colin Tanner[1], Christian Brandes[5], Christoph von Hagke[6] (1.Leibniz Institute for Applied Geophysics , 2.Technical University of Denmark, 3.Yamaguchi University, 4.Geological Survey of Japan, AIST, 5.Leiniz University of Hannover, 6.RWTH Aachen University)

[SCG59-03] Thermal characteristics of slab fluid in Hongu area, southwest Japan: Insights form thermochronology and fluid inclusion analyses

*Shigeru Sueoka[1], Mizuho Kanno[1], Makoto Kawamura[1], Masakazu Niwa[1], Hideki Iwano[2], Tohru Danhara[2] (1.Japan Atomic Energy Agency, 2.Kyoto Fission-Track Co., Ltd.)

[SCG59-04] Tectono–thermal history of the Lesser Himalaya in eastern Nepal: Insights from multi-thermochronological study and thermo-kinematic modeling

*Nakajima Toru[1], Hideki Iwano[2], Tohru Danhara[2], Harutaka Sakai[1] (1.Division of Earth and Planetary Sciences, Graduate School of Science, Kyoto University, 2.Kyoto Fission-Track Co. Ltd)

[SCG59-05] Resolving rates of landscape evolution with $^{4}He/^{3}He$ thermochronometry: examples from Grand Canyon and Yosemite Valley

★Invited Papers

*Matthew Fox[1] (1.Dept. of Earth Sciences, University College London, London UK)

Overview of geo- and thermo-chronology applicable to unravel the earth's surface evolution

*Takahiro Tagami[1], Shigeru Sueoka[2], Noriko Hasebe[3], Frederic Herman[4]

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The earth’s surface has been evolved dynamically since its birth, and predominantly governed by the plate tectonic regime in Cenozoic time. While the passive continental margin reflects lithosphere’s continued cooling associated with the ocean floor’s spreading after breakup and rifting, the active margin exhibits more dynamic geological phenomena, such as widespread magmatism, earthquake and crustal deformation, accretionary growth/erosion, etc. As a result, the structure and topography of plate convergence zones, i.e., island arc and marginal sea, continental arc and collisional orogens, represent dynamic spatial and temporal geological developments. In addition, the geomorphological features of the earth’s surface have been modified by denudation (i.e., erosion and tectonic denudation), sediment transportation and deposition. The denudation, in particular, has also been significantly controlled by orbital forcing and resultant climatic episodes coupled with global sea level changes.

Many of those geological developments have been recorded in geological materials and can be decoded by modern geo- and thermo-chronological techniques (e.g., Kelly, 2002; Schmitt, 2011; Tagami, 2012; Herman et al., 2013; Sueoka et al., 2016; Ault et al., 2019; Malusa and Fitzgerald, 2019). In this presentation, we give an overview of geo- and thermo-chronology to tackle those geoscientific targets, especially focusing upon the plate convergence zone developments. These techniques, coupled with other available geophysical, geological and geomorphological information, place important constraints on the earth’s surface evolution.

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Keywords: thermochronology, geochronology, earth surface

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Direct dating of faults by luminescence and ESR: Case studies from Japan and Switzerland

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Luminescence and electron spin resonance (ESR) signals from quartz and feldspar have ultralow closure temperatures, and therefore these dating methods have a significant potential in elucidating neotectonic activities and erosion histories (King et al., 2016). Direct dating of fault gouge using luminescence and ESR has been proposed and tested as a possible method to estimate the last movement of faults (e.g. Ikeya et al., 1982). However, when apparent luminescence and ESR ages were compared with a known age of the last large earthquake, in most cases the ages are overestimated, because the signals used for dating have not been fully reset at the last earthquake.

In this study, we show our results of direct dating of fault gouges from the Simplon Fault, Switzerland, and the Atotsugawa Fault, Japan using luminescence and ESR. The Simplon Fault is a major, late orogenic, normal fault in the Alps, and the Atotsugawa Fault is a very active dextral strike slip fault, in central Japan.

The natural feldspar infrared stimulated luminescence (IRSL) signals from the Simplon Fault were indistinguishable from saturation, whereas the natural quartz ESR signal (Al centre) was not in saturation, yielding a preliminary equivalent dose value of ~1500 Gy. Our results suggest that by combining luminescence and ESR dating with different saturation limits, it is possible to narrow down the age range of the last seismic activity on the fault.

The apparent quartz optically stimulated luminescence (OSL) ages from four gouge samples from the Atotsugawa Fault yielded a mean age of 38 ±6 ka, which is about two order of magnitude older than the age of the last large earthquake, occurred in 1858 (~ 170 a). We measured the thermal decay of the OSL signal in the laboratory and converted the mean apparent age to a mean apparent temperature (T_{app}), 54 ±1 ˚C. We propose that T_{app} could be used as a new metric to evaluate the activity of faults.

Keywords: fault gouge, direct dating, optically stimulated luminescence, electron spin resonance

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Thermal characteristics of slab fluid in Hongu area, southwest Japan: Insights form thermochronology and fluid inclusion analyses

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Non-volcanic thermal fluid activities have been reported in subduction zones, which are derived from dehydration of the subducting slab (e.g., Ito et al., 1983, GCA; Jarrard, 2003, GGG; Hacker, 2008, GGG). In the Japanese Islands, slab-derived fluids are identified such as in Iwaki region (Togo et al., 2014, EPS) of NE Japan Arc, Kii peninsula (Morikawa et al., 2016, GCA) and Arima region (Nishimura et al., 2006, J. Hot Spring Sci.; Kusuda et al., 2014, EPS) in SW Japan Arc. Understanding of fundamental features of these slab-derived fluids, e.g., the thermal and chemical characteristics, are important because slab-derived fluids can be related to seismicity (Zhao et al., 1996, Science; Obara, 2002, Science), formation of ore deposits (Cox, 2005), development of geothermal resources (Adachi et al., 2014, J. Hot Spring Sci.), and stability of underground facilities (AIST, 2016).

This study attempted estimating of thermal characteristics of slab-derived fluids in Hongu region, southwest Japan, based on thermochronology and fluid inclusion analyses. We measured homogenization temperatures of fluid inclusions of quartz veins to estimate temperature of the thermal fluids. Thermochronometries, e.g., fission-track (FT) analyses on apatite and FT, (U-Th)/He and U-Pb analyses on zircon, were also applied to the host rocks to constrain the timing, duration, and spatial range of the thermal fluid activities.

Homogenization temperatures of the primary inclusions were estimated to be 140-210 deg. C. Apatite FT ages of 12-9 Ma, zircon (U-Th)/He ages of 24-9 Ma, zircon FT ages of 30-18 Ma, and zircon U-Pb ages of 77-68 Ma were also obtained. These cooling ages produced no spatial variation according to the distance from the quartz veins. These dating results can be explained by the three scenarios: 1) apatite FT ages of the all samples were totally reset at ~10 Ma by thermal fluid activities, 2) the thermal fluid activities occurred prior to ~10 Ma and the apatite FT ages reflect the regional exhumation at ~10 Ma, and 3) the thermal fluid activities occurred after ~10 Ma but had no effect on these apatite FT ages due to the short duration and/or low temperature. The scenario 1) is less possible because such a huge thermal event could have affected on ages of the higher-temperature thermochronometers. However, it is difficult to distinguish the scenarios 2) and 3) using our data set.

Thermal characteristics of the thermal fluid activities in the scenario 2) and 3) are summarized as below. In the scenario 2), the fluid activities occurred at the depth of 2-3 km or deeper, assuming a surface temperature of 10-20 deg. C and geothermal gradient of ~30 deg. C. Rise in temperature associated with the event is calculated at 20-130 deg. C from the ambient temperature and homogenization temperatures. The timing, duration, spatial range of the thermal fluid activities are not constrained. In the scenario 3), on the other hand, the upper limit of the duration of fluid activities can be constrained although the timing and spatial range are not. Based on annealing function of Ketcham et al. (1999, Amer. Min.), the upper limits are a few 10 years for 150 deg. C and one month for 200 deg. C. For further understanding of thermal characteristics of slab-derived fluids, further studies adopting the same approaches are desired in more slowly exhumated region, such as in Rokko area (Sueoka et al., 2010, J. Geogr.), where thermal anomalies related to recent events are easier to detect due to the older cooling

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ages of the host rocks.

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Keywords: thermochronology, fluid inclusion, slab-derived fluid, Hongu area

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Tectono–thermal history of the Lesser Himalaya in eastern Nepal: Insights from multi-thermochronological study and thermo-kinematic modeling

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We investigated the cooling history of the Higher Himalayan Crystalline (HHC) and underlying Lesser Himalayan sediments (LHS) distributed in eastern Nepal. Previous studies reported that the cooling ages varied in space along an across-strike section in the Lesser Himalaya, and have proposed several thermo–kinematic models to explain the observed cooling age distribution. We carried out zircon and apatite fission–track (ZFT/AFT) dating and thermochronological invert calculation in order to constrain the time–temperature (t–T) path and determined the thermo–kinematic process by comparing the t–T path with the thermo–kinematic forward model. We newly obtained 18 ZFT ages and 11 AFT ages from the Higher Himalayan Crystalline (HHC) nappe and Lesser Himalayan sediments (LHS) distributed in eastern Nepal. The FT ages showed the northward-younging distribution pattern (ZFT: 10.7–4.8 Ma; AFT: 9.6–2.3 Ma) along the N-S section, which indicates the progressive northward cooling of the HHC and LHS since middle Miocene. Results of the thermochronological invert calculation revealed that the shape of the t–T path varies with its structural position and horizontal distance along the N-S section. Forward modeling using 2D thermo–kinematic model Pecube (Braun et al., 2012) demonstrated that the cooling age distribution and variety of the t–T path reflect two main tectono–thermal processes: 1) post-emplacement gradual cooling of the HHC nappe and 2) tectonically driven denudation associated with the activity of the Main Himalayan Thrust beneath the Himalaya. We suggest that these two processes mainly determine the tectono–thermal process of the Lesser Himalaya.

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Keywords: continental collision , thermochronology, fission-track, Himalaya, denudation

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Resolving rates of landscape evolution with $^{4}He/^{3}He$ thermochronometry: examples from Grand Canyon and Yosemite Valley

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Despite decades of research, the relative importance of climate versus tectonics in shaping Earth’s surface remains debated. In particular, it is unclear whether recent glacial erosion has led to a significant increase in erosion rates over the last 2Ma. One way to investigate this in more detail is to collect data that are sensitive to very low-temperatures and can provide exhumation rate constraints in slowly exhuming locations. The (U-Th)/He system is sensitive to low temperatures (<100oC), however overdispersion of (U-Th)/He ages represents an obstacle to extracting accurate and precise thermal paths. An alternative to collecting multiple (U-Th)/He ages from the same locality is to collect a large amount of information from individual crystals using 4He/3He thermochronometry. In regions of slow cooling rates, the 4He/3He spectrum can be strongly influenced by intra-crystal variations in radiation damage. This can make detecting a recent cooling signal challenging. But, if such complexity is adequately understood, each crystal has potential to tightly constrain its continuous thermal path. Here, we present examples from Grand Canyon where these methods have been developed, and Yosemite Valley where we can test the role of glaciers in forming this dramatic landscape. In Grand Canyon, differences in zonation between crystals from the same sample have helped constrain the history of fluvial incision. In this case, ICP-MS data from polished sections through crystals were inverted to account for spatial smearing associated with large spot sizes. This allowed the U and Th zonation to be implemented in a 3D diffusion model and resolve recent cooling. In Yosemite Valley, we combine 3D diffusion models of 4He/3He data with thermo-kinematic models to test the magnitude of glacial erosion. In this case, the ability to measure incision is improved using three approaches: intra-crystal variations in zonation provide precise cooling histories; age variability across crystals from the same sample due to radiation damage provide overlapping temperature sensitivity; data from different locations across the landscape are linked with a thermal model. Our results suggest that a large amount of the current topography developed more recently than 20 million years during a time of tectonic uplift of the Sierra Nevada. Importantly, as Matthes believed, Yosemite Valley is largely not a Pleistocene feature and the role of glacial erosion in shaping this landscape is therefore likely to be relatively minor.

Keywords: Thermochronology, Inverse methods, Landscape evolution

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[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG60] Toward Discoveries in Solid Earth Sciences by Machine Learning

convener:Takahiko Uchide(Research Institute of Earthquake and Volcano Geology, Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (AIST)), Yuki Kodera(Meteorological Research Institute, Japan Meteorological Agency), Hisahiko Kubo(National Research Institute for Earth Science and Disaster Resilience)

The recent development of the machine learning techniques including the deep learning is leading innovations in various fields. The applications of these techniques, for example, the classification, the pattern recognition, and the regression of data, to solid earth sciences are also now under development. On the other hand, there are concerns on the human-interpretability of the deep learning.
This session will provide an opportunity to share the application studies to various fields in solid earth science and inspire each other. In particular, we encourage contributions which made discoveries in solid earth sciences. We also look forward to studies addressing the black box issue of the deep learning.

[SCG60-01] Automatic Digitization of Seismograms in Smoked Paper using Convolutional Neural Network

*Mitsuko Furumura[1], Yoko Ogawa[2], Kazuo Sakamoto[2], Ritsuko S. Matsu'ura[1] (1.Research Division, Earthquake Research Center, Association for the Development of Earthquake Prediction, 2.KOZO KEIKAKU ENGINEERING Inc.)

[SCG60-03] Improving the Retrieval of Offshore-Onshore Correlation Functions with Machine Learning

*Loic Viens[1], Tomotaka Iwata[1] (1.DPRI, Kyoto University)

[SCG60-04] Neural Network-Based Ground Motion Model Learning Site Property from Data

*Tomohisa Okazaki[1], Tomoharu Iwata[1,2], Asako Iwaki[3], Hiroyuki Fujiwara[3], Naonori Ueda[1] (1.Center for Advanced Intelligence Project, RIKEN, 2.NTT Communication Science Laboratories, 3.National Research Institute for Earth Science and Disaster Resilience)

[SCG60-05] Towards robust, reliable earthquake detection with deep neural networks

*Karianne J. Bergen[1] (1.School of Engineering and Applied Sciences, Harvard University)

[SCG60-06] Focal mechanism determination of inland microearthquakes in Japan based on P-wave first-motion polarities picked by neural network model

*Takahiko Uchide[1] (1.Geological Survey of Japan, AIST)

Automatic Digitization of Seismograms in Smoked Paper using Convolutional Neural Network

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1. Introduction

There are many analog seismograms of past destructive earthquakes in the world, and some researchers have already started digitization projects (e.g., Michelini et al., 2005; Paulescu et al., 2016). However, the digitization technique for unclear seismograms in smoked papers is still in progress.
Here, we tried experiments to digitize seismograms automatically through machine learning.

2. Used data and outline of the experiments

Two types of images were used in our experiments.
One type is synthesized from K-NET data (synthetic images). First, accelerograms of the earthquakes with various magnitudes, focal depth, and hypocenter distances are converted into displacement records. Then, the records were curved along the movement of the needle mechanism of the seismographs and background images were combined in order to make realistic seismograms. As the background of the synthetic images, we use scanned images described below, including characters, scratches or folds that sometimes hinder the tracing. The resulting 561 images were used as the synthetic images and the corresponding displacement records were used as supervised data.
The other type is scanned images of analog seismograms which are acquired using large flatbed color scanners with mechanical resolutions of 400 or 500 [dpi] (real images). As supervised data for these images, we used 21 open data digitized by the National Research Institute of Fire and Disaster (NRIFD) and 11 data that we digitized manually.
For training and testing our neural network, fixed height (1200 [pixel]) images containing target waveforms were clipped out from the synthetic and real images, and morphed to remove curvature due to the needle mechanism.
Our network directly outputs a Y coordinate for each X coordinate of a drawn waveform from a 2-D image input. We structure the neural network without full-connection layers for acceptance of various sizes of images and add a pooling layer at bottleneck to get 1-D outputs. The network is trained using mean squared error as the loss function.

3. Results

The convolutional neural networks are trained using three data sets; (1) 561 synthetic images only, (2) combination of 561 synthetic and 31 real images and (3) 31 real images only. We tested 22 real images of seismograms which were not used for the training and compared the output Y values with the true one generated by corresponding NRIFD data for verifying its performance. RMSEs (root mean square errors) of the three cases were 20.67, 16.41 and 15.48 [pixel], respectively, and case (3) was the best. Fig. 1 shows a result of case (3). It seems that automatic digitization of the seismograms works well in many parts, but the errors are still large at peaks of the waveforms. Fig. 2 shows comparison of the three cases. The errors of case (1) and case (2) at the peaks are less than one of case (3). However, case (1) and case (2) are susceptible to vertical edges in characters or folds, thereby the RMSEs of case (1) and (2) are larger than case (3).

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4. For future developments

We almost succeeded automatic digitization of the seismograms in the smoked paper. The scanned images of seismograms are quite useful for training the network but preparing many supervised data is not easy. Therefore, training using more synthetic images with the noises mentioned above is required to improve the performance.

Acknowledgements

This project has been supported by the Headquarters for Earthquake Research Promotion (HERP) of the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan. We used K-NET data by NIED and digital strong-motion data by the National Research Institute of Fire and Disaster.

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Paulescu et al. (2016). Acta Geophys. 64, no. 4, 963–977.

Keywords: automatic digitization, analog seismograms, convolutional neural network

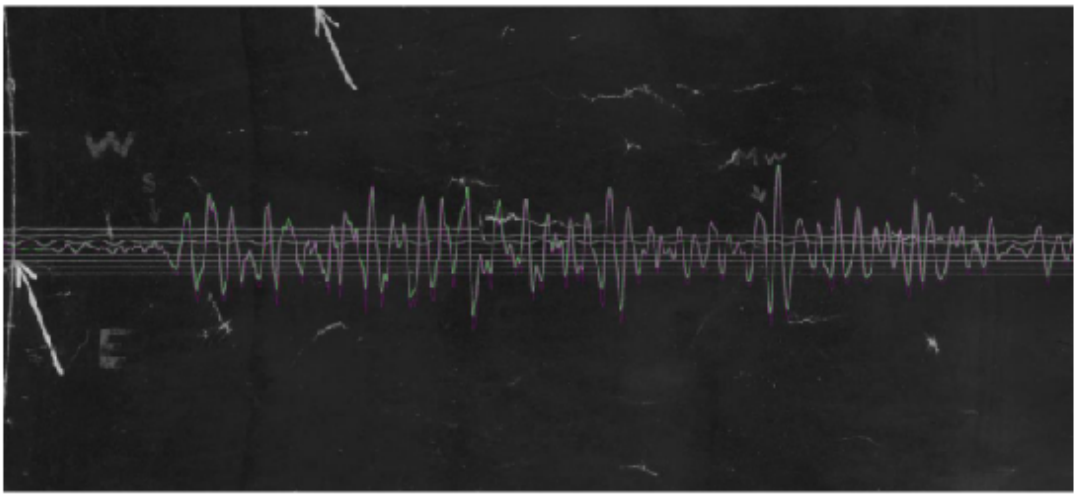

Fig. 1 Scanned image of a seismogram used for verification, manually digitized data (green) and output data of the neural network (magenta).

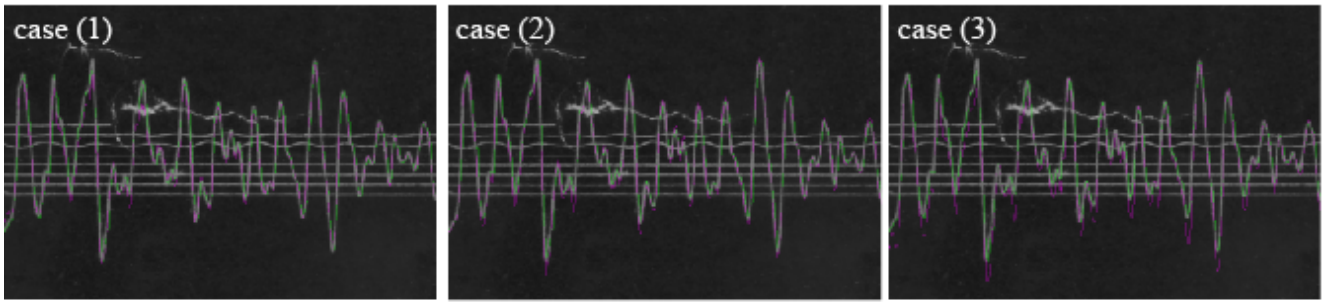

Fig. 2 Results of the three cases: manually digitized data (green) and output data of the neural network (magenta).

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Improving the Retrieval of Offshore-Onshore Correlation Functions with Machine Learning

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The retrieval of reliable offshore-onshore correlation functions is critical to improve our ability to image subduction zones and to predict long-period ground motions from potential megathrust earthquakes. However, localized and persistent ambient seismic field sources between offshore and onshore stations can bias both the amplitude and phase information of correlation functions and generate non-physical spurious arrivals. In this study, we present a two-step method based on unsupervised learning to improve the quality of correlation functions calculated with the deconvolution method (e.g., deconvolution functions, DFs). For a given DF set calculated between two stations over a long time period, we first reduce its dimension using the Principal Component Analysis (PCA) and then cluster the features of the low-dimensional space using a Gaussian mixture model. We finally stack the DFs belonging to each cluster together and select the cluster that maximizes the symmetry between the anti-causal and causal parts and minimizes spurious arrivals. We focus on DFs calculated every 30 minutes over one year between offshore DONET stations located on top of the Nankai Trough, Japan, and 77 surrounding onshore Hi-net receivers. Our method allows us to remove spurious arrivals, which dominate the raw stack of the DFs over the year, and therefore to significantly improve the signal-to-noise ratio of the DFs. To demonstrate that both the amplitude and phase information of DFs is preserved with our method, we use them to simulate the ground motions from a M_w 5.8 earthquake, which occurred on April 1, 2016 in the vicinity of the KME18 DONET station. Results show that the long-period (4-10 s) ground motions from the earthquake can be accurately simulated. Our method can easily be used as an additional processing step when calculating DFs between offshore and onshore stations to improve the retrieval of reliable phase and amplitude information, and to remove potential spurious arrivals.

Keywords: Machine Learning, Ambient seismic field, Correlation function, Green's function, Long-period ground motions

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Neural Network-Based Ground Motion Model Learning Site Property from Data

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We constructed a neural network-based ground motion prediction model estimating spectral accelerations. Instead of specifying physical quantities as site properties, we input site ID and let the network learn the site property from strong motion data. We demonstrated that this model improves the prediction performance by applying it to KiK-net data in Tohoku region of Japan. Moreover, the obtained site property indicates that, for intermediate depth earthquakes, the short-period (< ~1 sec) spectrum is mainly governed by the distance from the volcanic front. This suggests that the proposed model successfully learned not only the ground condition under the individual sites but also propagation path effects known as anomalous seismic intensity in this region.

Keywords: ground motion model, neural network, site property

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Towards robust, reliable earthquake detection with deep neural networks

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Researchers are increasingly adopting machine learning techniques for seismic signal processing (Kong et al., 2018; Bergen et al., 2019). A number of recent studies (e.g. Perol et al., 2018; Ross et al., 2018; Zhu and Beroza, 2018) have achieved promising initial using results deep neural networks for automatic earthquake detection and phase-picking.

Decision support systems for scientific and engineering applications, including earthquake monitoring systems, often require high standards of robustness, stability, uncertainty quantification and/or interpretability. For deep neural networks –black-box models with hundreds of thousands of parameters –it can be challenging to answer key questions about the robustness of the system: *How is the system making decisions? How confident are we in the system's predictions?* And critically, *under what conditions do we expect the system to fail?*

In this talk, we explore the robustness of deep learning-based earthquake detection methods. Deep neural networks perform well in practice for a broad range of tasks but are known to be unstable under small perturbations of the data (Szegedy et al., 2014); we discuss the challenge this poses in seismic signal processing applications. We use adversarial classifier evasion techniques to reveal limitations and potential vulnerabilities of pretrained detectors proposed in the literature. We propose strategies moving forward for improving the reliability of deep learning-based systems for scientific applications.

Keywords: neural networks, seismology, earthquake detection, machine learning

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Focal mechanism determination of inland microearthquakes in Japan based on P-wave first-motion polarities picked by neural network model

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Focal mechanism is one of earthquake source parameters that characterizes the fault geometry and the slip direction, which also implies the seismogenic stress field. In many areas in the world, focal mechanisms are routinely estimated only for earthquakes larger than a certain magnitude, such as M 3 in local cases. For better estimation of the crustal stress field, we desire a much richer focal mechanism catalog. The focal mechanism determination requires us to pick P-wave first-motion polarity, which is usually done manually and therefore time-consuming.

In this study, we construct a neural network model, whose input is three-dimensional seismogram and output is the P-wave first-motion polarity. We adopt a simple convolution network as done by prior studies (Ross et al., 2018; Hara et al., 2019). We used NIED Hi-net seismograms with P-wave arrival times in the JMA Unified Earthquake catalog. The seismograms were highpass-filtered at 1 Hz to and clipped at a certain level. By flipping the vertical component and rotating horizontal components, we augmented the data. We also prepared models with three, four, and five convolution layers followed by two fully connected layers. The clipping level, the number of the data augmentation, and the number of convolution layers are chosen according to their performance to a test dataset. ~ 280 k of seismograms are used for the training.

Finally, we applied the trained model to ~180 M of seismograms from ~110 k of inland microearthquakes with depths smaller than 20 km in Japan. We succeeded in determining the focal mechanisms of more than 99 % of the earthquakes.

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[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG61] The Japan Trench: Learning from the 2011 M=9 Tohoku-Oki earthquake, a decade later

convener:Takeshi Iinuma(National Research and Development Agency Japan Agency for Marine-Earth Science and Technology), Asuka Yamaguchi(Atomosphere and Ocean Research Institute, The University of Tokyo), Aitaro Kato(Earthquake Research Institute, the University of Tokyo), Tianhaozhe Sun(Pacific Geoscience Centre, Geological Survey of Canada)

Introduction

[SCG61-01] A review of decade-long marine geophysical studies in the Japan Trench since the 2011 Tohoku-oki earthquake

*Shuichi Kodaira[1], Toshiya Fujiwara[1], Yasuyuki Nakamura[1], Gou Fujie[1], Koichiro Obana[1], Ryota Hino[2] (1.Research Institute for Marine Geodynamics, Japan Agency for Marine-Earth Science and Technology, 2.Graduate school of Science, Tohoku University)

[SCG61-02] **Geologic constraints on the geometry composition and structural evolution of the shallow subduction interface and frontal prism in the Japan Trench**

★Invited Papers

*Christine Regalla[1], Emily Schottenfels[1], Paul Bierman[2] (1.Northern Arizona University, Flagstaff Arizona, USA, 2.University of Vermont, Burlington Vermont, USA)

[SCG61-03] Frictional properties of incoming sediments and rocks at shallow conditions of the Japan Trench subduction zone

*Kyuichi Kanagawa[1], Sayumi Sagano[2], Tomoya Nakanishi[2], Junya Fujimori[2], Michiyo Sawai[1] (1.School of Science, Chiba University, 2.Graduate School of Science and Engineering, Chiba University)

[SCG61-04] Seismic imaging of the Tohoku megathrust zone using S-net and Hi-net data

*Dapeng Zhao[1], Yuanyuan Hua[1], Genti Toyokuni[1] (1.Department of Geophysics, Tohoku University)

[SCG61-05] Modeling the hydromechanical effects of seamount subduction on megathrust stress and slip in southern Japan Trench

*Tianhaozhe Sun[1], Demian M Saffer[2], Susan Ellis[3] (1.Pacific Geoscience Centre, Geological Survey of Canada, 2.Univ. of Texas Institute for Geophysics, USA, 3.GNS Science, New Zealand)

A review of decade-long marine geophysical studies in the Japan Trench since the 2011 Tohoku-oki earthquake

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Numerous marine geophysical studies have been conducted in the Japan Trench since a rapid response survey immediately after the 2011 Tohoku-oki earthquake. As results from those studies, spatio-temporal distribution of the large coseismic slip near the trench, the structural factors that control the slip, and the seismicity activated after the earthquake around the trench and outer rise were revealed. The rapid response marine geophysical study obtained direct evidence showing large coseismic slips (~50m) reaching the trench axis along a profile in the central part of the rupture zone. Additional bathymetry and seismic data have been acquired following the rapid response survey along the strike of the trench. Those data show that the large coseismic slip to the trench is observed in a compact region of the central part of the Japan Trench (38 ~ 39.2 N). However, no clear evidence of the slip to the trench are observed at the north and south of this area. Seismic reflection data in the trench axis as well as in the incoming plate mapped a ~50km-wide thin subducting sediment, indicating a break of continuation of pelagic-clay layer, at the northern edge of the region of the coseismic slip to the trench. Integrating those structure with the result of the IODP JFAST, the smoothly distributed clay-rich sediment in the shallow portion of the Japan Trench is interpreted as one factor fostering the large fault slip. Tsunami data form the Tohoku-oki earthquake require an additional near-trench tsunami source north of 39–40°N. A mechanism to generate such a tsunami source remains to be an un-solved question. A working hypothesis is that a broad area experienced a small uplift caused by inelastic deformation in the trench-ward toe of the overriding block or seafloor deformation due to submarine land-slid near the trench. A drastic activation of seismicity has been observed in the near trench and the outer rise region since the 2011 earthquake due to complete change of a stress field. Clear lineations of normal fault earthquakes are observed along bending related faults in the outer rise region seaward side of the large coseismic slip region. The seismicity combined with seismic reflection images shows that the bending related normal fault earthquakes have been activating along the high-angle (dip angle of ~70°) faults down to ~40km deep.

Keywords: Japan Trench, Slip to the trench

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Geologic constraints on the geometry composition and structural evolution of the shallow subduction interface and frontal prism in the Japan Trench

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We present ^{10}Be concentration data and structural analyses of sediment cores and seismic data from the Japan Trench that provide insight on the geometry, composition, and evolution of the upper ~10-30 km of the plate boundary interface that experienced slip to the trench during the 2011 Tohoku-oki earthquake. We measured meteoric ^{10}Be concentrations in 24 samples across the frontal prism, décollement, and underthrust sediments from IODP Exp 343 Site C0019 (JFAST), and integrate these data with visual core descriptions, resistivity logs, and high-resolution multi-channel seismic profiles collected by JAMSTEC. Our data provide constraints on four key properties of the shallow subduction interface. First, our data show that the frontal prism contains an abundance of sediment with a high ^{10}Be concentration (>8 x 10^8 atoms/g) and young ^{10}Be ages (<1-2 Ma). When compared to ^{10}Be concentration data from the forearc slope and incoming plate, it is clear that the sampled frontal prism material cannot be sourced from reworked slope sediments, but must consist of recently accreted incoming plate sediment. These results are consistent with seismic profiles that show imbrication of sediments near the trench, and a dé collement located near the base of the incoming sediment section. Over geologic timescales, these data imply that the décollement may localize at or near a frictionally weak, smectite-rich clay layer near the base of the incoming sediment section, with relatively efficient sediment accretion (~50-90%) and minimal sediment subduction, even in the presence of horst-and-graben topography on the incoming plate. Second, within the frontal prism, ^{10}Be data show pervasive apparent thrust and normal faulting, at a spacing of 10s of meters, that likely reflects multiphase deformation of the frontal prism and décollement zone in response to the subduction of horst and graben topography. Such a complex deformation history may contribute to the chaotic nature of seismic refection data across the frontal prism and the lack of a mature imbricate thrust system commonly found in other accretionary margins. Third, our data also highlight the structural complexity that occurs within the plate boundary fault zone. Numerous age and ^{10}Be concentration inversions within the plate boundary decollement zone and underthrust sediment sequence require the presence of multiple discrete faults developed in both biogenic muds and smectite-rich clays. These data are consistent with trace element geochemistry and thermal maturation data that suggest multiple fault horizons, developed in a range of lithologies, have hosted seismogenic slip to the trench in past events. Finally, comparison of the seismic profiles at the JFAST site with those along strike highlights significant along-strike variability in décollement geometry and composition, and in the relative fluxes of accreted versus subducted sediment, at km to 10s-of-km length scales. The style of deformation appears to be a function of the offset of lower plate extensional structures relative to the local sediment cover thickness, and may contribute to small scale heterogeneities in the physical and mechanical properties of the shallow decollement. Collectively, these data suggest that the presence of frictionally weak clays may help localize plate boundary slip and promote sediment accretion over geologic time scales, but that the geometry, composition, and frictional properties of the shallow decollement and adjacent sediments vary over short spatial scales and between seismogenic events.

Keywords: meteoric 10Be, shallow decollement, Japan Trench

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Frictional properties of incoming sediments and rocks at shallow conditions of the Japan Trench subduction zone

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In order to examine the frictional properties of incoming sediments and rocks at shallow conditions of the Japan Trench subduction zone, we conducted triaxial friction experiments on gouges of the following samples at a confining pressure of 150 MPa, a pore water pressure of 50 MPa, temperatures of 25–200˚C, and axial displacement rates changed stepwise among 0.1, 1 and 10 μm/s. We used hemipelagic and pelagic clay samples cored from the cover sediments on the Pacific plate off Sanriku, a chert sample cored from the footwall of the plate boundary thrust near the Japan Trench, and a basalt sample cored from the oceanic basement of the Philippine Sea plate off Kii Peninsula.

The results show that the steady-state friction coefficient μ_{ss} decreases with increasing content of clay minerals at a given temperature. Although μ_{ss} of a given sample does not change noticeably with increasing temperature up to 100˚C, it increases with increasing temperature from 100˚C to 200˚C. *a*–*b* value (rate dependence of μ_{ss}) decreases with increasing temperature, and becomes negative at 200˚C where all samples showed stick-slip. However, the transition temperature at which *a*–*b* value becomes negative is different among four samples; ≈50˚C for the chert sample, ≈100˚C for the basalt sample, ≈ 125˚C for the hemipelagic clay sample and ≈150˚C for the pelagic clay sample. This implies that the transition temperature from aseismic faulting to seismic faulting is different among incoming sediments and rocks, suggesting that a heterogeneous distribution of asperities at the Japan Trench subduction zone as inferred from seismic studies possibly reflects the heterogeneous distribution of fault-zone materials along the plate boundary megathrust.

Keywords: frictional properties, incoming sediments and rocks, shallow Japan Trench subduction zone

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Seismic imaging of the Tohoku megathrust zone using S-net and Hi-net data

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The great 2011 Tohoku-oki earthquake (Mw 9.0) was one of the greatest earthquakes recorded by modern instruments, which occurred in a megathrust zone formed by the subducting Pacific plate and the overriding Okhotsk plate. It produced a huge tsunami and caused great damage to the local society and infrastructure in NE Japan. The occurrence of this great megathrust earthquake has updated our knowledge about megathrust ruptures, especially due to the large coseismic slip at shallow depth near the Japan trench and high-frequency radiations from small-slip areas. However, the mechanism and rupture process of the great 2011 Tohoku-oki earthquake are still a matter of some controversy due to the lack of permanent near-field observations. In this work we used high-quality P-wave arrival-time data of local earthquakes from June 2002 to December 2018 recorded at 480 permanent stations of the Japanese Kiban seismic network on land and 120 OBS (ocean bottom seismometer) stations of the S-net. We selected 2446 local earthquakes that occurred beneath the Kiban seismic network and 1281 events that were recorded by the S-net. From the high-quality vertical-component seismograms recorded by the S-net, we picked P-wave arrival times generated by the 1281 events. The picking accuracy of the arrival times is estimated to be 0.05-0.15 s. As a result, our data set contains a total of 100,662 P-wave arrival times from 3727 local earthquakes. Only arrival times of the events with well-located hypocenters (uncertainty < 3 km) are used in the tomographic inversion. The tomographic method of Zhao et al. (1992, 2011) is used to determine a detailed 3-D Vp model of the Tohoku subduction zone. The well-determined geometries of the Conrad and Moho discontinuities and the upper boundary of the subducting Pacific slab (UBP) are considered in the velocity model. The general pattern of the obtained tomographic model is similar to that of previous models (e.g., Zhao et al., 2011; Liu and Zhao, 2018), but our present model shows that a low-velocity anomaly exists near the Japan trench off Miyagi and Sanriku. The mainshock hypocenter of the great 2011 Tohoku-oki earthquake is located at a boundary between a down-dip high-velocity anomaly and the up-dip low-velocity anomaly. The slow anomaly at shallow depths near the Japan trench may reflect low-rigidity materials that are close to the free surface, resulting in large slip and weak high-frequency radiation. Our new tomographic model can account for not only large slip near the trench but also weak high-frequency radiation from the shallow rupture areas.

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Keywords: the 2011 Tohoku-oki earthquake, seismic tomography, suboceanic seismic network S-net

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Modeling the hydromechanical effects of seamount subduction on megathrust stress and slip in southern Japan Trench

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The large trench-breaching rupture of the 2011 M=9 Tohoku-Oki earthquake was confined to the central segment of the Japan Trench subduction zone (off Miyagi). Numerous studies have shown that southward propagation of the rupture stopped offshore of Ibaraki upon reaching an area of seamount subduction. The observed rupture termination is consistent with the notion that extremely rugged subducting seafloor tends to stop large earthquakes but promote fault creep (Wang and Bilek, 2011; 2014). It is considered to be a consequence of stress and structural heterogeneity associated with the severe damage of the upper plate caused by the subducting seamount, which hinders shear localization along the plate interface.

Rapidly improved offshore geophysical observations over the past decade help constrain the creeping state of the megathrust in the southern seamount region in the Japan Trench. High-resolution seismic monitoring (including S-net) suggests that: (1) small earthquakes (up to M ~7) cluster at the downdip leading edge of a subducted seamount previously studied by Mochizuki et al. (2008); and (2) low-frequency tremors are localized at shallower depths (<10 km below seafloor) on top of the same seamount (Nishikawa et al., 2019). Seafloor GNSS measurements of postseismic deformation at an increasing number of sites show rapid trenchward motion (at 10s of cm yr^{-1}) in the seamount region, in contrast with the landward motion of the trench area in the main rupture zone (Tomita et al., 2017). These data are most consistent with shallow aseismic afterslip that likely extends to the trench in the southern seamount region, along-strike of the main rupture (Sun et al., 2018).

To quantitatively investigate key mechanical and hydrological processes underlying the observed megathrust slip behavior and its association with seamount subduction, we employ a two-dimensional Lagrangian-Eulerian finite element model to simulate coupled deformation and fluid flow. Our numerical approach describes the interplay between sediment consolidation, development of faults, and the evolution of stress and pore fluid pressure driven by ongoing plate convergence and the subduction of seamounts. Using laboratory and field observations as constraints, we define relations between key physical parameters (e.g., porosity, permeability, effective stress) associated with mechanical loading and fluid drainage during sediment subduction and accretion. To incorporate the role of fault damage zones as permeable pathways for fluid migration, we include a simple description of permeability enhancement along fault zones with increasing modeled shear strain. Our models show that, compared with the case of a smooth plate interface, seamount subduction leads to more severe damage of the upper plate with more densely developed off-megathrust splay faults. Our results also show that subducting seamounts can drive large spatial variations in tectonic loading, the degree of sediment consolidation, and the distributions of pore pressure and megathrust stress. Above the downdip leading flank of a subducting seamount, enhanced tectonic compression and drainage lead to amplified compressive stress normal to the megathrust (twice the magnitude for a smooth interface) and over-consolidated wall rocks (porosity lowered by 50% compared with a smooth-interface case). The enhanced stress and consolidation are accompanied by an opposite “stress shadow” behind the trailing flank (in the wake) of the subducting seamount, where reduced lateral compression leads to abnormally high sediment porosity and low stress normal to the megathrust. These variations help explain the observed patterns of megathrust slip

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distribution in southern Japan Trench and a number of other margins, with earthquakes and microseismicity favored by increased megathrust-normal stress and strengthened hanging wall at the downdip edge of the subducting seamount, and aseismic slow slip or afterslip in the stress shadow.

Keywords: seamount subduction, megathrust, shallow aseismic slip, fluid drainage, sediment consolidation, Lagrangian-Eulerian finite element model

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[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG61] The Japan Trench: Learning from the 2011 M=9 Tohoku-Oki earthquake, a decade later

convener:Takeshi Iinuma(National Research and Development Agency Japan Agency for Marine-Earth Science and Technology), Asuka Yamaguchi(Atomosphere and Ocean Research Institute, The University of Tokyo), Aitaro Kato(Earthquake Research Institute, the University of Tokyo), Tianhaozhe Sun(Pacific Geoscience Centre, Geological Survey of Canada)

The 2011 Tohoku-Oki earthquake (M=9) and its devastating tsunami triggered numerous new studies of earthquake processes in the northeast Japan subduction zone and worldwide. Multidisciplinary data in great quality and quantity have been collected across the shoreline during and since the earthquake. Important offshore observations include seafloor mapping, sub-seafloor geophysical imaging, coring, logging, and laboratory measurements associated with ocean drilling, GNSS-acoustic measurements of crustal deformation in and beyond the rupture area at an increasing number of sites, and multi-dataset geophysical observations by the newly established cabled seafloor monitoring network (the S-net) that covers the entire offshore area of the margin. Many geophysical and geological studies such as seismological and geodetic analyses, field surveys on fault-zone, regional and margin-wide structures, laboratory experiments on fault-zone and wall rock properties, and the associated numerical modeling have been conducted to investigate the preparation and generation of the M=9 rupture, its postseismic deformation, and its impacts on the general margin geodynamics. Today, approaching a decade from the earthquake, we need to synthesize these results to summarize what we have learned, what is still unknown, and what new studies should be conducted in the future. In this session, we welcome presentations on all aspects of the 2011 Tohoku-Oki earthquake and the seismogenic processes in the Japan Trench and other subduction margins based on, but not limited to, geophysical and geological field observations, laboratory experiments, and modeling studies.

[SCG61-06] Seismicity in the trench-outer rise region along the Japan Trench based on repeated OBS observations: Implications for large outer-rise earthquakes

*Koichiro Obana[1], Gou Fujie[1], Yasuyuki Nakamura[1], Tsutomu Takahashi[1], Yojiro Yamamoto[1], Takashi Tonegawa[1], Yuka Kaiho[1], Seiichi Miura[1], Shuichi Kodaira[1] (1.Research Institute for Marine Geodynamics, Japan Agency for Marine-Earth Science and Technology)

[SCG61-07] Head and tail of massive earthquakes: Mechanism arresting growth of interplate earthquakes

*Ryota Hino[1], Naoki Uchida[1], Masanao Shinohara[2], Yoshihiro Ito[3], Takeshi Iinuma[4], Yasuyuki Nakamura[4], Toshiya Kanamatsu[4], Ken Ikehara[5], Ryoko Nakata[1,4] (1.Graduate School of Science, Tohoku University, 2.Earthquake Research Institute, University of Tokyo, 3.Disaster Prevention Research Institute, Kyoto Univesity, 4.Japan Agency for Marine-Earth Science and Technology, 5.National Institute of Advanced Industrial Science and Technology)

[SCG61-08] Development of GNSS-A in this decade and observation results along the Japan Trench

★Invited Papers

*Yusuke Yokota[1], Tadashi Ishikawa[2], Shun-ichi Watanabe[2], Yuto Nakamura[2] (1.Institute of Industrial Science, The University of Tokyo, 2.Hydrographic and Oceanographic Department, Japan Coast Guard)

[SCG61-09] On the cause of enhanced landward motion of the overriding plate after the Tohoku-Oki earthquake

Mario D'Acquisto[1], Matthew Herman[1], *Rob Govers[1] (1.Utrecht University, Netherlands)

[SCG61-10] Elucidation of locking state at the shallower plate boundary after the Tohoku Earthquake based on seafloor acoustic ranging

*Ryusuke Yamamoto[1,2], Ryota Hino[1], Motoyuki Kido[3], Chie Honsho[1], Shuichi Kodaira[4], Yasuyuki Nakamura[4] (1.Graduate School of Science, Tohoku University, 2.Tokio Marine & Nichido Risk Consulting

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Discussion

Seismicity in the trench-outer rise region along the Japan Trench based on repeated OBS observations: Implications for large outer-rise earthquakes

*Koichiro Obana[1], Gou Fujie[1], Yasuyuki Nakamura[1], Tsutomu Takahashi[1], Yojiro Yamamoto[1], Takashi Tonegawa[1], Yuka Kaiho[1], Seiichi Miura[1], Shuichi Kodaira[1]

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In subduction zone environments, intraplate normal-faulting earthquakes in the trench-outer rise region, so-called outer-rise earthquakes, are source of hazardous tsunami as well as interplate megathrust earthquakes. However, intraplate normal-faulting events are less frequent than interplate megathrust earthquakes and occurred far away from the land-seismic network. Therefore, accurate distribution of the intraplate normal-faulting earthquakes has not been clear. After the 2011 Tohoku-oki earthquake, seismicity in the trench-outer rise region, which includes several large M7-class earthquakes, has become active. We have conducted earthquake observations repeatedly in the trench-outer rise region along the Japan Trench by using ocean bottom seismographs (OBSs) since the 2011 earthquake. In these observations, we used ultra-deep type OBSs which can be deployed in the trench-axis area where the maximum water depth is more than 7000 m. We used these data to investigate hypocenter distribution and focal mechanisms of the earthquake in the trench-outer rise region and their spatial relations to the bending-related normal-faults and crustal structure heterogeneities in the incoming Pacific plate subducting into the Japan Trench.

The earthquakes observed by the repeated OBS observations were characterized by the shallow normal-faulting earthquakes. Most of the earthquakes occurred at depths shallower than 20 km, which corresponds to the oceanic crust and uppermost part of the oceanic mantle, although some events with normal-faulting focal mechanisms were observed at depths of 40 to 50 km below the sea surface. These observations suggest that the extensional stress regime extends down to a depth of 40 km within the Pacific plate. The shallow earthquakes within the oceanic crust and the uppermost part of the oceanic mantle generally showed trench-parallel linear trends along the horst-and-graben structures even though the horst-and-graben structures can be divided into small segments, both parallel and oblique to the trench. Therefore, large normal-faulting earthquakes might have complicated rupture process along the segmented normal-faults. Compared to the earthquakes at depths shallower than 20 km, earthquakes at depths of about 40 km occurred in the limited area. The seismicity at deeper depths generally coincide with areas of low Vp, which may suggest the localized hydration along the normal-faults extending into the oceanic mantle. Spatial heterogeneity of the seismic velocity structure might be an indicator of potential faults of large outer-rise normal-faulting earthquakes.

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Head and tail of massive earthquakes: Mechanism arresting growth of interplate earthquakes

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The behavior of the shallow part of the plate boundary fault, which is deeply involved in the growth of megathrust earthquakes, shows remarkable variations along the Japan Trench. New paleoseismological evidences acquired from the deep seafloor sediment cores revealed that massive seismic slip events like the 2011 Tohoku-Oki Earthquake (M9.0), repeatedly occurred with an interval of ~ 600 years only in the central part of the margin. In the southern part, where no clear evidences of the large coseismic slip near the trench axis, evident post-2011 slip is still taking places. Lack of evidences for the past large-scaled shallow slips suggests that aseismic slip mostly consumes the relative motion across the subduction megathrust. Compared to the southern region, postseismic deformation in long-term average was much smaller in the northern part of the Japan Trench, where occurrence of large coseismic slip during the 2011 mainshock has not proved conclusively. In the area, recent careful reanalysis of seafloor geodetic data suggested that an aseismic slow slip event happened in 2015 near the trench. We hypothesize that slow slip events have occurred periodically to release significant portion of the accumulated slip deficit. Anomalous tsunami earthquakes, like that occurred in 1896, considered as moderately slow failure of the shallow plate boundary can also another type of major process to release the slip deficit. Existence of these processes may explain why we do not have clear records of massive shallow slip in the region. In 2019, we started a comprehensive marine geophysical/geological research activity to explore 1) slip history of past tsunami earthquakes based on the sedimentary core study, 2) spatial extent of the periodic slow slip by seismological and geodetic monitoring, and 3) a realistic model to explain coexistence of massive earthquakes and various kinds of slow slip as observed and recorded.

Keywords: Subduction plate boundary, Slow slip, Tsunami earthquake

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Development of GNSS-A in this decade and observation results along the Japan Trench

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Our research group has been studying advanced GNSS-A (Global Navigation Satellite System –Acoustic ranging combination) technique over two decades. The detection sensitivity of GNSS-A observations has been sophisticated especially in this decade by improving the accuracy and frequency of analysis technology and acoustic systems (e.g., Sato et al., 2013, JG; Yokota et al., 2018, MGR; Ishikawa et al., in prep). The current observation frequency is more than 4 times/year, the observation accuracy for each observation is less than 2 cm, and it can detect a steady deformation rate of 1 cm/year or less and an unsteady fluctuation of 5 cm or less. Also, efforts are being made to strengthen the observation network. In this presentation, improvement of the observation capabilities and technological progress are introduced.

GNSS-A observations of the 2011 Tohoku-oki earthquake and its postseismic field revealed the details of the crustal deformation field on the Japan Trench side (Sato et al., 2011, Science; Watanabe et al., 2014, GRL). The long-term observation data in the Nankai Trough region revealed the strain accumulation process and shallow slow slip events during the interseismic period (Yokota et al., 2016, Nature; Watanabe et al., 2018, JGR; Nishimura et al., 2018, Geosphere; Yokota & Ishikawa, 2020, Science Advances). Observation data, especially in the Japan Trench, are the basis of many simulation, theoretical, and drilling observation studies. In these studies, the observation period is still insufficient for the postseismic deformation field after the M9 earthquake. It will be necessary to continue the observation in this area from a longer-term perspective.

What was inadequate in the case of the Tohoku-oki earthquake was the lack of observation network before the event. There was not enough data before and after the earthquake that we want to compare with the data after the earthquake. In the future, it will be necessary to build a thorough observation network in the trenches around Japan and establish technologies and systems that enable permanent operation.

Keywords: GNSS-A, Japan Trench, Postseismic deformation, Tohoku-oki earthquake, SSE

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On the cause of enhanced landward motion of the overriding plate after the Tohoku-Oki earthquake

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During and after the Tohoku-Oki megathrust earthquake, geodetic observations showed that most of the overriding plate above the rupture zone moved oceanward. Enigmatically, the post-seismic motion of the overriding plate at hundreds of km along strike from the rupture zone became faster (in a landward direction) than before the event. Similar observations were made following other recent and large megathrust earthquakes. Previous studies interpreted these changes as the result of increased mechanical coupling along the megathrust interface or transient slab acceleration. However, before invoking additional mechanisms, we need to account for in-plane bending of the overriding plate which is an inherent feature of megathrust earthquakes. The aim of our study is to quantify the contribution of in-plane bending of the overriding plate and determine whether additional mechanisms are needed to understand the observations.

We use velocity-driven 3D mechanical finite element models, in which large megathrust earthquakes are taken to occur periodically on the finite plate interface. The model geometry is similar to that of the Tohoku-Oki and other present-day subduction zones, but does not exactly match any specific subduction zone.

The results show increased co-seismic and post-seismic landward motion at (trench-parallel) distances greater than 450 km from the edge of the rupture zone. Post-seismic velocities are controlled by both viscous relaxation in the mantle wedge and deep afterslip on the shear zone downdip of the brittle megathrust interface. Landward displacement due to postseismic relaxation largely accumulates at exponentially decaying rates until ~6 Maxwell relaxation times after the earthquake. The spatial distribution of the landward displacements is broadly consistent with observations at both the Tohoku-Oki and 2010 Maule the earthquakes. The magnitude of the velocity changes is similar to that of published secular velocity changes associated with the Maule event.

Further model experiments show that patterns of landward motion due to afterslip and to viscous relaxation are insensitive to the locking pattern of the megathrust. The locking distribution does affect the magnitudes of the displacements and velocities. The results show that the increased landward displacement due to postseismic deformation scales directly proportionally to seismic moment.

We conclude that the landward motion results from in-plane horizontal bending of the overriding plate and mantle. This bending is an elastic response to oceanward tractions near the base of the plate around the ruptured asperity, causing extension locally and compression further away along- trench. This elastic in-plate bending consistently contributes to earthquake-associated changes in surface velocities for the biggest megathrust earthquakes, producing landward motion along strike from the rupture zone. Additional mechanisms (e.g., increased mechanical locking or slab acceleration) may not be needed to explain the observations.

Keywords: post-seismic, geodetic velocities, mechanical model

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Elucidation of locking state at the shallower plate boundary after the Tohoku Earthquake based on seafloor acoustic ranging

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Several geodetic studies reported that postseismic deformation continuously occurs along the Japan Trench after the 2011 Tohoku Earthquake. In particular, GNSS-Acoustic (GNSS-A) observations successfully revealed landward motion off Miyagi due to visco-elastic relaxation. On the other hand, direct evidences for the postseismic slip at the shallowest part of the plate boundary have not been presented. In this study, we curried out seafloor acoustic ranging measurements across the Japan Trench off Miyagi and Fukushima, aiming to measure shallow postseismic slip. Seafloor acoustic ranging periodically transmits and receives sound waves between two instruments (PXP: precision transponder) installed on the seafloor or a moored buoy (IPN: indirect path node). This method can detect local deformation such as fault movement or land slide by calculating baseline length from two-way travel time and sound velocity in the sea. The measurement between two PXPs is called direct path ranging (DPR) and between PXP and IPN is called indirect path ranging (IPR). In DPR, the key to improving measurement accuracy is to estimate the appropriate sound velocity near the seafloor by using the temperature and pressure data measured at the same time of the ranging and to correct time series of the instrumental attitude. In IPR, in addition to those corrections, it is necessary to estimate the position of IPN that moves arbitrarily. In contrast to the previous IPR studies that can move the IPN as needed under the control of hanging from the vessel, this study attempted to extended it to the new formulation that can handle the case of a small IPN movements moored from the seafloor.

Off Miyagi, three DPR observations were conducted from 2013 to 2016, and measurements were successfully made five across-trench paths. We estimated the rate of plate convergence using all the available benchmark pairs data acquired across the trench axis during the entire period as 0.02 ±0.17 mm/yr indicating no significant after slip happened during this period. As the previous work of the post-2011 deformation using the GNSS-A data suggested, the shallow plate boundary does not move at all and the deformation should be explained by the viscoelastic deformation and the slip-deficit on the fault off Miyagi Prefecture. In plate boundary drilling and seismic reflection surveys near the DPR observation site, the coseismic slip occurred all the way to the trench axis because of the dynamic weakening and no stress concentration at the edge of the dynamic fault slip did not occur. That is why we do not have evident postseismic slip near the trench axis.

Off Fukushima, we performed the DPR/IPR combined observation for one year from 2017 to 2018. DPR observations crossed the trench axis at one baseline, and IPR observations passed at all baselines. A convergence rate of 3.8 ±0.8 cm/yr was obtained from one baseline of the DPR observation. In the IPR observation, the convergence rate of 3.7 ±1.1 cm/yr was obtained by applying the analysis method developed in this study. Off Fukushima, the GNSS-A observation site closest to (~ 20 km landward of) our observation location shows a seaward motion of ~ 12 cm/yr relative to the incoming Pacific plate. The difference in the deformation rate between the GNSS-A result and our acoustic ranging near the trench suggest extremely large rate of internal deformation of overriding plate. It is considered that the reverse faulting on shallow faults branching from the plate boundary contribute as well as the megathrust itself to cause the observed fast postseismic at the toe of the hanging wall crust. In addition, through our

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observation, it was demonstrated that the deformation of the plate boundary can be captured with an accuracy of about ~1 cm/yr by IPR observation. Moored IPR is a very promising method that can perform long-term continuous observation and can extend the observation network to a wide area without being restricted by the direct conditions of the acoustic path.

Keywords: Tohoku Earthquake, Seafloor geodesy, Seafloor acoustic ranging, postseismic slip

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[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG62] Investigation of inputs to subduction zones: Influence of tectonic processes on the incoming plate

convener:Makoto Yamano(Earthquake Research Institute, the University of Tokyo), Tomoaki Morishita(School of Geoscience and Civil Engineering, College of Science and Technology, Kanazawa University), Gou Fujie(Japan Agency for Marine-Earth Science and Technology)

Various tectonic processes occur on the seaward side of the trench associated with bending of the incoming oceanic plate, e.g., fracturing of oceanic crust, infiltration of water, and intraplate volcanism. Investigation of these processes and their influence on the incoming plate provides important information on the boundary condition at the trench, inputs to subduction zones. Variation in inputs should significantly affect geophysical/geological phenomena around the plate interface and geochemical cycles in subduction zones. We welcome contributions from a broad range of earth science (geophysics, geology, petrology, and so on) discussing topics related to inputs to subduction zones such as occurrence of tectonic processes due to bending of the incoming plate, modification of the incoming plate by the processes, relationship between the processes and the inherited structure of the incoming plate, and influence of the processes on the subduction plate interface. We hope discussions are made on studies of a variety of subduction zones, including the Japan Trench and the Nankai Trough, and comparative studies among different subduction zones.

Introduction

[SCG62-01] CHIKYU IODP Full proposal for Bend-Fault Hydrology in the Old Incoming Plate (H-ODIN): Scientific objectives and drilling strategy

*Tomoaki Morishita[1,2,3], Gou Fujie[2], Shigeaki Ono[2], Makoto Yamano[4], Kohtaro Ujiie[5], Asuka Yamaguchi[4], Akira Ijiri[2], Tomohiro Toki[6], Takanori Kagoshima[4], Masahiro Ishikawa[2], Ikuo Katayama[7], Junichiro Kuroda[4], Yohey Suzuki[4] (1.Kanazawa University, 2.JAMSTEC, 3.Columbia University, 4.The University of Tokyo, 5.University of Tsukuba, 6.University of the Ryukyu, 7.Hiroshima University)

[SCG62-02] **Role of hydrated oceanic lithosphere on global water cycle in the Earth**

★Invited Papers

*Ikuo Katayama[1], Kohei Hatakeyama[1] (1.Department of Earth and Planetary Systems Science, Hiroshima University)

[SCG62-03] Heat flow observation around a young petit spot volcano on the old Pacific Plate subducting into the Japan Trench

*Yoshifumi Kawada[1], Makoto Yamano[2], Kouta Sasaki[2] (1.International Research Institute of Disaster Science, Tohoku University, 2.Earthquake Research Institute, The University of Tokyo)

[SCG62-04] $^{3}He/^{4}He$ ratios in pore fluids and bottom seawater around the Japan Trench

★Invited Papers

*Takanori Kagoshima[1], Naoto Takahata[1], Makoto Yamano[2], Asuka Yamaguchi[1], Jin-Oh Park[1], Yuji Sano[1] (1.Atmosphere and Ocean Research Institute, the University of Tokyo, 2.Earthquake Research Institute, the University of Tokyo)

[SCG62-05] **Shallow crustal structure in the outer rise of the Japan Trench by high-resolution seismic reflection survey**

*YUE SUN[1], Ehsan Jamali Hondori[1], GUO CHEN[1], Tomoko Hanyu[2], Jin-Oh Park[1] (1.Atmosphere and Ocean Research Institute, The University of Tokyo, 2.Kobe Ocean-Bottom Exploration Center, Kobe University)

CHIKYU IODP Full proposal for Bend-Fault Hydrology in the Old Incoming Plate (H-ODIN): Scientific objectives and drilling strategy

*Tomoaki Morishita[1,2,3], Gou Fujie[2], Shigeaki Ono[2], Makoto Yamano[4], Kohtaro Ujiie[5], Asuka Yamaguchi[4], Akira Ijiri[2], Tomohiro Toki[6], Takanori Kagoshima[4], Masahiro Ishikawa[2], Ikuo Katayama[7], Junichiro Kuroda[4], Yohey Suzuki[4]

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The oceanic plate has played a main role in global deep water circulation within the Earth. It has been considered that the main water reservoir of the subducting plate is the upper crust. Crustal hydration at mid-ocean ridges by hydrothermal circulation has been considered to be the first-order control on the degree of the oceanic plate hydration. Previous ocean drilling projects have aimed to reveal hydration processes and their extent of oceanic crust at spreading centers (e.g., Alt et al., Proc. ODP Sci. Res., 1996; Bach et al., G-cubed, 2003; Wilson et al., Science, 2006). In the last two decades, it has been, however, generally accepted that extensive hydration due to plate bending-induced normal faults (bend-faults) occurs in the region between trench and outer rise (outer rise) (e.g, Ranero et al., Nature, 2003; Key et al., EPSL, 2012, Fujie et al., GRL, 2013). It is emphasized that little is yet known about the degree and style of hydration in the oceanic plate at outer rises. Bend-fault hydration processes depend on thermal conditions and stress state. Investigating several subduction zones with various conditions is crucial to expand our knowledge of bend-fault hydration processes. The northwest Pacific (NW Pacific) region is one of the world oldest, thus coldest, and most studied oceanic plates, and is therefore a high priority region to study bend-fault hydration. Water circulation (deep penetration and deep upwelling) and hydration through the bend-faults in the NW Pacific region is supported by results from extensive recent geophysical survey: (1) Horst and graben structures formed by bend-faulting are the best developed in the world (Nakanishi, Springer, 2011) (2) Large bend-fault earthquakes (M>7) have repeatedly occurred and been well recorded, (3) Detailed Vp/Vs variations within the incoming plate have been determined (Fujie et al., 2013, Nature Comm, 2018), (4) The local stress state is likely to have changed significantly after the 2011 Tohoku Earthquake (Obana et al., Geophys. Jour. Inst., 2019), and (5) Anomalously high heat flow suggests heat transport by water circulation (Yamano et al., EPSL, 2014; Kawada et al, G-cubed, 2014). In addition, the NW Pacific Plate is the best place to comprehensively study relationships between subduction inputs, subduction tectonics, and subduction zone processes because one successful drilling project (JFAST) and a newly planned drilling project (JTRACK) will further augment the research goals of this proposal and because geochemical compositions of volcanic rocks and their quantitative modeling has also been extensively studied in the northeastern Japan Arc. Moreover, intraplate normal-faulting (i.e., bend-fault) earthquake in the outer rise occurred within a day to 37 years after the plate-interface earthquakes. Both types of earthquakes caused tsunamis that caused massive damage along the coast of northeastern Japan Although there have been several outer-rise earthquakes (M7 class) along the Japan Trench since the 2011 Tohoku-Oki earthquake (e.g. Asano et al. EPS, 2011), we must be aware of the possibility of the future outer rise earthquake (e.g. Lay et al. EPS, 2011). We are likely be in a rare phase between a giant megathrust event and its potential outer-rise doublet. It is imperative to understand the nature of the outer rise normal-fault earthquake and assess tsunami hazards.
In order to address (a) hydration processes and their extents along bend-faults, (b) geophysical, chemical and structural properties of the bend-faults, (c) outer rise earthquake and development of horst-graben structure, and (d) lithospheric biosphere: its living conditions and sustainability, we will analyze in-situ physical properties and lithofacies that will be best obtained by ocean drilling in the NW Pacific region.

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Two drill sites are absolute minimum requirement (fault along sediment and basement, fault within basement).

Keywords: Oceanic Plate, Outer rise, Subduction zone, Earthquake

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Role of hydrated oceanic lithosphere on global water cycle in the Earth

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Recent geophysical observations indicate extensive hydration of oceanic lithosphere even at mantle depths through water infiltration along the outer-rise faults (e.g., Ranero et al. 2003; Fujie et al. 2013; Obana et al. 2019). This has a large impact on the water budget carried by the subducting plate, although most previous estimates on the global water budget assume a hydrated oceanic crust but not include oceanic mantle. In this study, we reevaluate the extent and degree of hydration of the oceanic lithosphere based on recent experimental data that include the influences of porosity and anisotropy (Hatakeyama and Katayama 2020). Our preliminary calculation indicates that the global water flux carried by hydrated oceanic mantle is comparable or even higher than the water flux of hydrated oceanic crust. This results in a large regassing rate (water input) relative to degassing rate (water output), suggesting a decreasing ocean volume that is trapped in the Earth’s interior.

Keywords: global water budget, mantle hydration, subducting plate

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Heat flow observation around a young petit spot volcano on the old Pacific Plate subducting into the Japan Trench

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Estimating the temperature structure and fluid circulation inside the subduction zone is important for quantifying the behavior of the mega-thrust zone faults because the upper and lower ends of these faults are somehow affected by the temperature and the water content. In the Japan Trench, there are at least two factors potentially controlling the subduction zone temperature and water circulation before subduction: faults and fractures, and young volcanoes, both of which are due to plate bending near the trench. This presentation focuses on the latter, volcanoes, but aiming the transfer of heat and fluid through seafloor rather than the volcanic heat input. On some seafloor of the Japan Trench seaward of the trench axis, young petit-spot volcanoes (~1 Ma) exist on the very old Pacific Plate (>100Ma) subducting into the Japan Trench. Even for this young seamount age, heat input itself does not dominate. To date, there are few observations for the seamount of this type to asses their ability to transfer heat and fluid through the seafloor.

During the Shinsei-Maru cruise KS-19-13, we conducted heat flow observation around one of these petit-spot volcanoes. The targeted seamount has a diameter of ~2000 m above the seafloor. The seafloor southwest of the seamount is deeper than that of the northeastern side, indicating that a fault running NW-SE exists near or beneath the seamount. This direction may reflect the regional tectonics because many lineation structures of this direction are found in the bathymetric map of the target area. We used a 3-m-long Ewing-type heat flow probe with seven miniaturized temperature loggers equipped equally spaced at 40 cm, performing the pogo style operation from the mother ship. For each site, the temperature gradient estimated from at least four temperature time series during 15-minute-long penetration is multiplied by a common typical thermal conductivity for this site, 0.9 W/m/K, to calculate the heat flow. The tilt is corrected but little is changed.

The resulted heat flow values range between 20 and 300 mW/m^2, suggesting the existence of hydrothermal heat transport. The heat flows more than 3 km away from the summit of the seamount is 50 mW/m^2, a typical heat flow value predicted from the plate-cooling model with the corresponding plate age. The low heat flows are recorded on the northern to eastern foot areas of the seamount. The high heat flows are on the western foot areas as well as the mountain surface of this side. Along an ENE-WSW transect, the heat flow changed from the lowest to the highest values within two kilometers. From the observation, we may presume the existence of a single convection cell within the seamount. Seawater recharges into the seafloor from the northeastern side of the seamount, and heated hydrothermal fluid discharges from the southwestern side. Our numerical modeling targeting a single permeable seamount protrude from the seafloor indicates that this type of fluid flow can be formed using a certain parameter set. A simple energy balance calculation, with the basal heat flow of 50 mW/m^2, can estimate the heat output using either the observed heat flow deficit and the excess heat flow multiplied by the area involved. The heat output from the targeted seamount is around 1 MW for each case. If the discharge temperature is assumed as 10 degrees Celsius, a typical sediment-basalt interface temperature for the target area, the fluid flux is estimated to be of the order of 10 kg/s. These are comparable with those associated with one of a well-known pair of seamounts, the Baby Bare on the Juan de Fuca Ridge.

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Heterogeneous distribution of petit-spot seamount seaward of the Japan Trench causes heterogeneous fluid circulation along the Japan Trench subduction zone, which may affect the behavior of the thrust zone faults.

Keywords: crustal heat flow, temperature structure, seismogenic zone, hydrothermal circulation, seamount

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$^{3}He/^{4}He$ ratios in pore fluids and bottom seawater around the Japan Trench

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Geochemical characteristics of pore fluids may be strongly related to tectonic settings and physical phenomenon at convergent plate boundaries such as fault-bending and great earthquakes. For investigation of fluid origins and cycles, ^{3}He is one of the most useful tracer because of its chemical inertness and high sensitivity of mantle-derived components.
In April 2011, one month after the 2011 Tohoku-oki earthquake, high excess ^{3}He ($^{3}He/^{4}He$ anomaly relative to air saturated water) was detected in bottom seawater nearby rupture zones close to the epicenter on the Okhotsk plate (Sano et al., 2014). They suggested that the excess ^{3}He was supplied by pore fluids with mantle-derived components which were released from the plate interface between the Okhotsk and the Pacific plates via faults during the earthquake period, and that high-pressure mantle fluids presented in the seismogenic zone may have triggered the great earthquake. In November 2016, Escobar et al. (2019) collected sweater and sediment samples nearby the same rupture zones, and detected less excess ^{3}He in the samples relative to those reported by Sano et al. (2014), which suggests dissipation of pore fluids with high $^{3}He/^{4}He$ ratios observed just after the earthquake in 2011. On the over-riding plate nearby the Japan Trench, He isotopic ratios in pore fluids may reflect addition of mantle-derived components associated with earthquake activity.
In order to investigate origin of fluids at outer rise regions of the Japan Trench, we collected sediment samples during KS-19-13 and KS-19-14 cruises onboard R/V Shinsei Maru. Sediment samples were collected from the seafloor using multi-corer and piston corer systems. The samples were immediately transferred into copper tubes and both ends were sealed by metal clamps on the ship in order to avoid air contamination. Subsequent sample preparation and analyses were conducted in Atmosphere and Ocean Research Institute, University of Tokyo. Pore fluids were extracted from the sediment by centrifugation. Then gases dissolved in the pore fluid samples were extracted and introduced into the vacuum line connected to a QMS and a noble gas mass spectrometer (Helix SFT). In the line, the sample gases were purified and $^{4}He/^{20}Ne$ ratios were measured with the QMS, and $^{3}He/^{4}He$ ratios were measured with Helix SFT. The obtained ratios were calibrated against those of atmosphere standard. In several sampling sites, vertical profiles of $^{3}He/^{4}He$ ratios indicated existence of deep fluid end-members with $^{3}He/^{4}He$ ratios apparently higher than atmosphere. This may reflect migration of mantle-derived or magmatic volatiles, which might be related to presence of petit-spot volcanism or pathways between the mantle and the ocean at the incoming Pacific plate, but the situation should be considered carefully also based on geophysical data.

(References)
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Keywords: Helium isotopes, Sediment pore fluids, 2011 Tohoku-oki earthquake, Petit-spot volcanism

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Shallow crustal structure in the outer rise of the Japan Trench by high-resolution seismic reflection survey

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Introduction

Several historically large earthquakes with magnitude higher than 8 occurred in the Japan Trench subduction zone, with the March 2011 Tohoku earthquake (M 9.0) being the latest one. Obana et al. (2012) suggested that the stress regime of the Pacific plate has changed to a tensional stress down to a depth of 40 km after the Tohoku earthquake. This could have a direct impact on the occurrence of the large normal faulting earthquakes which could trigger a Tsunami. In order to investigate the detailed geological setting of the outer rise of Japan Trench off Sanriku and Miyagi of northeast Japan, we have conducted a high resolution multichannel seismic reflection survey in April 2019.

Data Acquisition and Processing

We used research vessel *Shinsei-Maru* for survey KS-19-05 to acquire seismic reflection data along two seismic lines. Line 5 off Miyagi passes closely to the epicenter of Tohoku earthquake, and line 1 off Sanriku is in the northern part of the study area. The total length of line was 100 km and 150 km for line 5 and line 1. We used a time-variant band-limited envelope thresholding technique to suppress the strong swell noise. The spiky traces were manually edited to be excluded from data processing, and FX deconvolution filter was applied to further reduce the noise effect. Stacked sections and post-stack time-migrated sections illustrated the high resolution subsurface structure of the Japan Trench outer rise. We then used a layer stripping method to build an interval velocity model in depth domain to apply Kirchhoff prestack depth migration (KPSDM) to develop reliable depth sections.

Results and Future Work

We could recognize many horst-and-graben structures in the outer rise of the Japan Trench, which develop from the seaside and continue toward the trench axis with clear associated normal faults. There are three major vertical displacements of the normal faults along line 5 that is close to the 2011 Tohoku earthquake epicenter. We also observe a series of horst-and-graben structures that are characterized by normal faults with displacements of several hundreds of meters along line 1. We identify slumping-like structure containing turbidites in the major grabens, which we believe were produced by the normal faulting earthquakes.

We picked top of ocean crust horizon in both line 1 and line 5 when building interval velocity model of KPSDM. Referring to this horizon, we interpreted all the major normal faults in line 1 and line 5, then measured the faults angles and displacements. Also, learned from the method of Fujie et al. (2018), we used the top of ocean crust horizon in both lines to calculate their cubic approximation curves and the difference between them for each line. Overall, line 1 has lager fault displacements but smaller fault angles than line 5. The flaults displacements increase when approaching to the trench axis in both line 1 and line 5, which is consistent with the general trend expected at the subduction zone. However, in line 1

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within an area of 10 km to 40 km from the trench axis, the faults displacements increase abnormally. This may imply a relationship between this abrubt phenomenon and seismic activity. The faults angles near the trench axis are similar to the faults angles of the area that is far away from trench axis at the seaside. This shows that the faults angles may not be relevant to plate bending. However, at a middle distance about 20 km to 50 km from the trench axis, the faults angles change drastically in both lines. This may be caused by inherent physical properties of the subducting plate rather than plate bending motion.

The results obtained from the two lines are limited, so our future work is to apply our method to other MCS lines in the outer rise of Japan Trench to discuss the relationship between the normal fault development, plate bending, and seismic activity.

Keywords: Japan trench, Outer rise, Multichannel seismic reflection survey, Normal fault

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[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG62] Investigation of inputs to subduction zones: Influence of tectonic processes on the incoming plate

convener:Makoto Yamano(Earthquake Research Institute, the University of Tokyo), Tomoaki Morishita(School of Geoscience and Civil Engineering, College of Science and Technology, Kanazawa University), Gou Fujie(Japan Agency for Marine-Earth Science and Technology)

Various tectonic processes occur on the seaward side of the trench associated with bending of the incoming oceanic plate, e.g., fracturing of oceanic crust, infiltration of water, and intraplate volcanism. Investigation of these processes and their influence on the incoming plate provides important information on the boundary condition at the trench, inputs to subduction zones. Variation in inputs should significantly affect geophysical/geological phenomena around the plate interface and geochemical cycles in subduction zones. We welcome contributions from a broad range of earth science (geophysics, geology, petrology, and so on) discussing topics related to inputs to subduction zones such as occurrence of tectonic processes due to bending of the incoming plate, modification of the incoming plate by the processes, relationship between the processes and the inherited structure of the incoming plate, and influence of the processes on the subduction plate interface. We hope discussions are made on studies of a variety of subduction zones, including the Japan Trench and the Nankai Trough, and comparative studies among different subduction zones.

[SCG62-06] Event layers within graben-fill deposits in the outer ruse of the Japan Trench

*Asuka Yamaguchi[1], Hiroaki Kurano[1], Rina Fukuchi[2], Kazuno Arai[3], Ken Ikehara[4], Toshiya Kanamatsu[5], Takanori Kagoshima[1], Tomoko Hanyu[6], Juichiro Ashi[1], Jin-Oh Park[1] (1.Atomosphere and Ocean Research Institute, The University of Tokyo, 2.DIA CONSULTANTS CO., Ltd., 3.Center for Advanced Marine Core Research, Kochi University, 4.National Institute of Advanced Industrial Science and Technology, 5.Japan Agency for Marine-Earth Science and Technology , 6.KOBEC, Kobe University)

[SCG62-07] Spatial variations in incoming oceanic plate and its implications for subduction zone processes along the Japan Trench

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[SCG62-08] Active-source seismic study with a dense linear OBS array off Nemuro, the southern Kuril subduction zone

*Ryosuke Azuma[1], Shuichi Kodaira[2], Ryota Hino[1], Gou Fujie[2], Koichiro Obana[2], Fumiaki Tomita[2], Yusaku Ohta[1] (1.Recearch Center for Prediction of Earthquake and Volcanic Eruption, Graduate School of Science, Tohoku University, 2.Japan Agency for Marine-Earth and Technology)

[SCG62-09] Fluid circulation and heat transport in fractured oceanic crust in the Japan and Kuril trench outer rise regions

*Kouta Sasaki[1], Makoto Yamano[1], Yoshifumi Kawada[2] (1.Earthquake Research Institute, the University of Tokyo, 2.International Research Institute of Disaster Science, Tohoku University)

[SCG62-11] Discussion on inputs to subduction zones

*Makoto Yamano[1] (1.Earthquake Research Institute, the University of Tokyo)

Event layers within graben-fill deposits in the outer ruse of the Japan Trench

*Asuka Yamaguchi[1], Hiroaki Kurano[1], Rina Fukuchi[2], Kazuno Arai[3], Ken Ikehara[4], Toshiya Kanamatsu[5], Takanori Kagoshima[1], Tomoko Hanyu[6], Juichiro Ashi[1], Jin-Oh Park[1]

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In the trench outer rises, horst-and-graben structures are formed by normal faulting in response to bending of oceanic plates. Although large outer rise earthquakes tend to occur posterior to large plate boundary earthquakes, no large outer rise earthquakes have been occurred in the Japan Trench after the 2011 Tohoku Earthquake. Therefore, it is important to reveal recurrence history of large outer rise earthquakes in the Japan Trench. However, displacements of outer rise events are likely to be distributed into ~10 normal faults, and activity and seismic/aseismic slip distribution of each fault has not been clarified. In addition to large-scale lithospheric structural analysis, investigations using local sedimentary record is needed to understand activity of specific fault in outer rise fault system.

In this presentation we overview findings of R/V Shinseimaru KS-15-3 and KS-19-14 cruises. During KS-15-3 cruise, we sampled seven piston cores from the outer rise of off-Sanriku Japan Trench. Based on tephrochronology, surface sediments in the outer rise have mean sedimentation rates of ~2-45 cm/kyr, which is high in the graben and low in the horst. Visual core description, X-ray CT image, physical property analysis using multi-sensor core logger, and geochemical analysis using X-ray fluorescence core scanner ITRAX on a graben core revealed that a sedimentary facies characterized by basal parallel lamina enriched in Ca, Fe, Mn and overlying homogeneous mud slightly enriched in Mn, is interbedded with bioturbated mud layer. We interpret the combination of lamina and homogeneous layer as event layers formed by sediment remobilization. Because the studied graben is isolated from the trench axis and no influx of terrigenous sediment is expected, the remobilized event layer would reflect earthquakes rather than flood or landward-based sedimentation event. The recurrence interval of the event layer deposition is in the order of ~1000 years (five layers above To-Cu tephra erupted ~6000 yrs BP), which is sparse than the frequency of subduction-zone earthquakes. Therefore, the event layer might record the history of large outer rise earthquakes occurred in adjacent area. During KS-19-14 cruise, we performed subbottom profiler analysis along the strike of grabens. As a result, we found that graben-fill deposits are limitedly distributed at the deepest portions of grabens, and the thicknesses of graben-fill deposits increase toward the trench. Although analysis of eight cores sampled during the cruise is still on-going, according to core data from KS-15-3, event layers would fill approximately half volume of such graben-fill deposits. By using cores and geophysical data obtained during two cruses, we further aim to understand seismic record of outer rise fault system.

Keywords: outer rise, Japan Trench

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Spatial variations in incoming oceanic plate and its implications for subduction zone processes along the Japan Trench

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Since 2009, to reveal the nature of the incoming oceanic plate in the western part of the Kuril Trench and the northern half of the Japan Trench, we have conducted extensive controlled-source seismic experiments at the northwestern margin of the oceanic Pacific plate. Like the other subduction trenches around the world, we have confirmed that the seismic velocities within the oceanic crust and the topmost mantle gradually reduce toward the trench owing to plate bending-related faulting near the trench. Previously, other than areas where bend faulting and fracture zones are observed, the northwestern part of the oceanic Pacific plate was generally considered to be laterally homogeneous. However, seismic velocity models and seismic reflection profiles we obtained show lateral variations within the crust and the topmost mantle which cannot be explained by the bending of the oceanic plate. Observations including seismic structure, seafloor topography, and gravity anomalies are summarized as the following. (1) In the area within 300 km from the trench axis, the crustal thickness is about 7 km. This area roughly corresponds to the Hokkaido rise, which is a topographic high clearly observed on the bathymetry data. (2) In the eastern and southern area of the Hokkaido rise, the crustal thickness is about 6 km, significantly thinner than the crustal thickness beneath the Hokkaido rise. (3) The water depth of the thin-crust area is deeper than the water depth expected by the plate age. (4) The gravity anomalies are basically consistent with the spatial variations in the crustal thickness. These observations indicate that the Hokkaido rise, conventionally considered as the topographic high caused by plate bending, has different nature from the surrounding area.

In 2017 and 2018, we conducted additional seismic experiment at the trench-outer rise areas of the southern Japan Trench off Fukushima. Unlike the northern part of the Japan trench, a large seamount chain exists on the incoming plate off Fukushima, but the water depth other than the seamounts are basically deeper than the northern area. The maximum water depth at the trench axis is significantly deeper in the southern Japan Trench than in the northern Japan Trench and the western Kuril Trench. We applied traveltime inversion to the OBS-airgun data and obtained a P-wave velocity structure model along the survey line. The Vp model clearly shows the reduction in Vp near the trench axis which can be explained by bend faulting. The crust is remarkably thick beneath a large seamount, but except for the seamount, the crustal thickness seems to be a little thinner than the northern Japan Trench area, which is consistent with the gravity anomalies. These observation implies that the thickness of the crust show regional variations along the Japan Trench and the Kuril Trench, which is well correlated with the seafloor topographic high called the Hokkaido rise. As the plate bending prior to subduction cannot explain the thickening of the oceanic crust, we infer that the crustal thickness beneath the Hokkaido rise is originally thicker than the other areas, suggesting the nature of the incoming oceanic plate, the thickness and the weight, is different between the northern and the southern Japan Trench. In this presentation, we will show Vp models on the oceanic Pacific plate in the western part of the Kuril Trench and northern and southern Japan Trench, and discuss the variations in the crustal thickness and implication for the subduction zone.

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Keywords: incoming oceanic plate, seismic structure, crustal thickness

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Active-source seismic study with a dense linear OBS array off Nemuro, the southern Kuril subduction zone

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The Kuril Trench subduction zone, the northwestern Pacific, is known as one of the most active seismogenic zone having super cycle M9-class earthquakes. For the coming event, an occurrence of ‘slip to the trench’ like the 2011 Tohoku-oki earthquake occurs, which is related to the crustal structural heterogeneity, is essential for the tsunami disaster mitigation. Thus, a comparison of the interplate structure between Kuril and Japan trench M9 source regions helps to consider what happens in the next event. The normal faulting of the incoming plate before subduction relates to control a frictional property of the plate boundary because the faulting makes the plate surface rough and transports fluid captured by crust and mantle hydration into the plate boundary. Whereas, the frontal structure in the hanging wall side of the plate boundary, especially the location of the backstop against the trench, also assumes an important role in the occurrence of ‘slip to the trench.’ From these backgrounds, this study aims to understand relationships between these interplate fault properties and plate subduction through an active-source seismic study around the super cycle source area.

In 2019, a seismic survey was conducted off Nemuro Peninsula, Hokkaido, in the southern Kuril Trench, by the R/V Kairei and Yokosuka of JAMSTEC. We set one refraction/reflection line (KT209) and three reflection lines (KT150, KT169, KT187), and each line run from the land slope to the outer rise area of the incoming Pacific Plate. Along KT209 with a length of 208 km, 80 of ocean bottom seismometers (OBSs) were deployed every 2 km (67 sites on the land slope and 13 on the incoming plate). An airgun array with a total volume of 7,800 cu.in. was used as a controlled source and shoot every 200 m. During the refraction survey, a reflection data was also collected by a 444-ch hydrophone streamer cable with a group interval of 12.5 m.

The obtained record sections of OBSs show clear fast arrivals of refracted P-wave which can be correctly traced to an offset distance of 40 km at least (200 km in maximum). 23,889 of first arrivals were preliminary picked with a pick uncertainty of ±50 msec, and their apparent velocities increase from ~2 km/s to ~8 km/s by increasing offset distances. Several later phases thought as wide-angle reflections were also observed and are under investigation.

To obtain a P-wave velocity (Vp) structure, we applied a 2D tomographic inversion method for traveltimes of first arrivals (Fujie et al., 2006). For the inverse analysis, we prepared four starting models to investigate a dependency of the analysis on an initial model; an original model by smoothing the layered structure constructed at the neighbor refraction line (Nakanishi et al., 2004), and others by editing Vp in the island arc crust and the incoming plate from the original model. Then, we started the inverse analysis from these models.
As a preliminary result, root-mean-square traveltime residuals (T_{RMS}) of final models were decreased from 500.3–973.1 msec to 45.7–47.6 msec, and normalized T_{RMS} by pick uncertainty (χ^2, < 1 indicates good data reproducibility) were converged to 0.84–0.91. A checker-board resolution test (CRT) with a checker board size of 8 km ×4 km (horizontal ×vertical) for every final model shows that the current traveltime

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data can resolve the structure with depths down to ~8 km from the sea bottom. The rays also distribute around depths corresponding to the oceanic mantle but the CRT are less recovered because traveltime data of deeper arrivals is insufficient. Although all models commonly show the low Vp (< ~3 km/s) zone on the plate boundary from the trench axis to ~30 km landward, Vp in the deeper crust certainly differs between models. To obtain more objective result through the inverse analysis, we will investigate to dependency of initial models more in detail by the Monte Calro approach.

Keywords: Seismic survey, Incoming Pacific plate, Island arc crust, Subduction zone earthquake

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Fluid circulation and heat transport in fractured oceanic crust in the Japan and Kuril trench outer rise regions

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Prominent high heat flow values, higher than that expected for the seafloor age, are pervasively distributed in the outer rise region of the Japan Trench. Overlapping the broad high anomaly, local steep variations at a scale of several kilometers were observed. By contrast, most of the heat flow values measured on the outer rise of the Kuril Trench were normal for the seafloor age (Sasaki et al., JpGU Meeting 2019). Anomaly in the seismic velocity structure of oceanic crust (high Vp/Vs anomaly) was also detected off both trenches. The velocity anomaly indicates high water content in the crust probably due to fracture development associated with bending of the incoming plate. The observed heat flow anomalies may also result from fracturing of the crust, which leads to increase in permeability and allows pore fluid circulation. We examined fluid flow and heat transport processes in fractured oceanic crust through numerical modeling in order to elucidate the relationship between surface heat flow and permeability structure.

The broad high heat flow anomaly observed off the Japan Trench can be attributed to thickening of a permeable layer (aquifer) in the oceanic crust toward the trench (Kawada et al., 2014). The seismic velocity anomaly is reported to be more significant off the Japan Trench than off the Kuril Trench (Fujie et al., 2018). It suggests that the permeability structure of the oceanic crust may be different between the two trenches. We conducted numerical simulations of fluid flow and heat transport for gradual aquifer thickening with various permeability structures. Modeling results for the aquifer with uniform permeability show that a broad high heat flow zone is formed only when the permeability exceeds a certain critical value. In cases where the aquifer permeability decreases with depth, the deeper the high permeability part extends, the more heat fluid circulation pumps up and the broader the high heat flow zone is.

Local heat flow variations are inferred to originate from the heterogeneity in crustal structure or fracturing process. Surface heat flow should increase above a local high-permeability zone formed by intensive fracturing, in which vigorous fluid circulation occurs. Numerical simulations were conducted assuming abrupt development of local high-permeability zones with various shapes and distributions. We found that high-permeability zones with widths of tens to hundreds of meters may yield surface heat flow anomalies extending over several kilometers and narrow high-permeability zones do not necessarily produce high heat flow anomalies.

The results of numerical modeling suggest that higher average heat flow off the Japan Trench than off the Kuril Trench may reflect higher permeability of oceanic crust in the Japan Trench outer rise region. Local heat flow variations indicate that the crustal permeability structure is highly heterogeneous. The width of high-permeability zones could be much smaller than the spatial scale of surface heat flow variations.

Keywords: heat flow, oceanic crust, fluid circulation, Japan Trench, Kuril Trench, outer rise

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Discussion on inputs to subduction zones

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We will discuss key issues to be addressed in future research programs on inputs to subduction zones.

Keywords: subduction zone, oceanic plate, trench

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[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG63] Dynamics in mobile belts

convener:Yukitoshi Fukahata(Disaster Prevention Research Institute, Kyoto University), Ray Y Chuang(Department of Geography, National Taiwan University), Toru Takeshita(Department of Natural History Sciences, Graduate School of Science, Hokkaido University), Hikaru Iwamori(Earthquake Research Institute, The University of Tokyo)

The dynamic behaviors of mobile belts are expressed across a wide range of time scales, from the seismic and volcanic events that impact society during our lifetimes, to orogeny and the formation of large-scale fault systems which can take place over millions of years. Deformation occurs on length scales from microscopic fracture and flow to macroscopic deformation to plate-scale tectonics. To gain a physical understanding of the dynamics of mobile belts, we must determine the relationships between deformation and the driving stresses associated with plate motion and other causes, which are connected through the rheological properties of the materials. To understand the full physical system, an integration of geophysics, geomorphology, geology, petrology, and geochemistry is necessary, as is the integration of observational, theoretical and experimental approaches. In particular, rheological properties, which are physically affected by fluids in the crust and chemical reactions assisted by fluids, can be resolved only through such an interdisciplinary approach. After the 2011 great Tohoku-oki earthquake, large-scale changes in seismic activity and regional scale crustal deformation were observed, making present-day Japan a unique natural laboratory for the study of the dynamics of mobile belts. This session welcomes presentations from different disciplines, such as seismology, geodesy, tectonic geomorphology, structural geology, petrology, geochemistry and hydrology, as well as interdisciplinary studies, that relate to the dynamic behaviors of mobile belts.

[SCG63-01] Onshore temporal aftershock observation for the 2019 Yamagata-Oki earthquake (2)

*Tomomi Okada[1], Ayaka Tagami[1], Tatsuya Mizuta[1], Shin'ichi Sakai[2], Keisuke Yoshida[1], Naoki Uchida[1], Takashi NAKAYAMA[1], Satoshi Hirahara[1], Toru Matsuzawa[1] (1.Research Center for Prediction of Earthquakes and Volcanic Eruptions, Graduate School of Science, Tohoku University, 2.ERI, University of Tokyo)

[SCG63-02] Stationarity of aftershock activities of the 2016 Central Tottori Prefecture Earthquake revealed by dense seismic observation

*Yoshihisa Iio[1], Satoshi Matsumoto[2], Joint aftershock observation group of the Central Tottori Prefecture earthquake[1] (1.Disater Prevention Research Institute, Kyoto University, 2.Institute of Seismology and Volcanology, Faculty of Sciences, Kyushu University)

[SCG63-03] Hyperdense seismic network reveals multiscale complexity in the young fault system that hosted the 2000 Tottori earthquake, Japan

*Aitaro Kato[1], Shin'ichi Sakai[1], Satoshi Matsumoto[2], Yoshihisa Iio[3] (1.Earthquake Research Institute, the University of Tokyo, 2.Kyushu University, 3.Disaster Prevention Research Institute, Kyoto University)

[SCG63-04] Characteristic of fault geometry of the 2016 Mw7.8 Kaikoura Earthquake, New Zealand inferred from high precision aftershock distribution

*Yuta Kawamura[1], Satoshi Matsumoto[1], Tomomi Okada[2], Miu Matsuno[2], Yoshihisa Iio[3], Tadashi Sato[2], Stephen Bannister[4], John Ristau[4], Martha Savage[5], Clifford Thurber[6], Richard Sibson[7] (1.Kyushu University, 2.Tohoku University, 3.Kyoto University, 4.GNS Science, 5.Victoria University of Wellington, 6.University of Wisconsin - Madison, 7.University of Otago)

Onshore temporal aftershock observation for the 2019 Yamagata-Oki earthquake (2)

*Tomomi Okada[1], Ayaka Tagami[1], Tatsuya Mizuta[1], Shin'ichi Sakai[2], Keisuke Yoshida[1], Naoki Uchida[1], Takashi NAKAYAMA[1], Satoshi Hirahara[1], Toru Matsuzawa[1]

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On June 22 (JST), a M6.7 earthquake occurred off Yamagata Prefecture in NE Japan. This Yamagata-Oki earthquake is located within the East Margin of the Japan Sea (EMJS) strain/deformation concentration zone.

To obtain more reliable aftershock distribution of the 2019 Yamagata-Oki earthquake, we deployed temporal seismic stations. It began about two days after the earthquake. We used the double-difference tomography method (Zhang and Thurber, 2003, 2006) for relocation. Initial velocity structure is from Okada et al. (2015).

We can see major eastward-dipping alignment with a dip angle of 30 degrees. In southern area of aftershock area, aftershock distribution seems to be complex and we can see westward-dipping alignment with a dip angle of about 60 degrees.

Focal mechanism of the 2009 Yamagata-Oki earthquake is reverse-type with P-axis oriented NNW-SSE by F-net_NIED and JMA. One of nodal planes is eastward dipping with a dip angle of about 30 degrees, and anothers is westward dipping with a dip angle of 60 degrees. These nodal planes of focal mechanism seem to correspond well with the aftershock distribution.

We also obtained focal mechanisms of aftershocks. Stress inversions (Tagami et al., this meeting) from the earthquakes surrounding the focal area in this study and other previous studies (e.g. Terakawa and Matsu’ura (2010)) show almost pure reverse faulting with a sigma-1 axis oriented to “WNW-ESE”.

We analysed shear wave splitting (polarization anisotropy) using data from the temporal and routinely operated stations (cf. Mizuta et al., this meeting). The method we have deployed was MFAST (Savage et al., 2010). Results at some of the stations shows polarization azimuth of fast shear wave (PAFS) is oriented to WNW-ESE, which corresponds to the sigma-1 axis orientation. Results at the other stations shows polarization azimuth of fast shear wave is oriented to about N-S. The N-S oriented anisotropy would be interpreted as the structure-controlled anisotropy caused by faulting and deformation, mylonitazed rock near the station.

In conclusion, the 2019 Yamagata-oki earthquake is an reverse-fault earthquake in very complex crustal structure formed in a long time range.

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Stationarity of aftershock activities of the 2016 Central Tottori Prefecture Earthquake revealed by dense seismic observation

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To clarify the relationship between earthquake occurrence and fluid, we analyzed data from a dense aftershock-observation network with 69 high-gain short-period seismographs installed immediately after the mainshock occurrence (October 21) in the aftershock area of the 2016 Central Tottori Prefecture earthquake. We determined the hypocenters and focal mechanisms of the aftershocks very precisely in the period from October 22 to December 15. We then investigated the temporal changes in the spatial distributions of hypocenters and T-axis azimuths of focal mechanisms. The distributions of aftershock hypocenters and T-axis azimuths are basically temporally stable, except those in limited portions in the shallow layer near the western edge of the aftershock area. If fluid rises from the lower crust due to fault rupture, the locations of aftershocks and focal mechanisms may change over time, especially in the deepest part of the aftershock region. However, the temporal change in these parameters was not apparent at depth. These observations suggest that the aftershock activity of the Central Tottori Prefecture earthquake was controlled mainly by stress concentration rather than strength reduction due to high fluid pressure.

Keywords: Intraplate earthquake, Aftershock, Stress, Strength, Fluid

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Hyperdense seismic network reveals multiscale complexity in the young fault system that hosted the 2000 Tottori earthquake, Japan

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1. Earthquake Research Institute, the University of Tokyo, 2. Kyushu University, 3. Disaster Prevention Research Institute, Kyoto University

Young faults display complexity across multiple length scales, but it is unclear how this relates to earthquake occurrence. To address this issue, we obtained high-spatial-resolution images of seismic sources along a young fault zone in SW Japan and reconstructed the structural properties of the zone at seismogenic depths based on data from a hyper-dense network of 1000 seismic stations. A highly precise micro-earthquake catalog and seismic imaging reveal conjugate faulting over multiple length scales. These conjugate faults are well developed in zones of low seismic velocity. An aseismic blind fault is apparent as a thin, low-velocity band. A tiny, vertically dipping seismic cluster of ~200 m length localizes to a width of ~10 m. Earthquake migrations in this cluster have a speed of ~30 m/d, suggesting fluid diffusion. The spatio-temporal pattern of seismic activity could be controlled by multiscale complexity in this young fault system.

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Characteristic of fault geometry of the 2016 Mw7.8 Kaikoura Earthquake, New Zealand inferred from high precision aftershock distribution

*Yuta Kawamura[1], Satoshi Matsumoto[1], Tomomi Okada[2], Miu Matsuno[2], Yoshihisa Iio[3], Tadashi Sato[2], Stephen Bannister[4], John Ristau[4], Martha Savage[5], Clifford Thurber[6], Richard Sibson[7]

1. Kyushu University, 2. Tohoku University, 3. Kyoto University, 4. GNS Science, 5. Victoria University of Wellington, 6. University of Wisconsin - Madison, 7. University of Otago

On November 14, 2016, a large earthquake with Mw7.8 occurred in northeastern South Island, New Zealand. The earthquake showed a complex rupture process involving many faults. Based on geodetic and geologic observation, previous studies (e.g., Clark et al., 2017) pointed out that over 20 faults were ruptured by the main shock. Two previous studies have relocated aftershocks using double-difference techniques (Mouslopoulou et al., 2019; Lanza et al., 2019). However, the event distribution in these studies was not always sufficient to reveal the fine fault geometry due to the low station spacing above the focal area within 50 km. More precise fault geometries than the previous studies are required in order to examine the relationship between coseismic fault behaviour and the observed surface breaks. In this study, we used temporary seismic stations that were deployed close to the rupture area prior to the main shock occurrence. We applied the double-difference earthquake relocation algorithm (Waldhauser and Ellsworth, 2000) to the phase data including time-domain waveform cross-correlation (Poupinet et al., 1984).

We obtained the hypocenter distribution concentrating around the surface breaks, with a depth range from 5 km to 25 km. From the aftershock distribution, we identified 10 or more faults. The geometry of the fault planes is consistent with the focal mechanism of the relatively large events in each cluster. In particular, one of the faults in this study, which was located in the area of large coseismic slip, may correspond to the fault orientation of the main shock inferred from its CMT solution.

Keywords: Kaikoura Earthquake, New Zealand, high precision hypocenter location, aftershock distribution, fault geometry

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[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG63] Dynamics in mobile belts

convener:Yukitoshi Fukahata(Disaster Prevention Research Institute, Kyoto University), Ray Y Chuang(Department of Geography, National Taiwan University), Toru Takeshita(Department of Natural History Sciences, Graduate School of Science, Hokkaido University), Hikaru Iwamori(Earthquake Research Institute, The University of Tokyo)

The dynamic behaviors of mobile belts are expressed across a wide range of time scales, from the seismic and volcanic events that impact society during our lifetimes, to orogeny and the formation of large-scale fault systems which can take place over millions of years. Deformation occurs on length scales from microscopic fracture and flow to macroscopic deformation to plate-scale tectonics. To gain a physical understanding of the dynamics of mobile belts, we must determine the relationships between deformation and the driving stresses associated with plate motion and other causes, which are connected through the rheological properties of the materials. To understand the full physical system, an integration of geophysics, geomorphology, geology, petrology, and geochemistry is necessary, as is the integration of observational, theoretical and experimental approaches. In particular, rheological properties, which are physically affected by fluids in the crust and chemical reactions assisted by fluids, can be resolved only through such an interdisciplinary approach. After the 2011 great Tohoku-oki earthquake, large-scale changes in seismic activity and regional scale crustal deformation were observed, making present-day Japan a unique natural laboratory for the study of the dynamics of mobile belts. This session welcomes presentations from different disciplines, such as seismology, geodesy, tectonic geomorphology, structural geology, petrology, geochemistry and hydrology, as well as interdisciplinary studies, that relate to the dynamic behaviors of mobile belts.

[SCG63-07] Development of Strike-Slip Fault Related to the Mud Diapirism in SW Taiwan

★Invited Papers

*Kuo-En Ching[1], Yu-Tsung Lo[2], Song-Chuen Chen[3], Ruey-Juin Rau[1] (1.National Cheng Kung University, 2.National Central University, 3.Central Geological Survey)

[SCG63-08] **Fluid pressure gradients and permeability evolution in the crust: insights from metamorphic fluid-rock reaction zones and hydrothermal experiments**

★Invited Papers

*Masaoki Uno[1], Atsushi Okamoto[1], Diana Mindaleva[1], Hisamu Kasahara[1], Naoki Sugisawa[1], Jun Kameda[2], Noriyoshi Tsuchiya[1] (1.Graduate School of Environmental Studies, Tohoku University, 2.Department of Natural History Sciences, Graduate School of Science, Hokkaido University)

[SCG63-09] **Grain growth experiment of albitic feldspar**

*Norio Shigematsu[1], Masanori Kido[1], You Zhou[2], Hideki Hyuga[2], Yuuichi Yoshizawa[2] (1.Research Institute of Earthquake and Volcano Geology, Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology, 2.Structural Materials Research Institute, National Institute of Advanced Industrial Science and Technology)

[SCG63-10] **3D fault zone architecture across the brittle-plastic transition along the Median Tectonic Line, eastern Kii Peninsula, SW Japan**

*Takuma Katori[1,2], Norio Shigematsu[1], Jun Kameda[3], Ayumu Miyakawa[1], Tatsuya Sumita[1] (1.Geological Survey of Japan, AIST, 2.Graduate School of Science & Technology, Niigata university, 3.Department of Natural History and Sciences, Hokkaido university)

[SCG63-11] Development of the Median Tectonic Line fault zone, Mie Prefecture, southwest Japan: Processes of strain localization

*Toru Takeshita[1], Dong Van Bui[1], Jun-ichi Ando[2] (1.Department of Natural History Sciences, Graduate School of Science, Hokkaido University, 2.Department of Earth and Planetary Systems Science, Graduate School of Science, Hiroshima University)

[SCG63-12] **Fault strength of the ancient Median Tectonic Line at the brittle-ductile transitional depths**

*Ichiko Shimizu[1], Ayumi S. Okamoto, André R. Niemeijer[2], Masao Nakatani[3], Shun Arai[4], Spiers J. Christopher [2], Toru Takeshita[5], Tadamasa Ueda[1] (1.Kyoto University, 2.Utrecht University, 3.Earthquake Research Institute, the University of Tokyo, 4.Tohoku University, 5.Hokkaido University)

Development of Strike-Slip Fault Related to the Mud Diapirism in SW Taiwan

*Kuo-En Ching[1], Yu-Tsung Lo[2], Song-Chuen Chen[3], Ruey-Juin Rau[1]

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Tectonic escape theory has been applied to the tectonic development explanation in SW Taiwan. Following the lateral extrusion of tectonic blocks, the major strike-slip faults was generated as the block boundaries. The approximately 45-km-long N-S-striking Kaoping fault has been proposed as one of the major strike-slip fault in SW Taiwan. Although the slip rate of approximately 10-15 mm/yr was derived based on the geodetic data, no geological evidence proofs the existence of Kaoping fault so far. In addition, rather than the tectonic escape theory, the mud diapirism has also been proposed to explain the development of tectonics in SW Taiwan in recent studies. Based on this school, it is easy to understand why the material motions in upper crust and upper mantle are different and to understand why the seismic rate is extremely lower than derived earthquake potential in SW Taiwan. However, whether the vertical motion caused by mud diapirism has possibility to derive the strike-slip faulting? The 13-year surface displacements derived from GNSS and leveling measurements and seismic reflection profiles in an island off SW Taiwan has indicated that the active mud diapirism would cause the active strike-slip faulting. Therefore, the existence of Kaoping fault is possible if the mud diapir location is the same as the Kaoping fault. The recent distribution of residual Bouguer gravity anomaly in SW Taiwan indicates that a series of positive gravity anomalies align along the possible location of Kaoping fault. The confidential seismic reflection profiles from oil company also indicate that the N-S trending mud diapir located beneath the Kaoping fault. Therefore, we proposed the initial development of Kaoping fault is related to the activity of the mud diapirism in this study. In other words, even though a high slip rate of approximately 10-15 mm/yr was inferred on the Kaoping fault, the earthquake potential of this fault is not as high as what we expected.

Keywords: strike-slip fault, mud diapir, GPS velocity field

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Fluid pressure gradients and permeability evolution in the crust: insights from metamorphic fluid-rock reaction zones and hydrothermal experiments

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1. Graduate School of Environmental Studies, Tohoku University, 2. Department of Natural History Sciences, Graduate School of Science, Hokkaido University

Fluid pressure and permeability in the crust is one of the most important parameters that govern the fluid activities in the crust. High pore fluid pressures and associated permeability changes in the crust and mantle have been recognized by geophysical observations, and are generally considered as triggers of earthquakes and slow–earthquakes (e.g., Audet and Bürgmann, 2014; Nakajima and Uchida, 2018). Although such high pore fluid pressures are evidenced as mineral filled fractures in geologic observations, the actual fluid pressure gradients and permeability in the crust have not been evaluated quantitatively and remain largely unknown. In this talk we show constraints on the crustal permeability evolution from (a) natural metamorphic reaction zones showing high fluid pressure gradients and permeability changes in the crust, (b) hydrothermal experiments showing the evolution of transport properties (permeability and diffusion) and mechanical responses (stress) during hydration reactions.

(a) Fluid pressure and permeability evolution constrained from natural metamorphic fluid-rock reaction zones
Here we show (1) various geologic evidences of fracturing and permeability enhancement in the supercritical, deep crustal conditions where plastic deformation is dominant (upper-greenschist to lower-granulite facies conditions of 200–500 MPa, 450–700˚C; Tsuchiya et al., 2016; Uno et al., 2017; Nohara et al., 2019; Mindaleva, et al., under revision). (2) A new, quantitative estimates of crustal fluid pressure gradients and permeability recorded in metamorphic fluid-rock reaction zones, associated with crustal fracturing (Uno et al., 2017; Mindaleva et al., under revision).
These results show that the permeability of intact crust is ~$10^{-20–22}$ m^2 for the granulite– and amphibolite–hosted reaction zones, and are several orders smaller than the widely accepted crustal permeability model (~10^{-18} m^2; e.g., Ingebritsen and Manning, 2010). On the other hand, permeability along the fractures are estimated as high as >$10^{-14–15}$ m^2 for the granulite and amphibolite-hosted fractures, which is analogous to the permeability estimated for the hypocenter migrations in the crust (~$10^{-14–15}$ m^2; e.g., Okada et al., 2014; Nakajima and Uchida, 2018). These results show the importance of low permeability of intact amphibolite/granulite-facies metamorphic rocks in conjunction with episodic high permeability of brittle fractures even at high temperature conditions of 450–700˚C, both of which affect the regional scale permeability in the deep crust.

(b) Reaction-enhanced permeability, diffusivity and stress during fluid-rock reactions revealed by hydrothermal experiments
We further show the recent advances in reaction-enhanced transport properties of rocks revealed by hydrothermal experiments including (3) more than 2-orders of permeability enhancement by reaction-induced fracturing during hydration reactions (Uno et al., in prep.), (4) reaction-enhanced diffusion that are ~10 times faster than the static diffusion rate during replacement reactions and (5) role of reaction-induced stress or swelling of clays on the weakening of fault (Kameda et al., 2019).

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These experimental results show the importance of fluid-rock reactions controlling the hydro-mechanical properties of the crust. We discuss non-dimensional parameters that controls the permeable/impermeable nature of crust during hydration reactions.

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Keywords: Fluid-rock reactions, Permeability, Fluid pressure, Reaction-induced stress

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Grain growth experiment of albitic feldspar

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Feldspar is one of the main constituent minerals of the Earth’ s crust. The grain growth and the mechanical behavior of plastic deformation of feldspar have well studied for anorthite ($CaAl_2Si_2O_8$) previously, because this mineral controls the strength of the lower crust. On the other hand, the grain growth of albite ($NaAlSi_3O_8$) has not been studied previously. In this study, we examined the grain growth of albite. Grain growth follows the grain growth law and the rate constant was determined in the experiments.
The starting materials were prepared as follows. Albite powders for industrial use were pulverized using an automatic pulverizer (HERZOG HSM-250A at AIST Tsukuba Central 7) and fine-grained fractions less than a few hundred nm were separated by decantation. The fine-grained powders were hot pressed using a multi-purpose high temperature furnace (Fuji Dempa High Multi 10000 at AIST Chubu) at temperature of 1080 ºC and pressure of 120 MPa for 16 hours. The initial grain size is about 200 nm by linear intercept method after thermal etching.
The grain growth experiments were performed by annealing the sample in a tube furnace (Carbolite 14/450 at AIST Tsukuba Central 7) at the atmospheric pressure. To avoid the melting during the experiments, it is necessary to determine the subsolidus temperatures before annealing experiments. The results suggest that the sample were melted at the temperatures above 1070 ºC.
We obtained the preliminary results at the temperature of 1050 ºC. The grains grow to the grain size of about 370 nm after 140 hours annealing. The regression of the results yields the growth exponent of 2.5 and the rate constant of 1.8×10^{-22} $m^{2.5}s^{-1}$. To compare the result with the previously obtained results for anorthite (Dresen et al., 1996), we calculate the rate constant of 1.35×10^{-18} $m^{2.6}s^{-1}$ at 1050 ºC. The obtained rate constant for albite is four order of magnitude slower than that for anorthite. The results suggest that once fine grained feldspar with composition close to albite is formed, these grains will never grow and affect the mechanical behavior for long time. This process is presumably important not only for the generation of earthquakes along inland active faults but also subduction megathrust earthquakes.

Keywords: Albite, Grain growth, Hot press, Crustal rheology

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3D fault zone architecture across the brittle-plastic transition along the Median Tectonic Line, eastern Kii Peninsula, SW Japan

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The heterogeneous fault deformation at depth possibly affects the fault behavior significantly including the generation of earthquakes (e.g. Scholtz, 2001). To understand the effect, it is essential to reveal a detailed fault zone architecture (e.g. Norris and Cooper, 2007). In this study the features and extents of fault rocks are described along the Median Tectonic Line (MTL), eastern Kii Peninsula, SW Japan, to reveal a 3D fault zone architecture across the brittle-plastic transition.

3D digital outcrop models (DOMs) (Triantafyllou et al., 2019) were first constructed using SfM-MVS (e.g., Furukawa and Hernández, 2013; Bemis et al., 2014) to provide the precise positions within all of geological descriptions. After the georeferencing, the type of fault rocks were described based on the visual inspections and microstructural observations.

The cataclasites exposed close to the lithological boundary fault (the MTL) were divided into those formed by sinistral faulting around 300 ˚C and those formed by dextral faulting around 250 ˚C. The mylonites distributed north of the cataclasites were formed by sinistral faulting and were divided into the lower-temperature mylonite (L-T mylonite) close to the MTL and the higher-temperature mylonite (H-T mylonite) far from the MTL, where the deformation temperatures were below and above 400 ˚C.

The fault zone architecture was calculated by a least square regression based on the above structural units. The structures formed by the sinistral faulting are oblique to those formed by dextral faulting, indicating that the former structures are older than the later ones.

The structures formed by sinistral faulting experienced uplifting caused by the fault displacement and the deformation around the brittle-plastic transition. Thus, the MTL fault zone records the deformation across the crust. The microstructural observations suggest that the differential stress just below the brittle-plastic transition (L-T mylonite) was about 200 MPa and this value does not significantly change in the deep crust corresponding to the H-T mylonite. In these structures the dipping angles of foliations are steeper in accordance with the decrease of deformation temperature, suggesting these structures represent a listric fault (e.g. Ramsay and Huber, 1987).

Keywords: 3D fault zone architecture, Brittle-Plastic transition, Median Tectonic Line, Cataclasite, Mylonite

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Development of the Median Tectonic Line fault zone, Mie Prefecture, southwest Japan: Processes of strain localization

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The Median Tectonic Line (MTL) sensu stricto is defined by the boundary fault between the Cretaceous high-P/T type Sambagawa metamorphic rocks and Cretaceous low-P/T type metamorphic rocks and granitoids, which was formed by large-scale normal faulting at c. 59 Ma (Kubota and Takeshita, 2008; Kubota et al., accepted for Tectonics). It is interesting to note however that the present MTL is originally formed in the Ryoke southern marginal shear (i.e. mylonite) zone up to a few km wide in Late Cretaceous (Hara et al., 1980), and therefore the strain becomes so much localized to form the very narrow MTL fault cataclasite and gouge zone at c. 59 Ma (Paleocene). We examined the development of the MTL mylonite zone, Mie Prefecture, southwest Japan, which originated from the Cretaceous Ryoke granitic rocks, in order to understand the development and strain localization during exhumation and cooling. The mylonitic rocks originated from two types of granitoids distributed in different areas at the north of the MTL: Areas A and B mostly consisting of protomylonite and mylonite originated from tonalite and granite, which are distributed from the distance of c. 0-300 m and 300-800 m from the MTL, respectively.

Microstructures and crystallographic preferred orientations (CPOs) of quartz and two feldspar geothermometry have been analyzed to infer the deformation conditions and a spatiotemporal distribution of these in the MTL mylonite zone. It has been found that in Area B mylonite can be divided into two mylonite zones showing the S-type and P-type quartz microstructures (Masuda and Fujimura, 1981; Masuda, 1982), which are created by subgrain rotation (SGR) and grain boundary migration (GMB) recrystallization, respectively. These mylonite zones are distributed from the distance of 300-490 m and 490-800 m from the MTL, respectively. The quartz c-axis CPOs dominantly show a medium-temperature Y-maxima pattern in both areas A and B, with some occurrences of a low-temperature type-I crossed girdle quartz c-axis CPO. K-feldspar in mylonites of Area B, which is accompanied by the formation of myrmekite, shows brittle and ductile deformation in mylonite with the S-type and P-type quartz microstructures, respectively.

The strain localization in the MTL mylonite zone during exhumation and cooling will be summarized below. Originally, the deformation of quartz occurred at high temperatures at 400-500 °C in a wide zone forming mylonite with the P-type quartz microstructure in Area B. However, the strain became localized into the southern part of Area B, where S-type quartz microstructure formed at 350-400 °C. Also, protomylonite formed at the similar temperature conditions in Area A. Below 350 °C, ductile deformation stopped in mylonite in Area B, which could be succeeded by ductile deformation in a very narrow zone up to 50 m wide forming ultramylonite in direct proximity to the MTL in area A, where a low-temperature type-I crossed girdle quartz c-axis CPO develops (Czertowicz et al., 2019). We interpret that the formation of ultramylonite in Area A (i.e. tonalite region) might be induced by the fluid percolation during brittle fracturing (Zibra et al., 2018), which tends to occur more easily in area A than area B, because the ductile strength is lower in the granite and tonalite at the same temperature. A large amount of white mica in the ultramylonite could suggest that such fluid percolation in fact pervasively occurred to form the ultramylonite in area A.

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Keywords: Median Tectonic Line, mylonite, quartz c-axis CPO, dynamic recrystallization mechanism in quartz, strain localization, fluid percolation and formation of ultramylonite

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Fault strength of the ancient Median Tectonic Line at the brittle-ductile transitional depths

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To explore the fault strength at the middle crustal levels close to the brittle-ductile transition zone, we conducted friction experiments using natural fault rocks exposed along the Median Tectonic Line (MTL). The experiments were performed on powdered samples of cataclasite and protomylonite, which are originated from tonalite or basic rocks in the Ryoke belt on the northern side of MTL. Cataclasites contain ~30 wt.% mica and clay minerals. Among them, chlorite-rich cataclasite (Chl-cataclasite) contains ~14 wt.% chlorite, and mica-rich cataclasite (Ms-cataclasite) contains ~14 wt.% white mica. Chlorite is a hydrous mineral commonly observed in basic metamorphic rocks and fault zones, and is known to have low friction coefficients about 0.3 at hydrothermal conditions (Okamoto et al., 2019).

Chlorite geothermometer (Bourdelle *et al.*, 2013) yields a bimodal distribution (230–240˚C and 290–340˚C) for the protomylonite sample. The low-temperature chlorite occurs as blobs with the diameter of ~1–2 mm, which contain lamella of white mica. These chlorite grains are considered as pseudomorphs of biotite. The high-temperature chlorite filled fractures and interstice of grains. We therefore interpreted that brittle deformation first occurred at a temperature around 300˚C and subsequent hydrothermal alteration occurred at 230–240˚C. Chl-cataclasite also shows a bimodal temperature distribution (180–220˚C and 240–300˚C), although no clear relationships between temperatures and microstructures were found.

To simulate the deformation conditions at depth, friction experiments were conducted at temperature of 300˚C, normal stress of ~300 MPa, and pore fluid pressures of 120 MPa and 240 MPa, using the hydrothermal ring shear apparatus at Utrecht University. Sliding velocities were varied from 0.001 mm/s to 0.1 mm/s in the velocity stepping tests. The steady-state friction coefficients obtained for protomylonite were ~0.68, whereas those for Ms- and Chl-cataclasites were ~0.65 and ~0.56 at 120 MPa, and ~0.87 and ~0.66 at 240 MPa, respectively. Velocity stepping tests yielded velocity-weakening or neutral behaviours, although existing laboratory data for pure chlorite gouges mostly show velocity-strengthening behaviours. Our results indicate that fault strengths and sliding behaviours in the middle crusts are not drastically changed by the presence of phyllosilicates even if chlorite contents in fault zones are relatively high (<14 wt.%).

Herein we also report new results of stress-stepping tests, constant-velocity large-displacement tests, velocity-stepping tests at a higher temperature (450˚C), and discuss their implication to the crustal strength at the brittle-ductile transitional zone.

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Keywords: differential stress, fault strength, friction, Median Tectonic Line

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[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG63] Dynamics in mobile belts

convener:Yukitoshi Fukahata(Disaster Prevention Research Institute, Kyoto University), Ray Y Chuang(Department of Geography, National Taiwan University), Toru Takeshita(Department of Natural History Sciences, Graduate School of Science, Hokkaido University), Hikaru Iwamori(Earthquake Research Institute, The University of Tokyo)

The dynamic behaviors of mobile belts are expressed across a wide range of time scales, from the seismic and volcanic events that impact society during our lifetimes, to orogeny and the formation of large-scale fault systems which can take place over millions of years. Deformation occurs on length scales from microscopic fracture and flow to macroscopic deformation to plate-scale tectonics. To gain a physical understanding of the dynamics of mobile belts, we must determine the relationships between deformation and the driving stresses associated with plate motion and other causes, which are connected through the rheological properties of the materials. To understand the full physical system, an integration of geophysics, geomorphology, geology, petrology, and geochemistry is necessary, as is the integration of observational, theoretical and experimental approaches. In particular, rheological properties, which are physically affected by fluids in the crust and chemical reactions assisted by fluids, can be resolved only through such an interdisciplinary approach. After the 2011 great Tohoku-oki earthquake, large-scale changes in seismic activity and regional scale crustal deformation were observed, making present-day Japan a unique natural laboratory for the study of the dynamics of mobile belts. This session welcomes presentations from different disciplines, such as seismology, geodesy, tectonic geomorphology, structural geology, petrology, geochemistry and hydrology, as well as interdisciplinary studies, that relate to the dynamic behaviors of mobile belts.

[SCG63-13] Resistivity structure around the Atotsugawa fault system revealed by inversion schemes combining Wideband- and Network-MT methods

★Invited Papers

*Yoshiya Usui[1,2], Makoto Uyeshima[1], Tsutomu Ogawa[1], Ryokei Yoshimura[3], Naoto Oshiman[3], Satoru Yamaguchi[4], Hiroaki Toh[5], Hideki Murakami[6], Koki Aizawa[7], Toshiya Tanbo[8], Yasuo Ogawa[9], Tadashi Nishitani[10], Shin'ya Sakanaka[10], Masaaki Mishina[11], Hideyuki Satoh[12], Tada-nori Goto[13], Takafumi Kasaya[14], Toru Mogi[15], Yusuke Yamaya[16], Ichiro Shiozaki[17], Yoshimori Honkura[18] (1.Earthquake Research Institute, the University of Tokyo, 2.ITOCHU Techno-Solutions Corporation, 3.Disaster Prevention Research Institute, Kyoto University, 4.Graduate School of Science, Osaka City University, 5.Graduate School of Science, Kyoto University, 6.Natural Sciences Cluster-Science and Technology Unit, Research and Education Faculty, Kochi University, 7.Institute of Seismology and Volcanology, Faculty of Science, Kyushu University, 8.Tateyama Caldera Sabo Museum, 9.Volcanic Fluid Research Center, School of Science, Tokyo Institute of Technology, 10.Graduate School of International Resource Sciences, Akita University, 11.Graduate School of Science, Tohoku University, 12.Nuclear Regulation Department, Nuclear Regulation Authority, 13.Graduate School of Life Science, University of Hyogo, 14.Japan Agency for Marine–Earth Science and Technology, 15.Faculty of Science, Hokkaido university, 16.National Institute of Advanced Industrial Science and Technology, 17.Graduate School of Engineering, Tottori University, 18.Graduate School of Science and Engineering, Tokyo Institute of Technology)

[SCG63-14] High pressure electrical conductivity in a brine-saturated rock and microstructure of pores

*Tohru Watanabe[1], Kenta Yoshida[2], Katsuyoshi Michibayashi[3] (1.University of Toyama, 2.Japan Agency for Marine-Earth Science and Technology, 3.Nagoya University)

[SCG63-15] Fluid distribution beneath volcanically and seismically active island, Kyushu, based on 3-D electrical resistivity model

★Invited Papers

*Maki Hata[1] (1.Earthquake Research Institute, the University of Tokyo)

[SCG63-16] The Quaternary tectonics of central Kyushu and the 2016 Kumamoto earthquake: from a multifaceted viewpoint of geology, seismology, and geodesy

★Invited Papers

*Kiyokazu Oohashi[1], Makoto Otsubo[2], Satoshi Matsumoto[3], Kenta Kobayashi[4], Katsushi Sato[5], Takuya NISHIMURA[6] (1.Graduate School of Sciences and Technology for Innovation, Yamaguchi University, 2.Geological Survey of Japan, AIST, 3.Faculty of Science, Kyushu University, 4.Department of Geology, Faculty of Science, Niigata University, 5.Graduate School of Science, Kyoto University, 6.Disaster Prevention Research Institute, Kyoto University)

[SCG63-17] A semi-kinematic reference frame of Taiwan considering earthquake-cycle deformation at a plate boundary deformation zone

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[SCG63-18] Consideration of Formation factor of Trench-parallel fore-arc ridge

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Resistivity structure around the Atotsugawa fault system revealed by inversion schemes combining Wideband- and Network-MT methods

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The Atotsugawa fault system (central Japan) in the Niigata-Kobe tectonic zone is one of the best field to research the physical mechanism of strain accumulation along earthquake faults because of its potential of causing large earthquakes (~M7.0), high deformation rate and existence of many geophysical studies.

In order to elucidate the strain accumulation mechanism around the Atotsugawa fault system, we investigated the resistivity structure around the fault system. To delineate a reliable resistivity structure from the upper crust to the uppermost mantle, we estimated the resistivity structure by combined inversion schemes of the wideband-magnetotelluric method and the Network-MT method. In the Network-MT method, metallic telephone cables several kilometers in length are used to measure electric potential differences.

By a two-dimensional combined inversion scheme, we revealed that, in the lower crust, there are localized conductive areas below the Atotsugawa fault, the Ushikubi fault and the Takayama-Oppara fault zone. We interpreted that the lower-crustal conductors are localized ductile shear zones with highly connected fluid, being responsible for the strain accumulation along the respective active faults just above the conductive areas. In addition, in the mantle wedge under the Atotsugawa fault system, a large conductive area was imaged, which may be attributed to the fluid dehydrated from the Philippine Sea slab and/or the Pacific slab.

In addition, so as to evaluate the effects of three-dimensional distortion to the resistivity structure, such as caused by the land-sea boundary at the north of the Atotsugawa fault system, we newly developed a three-dimensional inversion scheme combining the wideband-magnetotelluric method and the Network-MT method.

In this presentation, we review the results of the two-dimensional modeling and show an early result of the three-dimensional modeling.

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Keywords: new inversion scheme, wideband and Network MT method, lower-crustal fluid, fault-zone conductor, ductile shear zone, upper mantle fluid

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High pressure electrical conductivity in a brine-saturated rock and microstructure of pores

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Pores in rocks will close under pressures to increase seismic velocities and decrease transport properties. Experimental studies have shown that the interconnected fluid path is maintained even at the pressure of 1 GPa (e.g., Brace et al., 1965). Watanabe et al. (2019) suggested that wide aperture parts in cracks form interconnected paths to govern electrical conductivity at high pressures. In order to understand the nature of wide aperture parts in cracks, we conducted SEM-EBSD and FIB-SEM observations on a granitic rock (Aji granite). SEM-EBSD studied the crystallographic orientation of grains to distinguish grain boundary and intragrain cracks. FIB-SEM made sequential images of grain boundary and intragrain cracks. One quartz-quartz grain boundary crack shows large variation in aperture along the crack. Quartz grain boundaries are faceted and euhedral small quartz grains (a few micrometers) are seen within wide aperture parts. These observations suggest that the grain boundary was filled with a fluid at high temperature. On the other hand, an intragrain crack in a quartz grain shows little variation in the aperture. Microstructure of pores must be controlled by coexisting fluids in depths.

Keywords: crack, electrical conductivity, fluid

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Fluid distribution beneath volcanically and seismically active island, Kyushu, based on 3-D electrical resistivity model

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The island of Kyushu is characterized by a high concentration of active Quaternary volcanoes along a volcanic front of N30˚E–S30˚W associated with the subduction of the Philippine Sea Plate. The active volcanoes exist in northern Kyushu (the northern volcanic region) and southern Kyushu (the southern volcanic region), whereas no volcano exists in central Kyushu (the non-volcanic region). Most of volcanoes in the northern volcanic region lie at the Beppu-Shimabara graben, travels across the island of Kyushu almost in an E-W direction, along three tectonic lines (Oita-Kumamoto tectonic line, Usuki-Yatsushiro tectonic line and Butsuzo tectonic line). Aso caldera was formed at the south-central part of the graben by a series of huge eruptions, with a volcanic explosivity index of 7, during 270–90 ka. A post-caldera cone of Naka-dake in Aso caldera is a quite active volcano, at which magmatic and phreatomagmatic eruptions occurred during 2014–2016 and ash eruptions (emissions) have continued since July 2019. On the other hand, most of volcanoes in the southern volcanic region exist in the Kagoshima Graben, whose formation was created with ejecting huge pyroclastic flows by the Quaternary volcanism. The Kirishima volcano group appears in Kakuto-Kobayashi caldera on the northern edge of the graben. Shinmoe-dake of the Kirishima volcano group experienced a magmatic eruption of the VEI 3 in 2011 and ash emissions in March 2018. Moreover, Iwo-yama of the Kirishima volcano group experienced hot material ejections in April 2018. Besides, Sakurajima volcano in the southern part of the graben has experienced 153–1,355 small eruptions per year for the last 10 years (the Japanese Meteorological Agency).
The Philippine Sea Plate, whose subduction involves the formation of the volcanic island of Kyushu, in and around Kyushu is classified into three portions: a younger portion, an older portion, and the other part of the Kyushu–Palau Ridge between the two portions. The non-volcanic region distributes in central Kyushu above a junction where the three portions of the subducting Philippine Sea Plate contact with each other. Owing to the subduction of the Philippine Sea Plate, moment magnitude (*Mw*) 7-class thrust earthquakes have repeatedly occurred in the Hyuga-nada, lying offshore of the southeast Kyushu. In addition, recent studies using continuous global-navigation-satellite-system data have revealed that long-term slow slip events and short-term slow slip events occur in the Hyuga-nada. Besides, in the land area, historic earthquakes of at least *Mw* 6.0 repeatedly occur along the three tectonic lines, which travels across the central part of Kyushu almost in an E-W direction.
Fluid distribution in the mantle wedge is an essential factor for the seismic activity and magmatism leading to volcanic activity. Electromagnetic sounding data have high sensitivity to a few percent of interconnected fluids (aqueous fluid and melt). In this presentation, three-dimensional (3-D) electrical resistivity models by inverting magnetotelluric (MT) data and/or network-MT data, which have been acquired on the whole of Kyushu island by various surveys, are shown to discuss the fluid distribution beneath Kyushu. The 3-D resistivity models indicate magma systems and fluid systems relating to slab-derived fluid as significant conductive features/anomalies. In addition, the conductive anomalies exist along the volcanic front beneath the northern and southern volcanic regions, respectively. Importantly, a clear conductive anomaly in the 3-D models fail to reach the crust through the Moho discontinuity beneath the non-volcanic region in Kyushu. Moreover, another conductor, relating to the presence of slab-derived fluid in the mantle wedge, appears at a blank area of the slow slip events.

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Keywords: 3-D electrical resistivity models, Fluid distribution, Volcanically and seismically active island, Mantle wedge, Slow slip events

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The Quaternary tectonics of central Kyushu and the 2016 Kumamoto earthquake: from a multifaceted viewpoint of geology, seismology, and geodesy

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The 2016 Kumamoto earthquake occurred in the tectonically complex central Kyushu area where several forcing factors such as the subducting Philippine sea plate, the Median Tectonic Line and the Nankai forearc sliver, the spreading Ryukyu trough, and the migrating volcanic front are involved. In this paper, we revisit the Neogene–Quaternary tectonics of central Kyushu through the integration of geological, seismological, and geodetical approaches. Also, we establish deformation histories of the Futagawa and Hinagu fault zones, source faults of the Kumamoto earthquake, in an attempt to explain the relationship between geologic structures and rupture processes of the earthquakes. Results show that the present-day tectonics surrounding central Kyushu is considered to have been originated in the last 1 Ma or younger, as a transtensional tectonic zone (the Central Kyushu Shear Zone) characterized by combined dextral faults and rift zones (or volcanoes). Reflecting the spatiotemporal variation of the crustal stress field and rift activity, the Futagawa and Hinagu fault zones show a multi-stage deformation throughout the Neogene–Quaternary periods; normal faulting to dextral faulting for the Futagawa fault zone and sinistral to dextral faulting for the Hinagu fault zone. Those diverse histories on stress and strain fields in central Kyushu possibly lead to the complexities of fault geometry and rupture process of the Kumamoto earthquake.

Keywords: Futagawa-Hinagu fault zone, Beppu-Shimabara graben, Okinawa trough, Median Tectonic Line, Philippine sea plate, transtensional tectonics

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A semi-kinematic reference frame of Taiwan considering earthquake-cycle deformation at a plate boundary deformation zone

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Taiwan’s current horizontal coordinate system, TWD97[2010], is a static geodetic datum located at the boundary between Eurasian and Philippine Sea plates. Due to the relative motions between different plates, the accuracy of TWD97[2010] has been constantly decreasing. To maintain the internal accuracy of a national coordinate system at a high level, establishing a semi-kinematic reference frame is a practical solution. The semi-kinematic reference frame includes a static datum and a surface deformation model that is composed of velocity grid models and displacement grid models. In this study, observations of 437 continuous GNSS stations from January 2003 to December 2019 were adopted to estimate the horizontal velocity field in Taiwan. We also integrated twelve horizontal velocity fields between 2003 and 2018 from 785 campaign-mode GNSS sites surveyed by the Central Geological Survey to derive the horizontal grid velocity model using the Kriging spatial interpolation method. Six coseismic displacement grid models from 2010 to 2018 were constructed using the dislocation model based on published coseismic source models. Independent GNSS observations of 1400 stations collected by the National Land Surveying and Mapping Center (NLSC) between 2013 and 2018 were also used for exterior checking on the accuracy of the surface deformation model. In addition, the network-based RTK system in Taiwan established by NLSC, named e-GNSS, is proposed to be used for assessing the accuracy of the velocity model and for the decision on the timing of velocity model renewal.

Keywords: TWD97[2010], semi-kinematic reference frame, surface deformation model, Kriging spatial interpolation, dislocation model

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Consideration of Formation factor of Trench-parallel fore-arc ridge

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This study revealed a nature of trench-parallel fore-arc ridge (TPFR). TPFR is a trench parallel rise of elevation and gravity existing in between trench and volcanic front, which is a general feature of fore-arc. Bassett and Watts (2015) suggested that TPFR corresponds to the down-dip limit of inter-plate earthquakes. Iwase (2017 JPGU) found a positive correlation between the TPFR’s free air anomaly and the age of the subducting slab. He suggested that the TPFR is caused by inter-plate interaction which reflects the rigidity of the subducting slab. But, Iwama (2018 JPGU) revisited the relationship between the free air anomaly and the slab age with more data to find that the slab age and the TPFR do not necessarily correlate each other. This suggested that the Iwase (2017)’s relationship would be artifacts due to a shortage of the data.

We considered the origin of the TPFRs from the view point of slab and fore-arc parameters. We studied the circum-Pacific subduction zones and the Jawa, the Puerto-Rico, the South-Sandwich trenches. The considered parameters are; sea floor age from National Oceanic and Atmospheric Administration (NOAA), topography from Global Bathymetric Chart of Ocean (GEBCO), slab angle calculating from slab-depth Slab1.0 from United States Geological Survey. We compared the gravity anomaly peak of TPFR with these parameters.
As a result, we found no correlation between slab age and the peak gravity value of the TPFR. However, when dividing the subduction zones by its slab age with interval of 10 Ma, we found a clear linearity between TPFR gravity and its elevation for each age range. The gradient of the gravity against the elevation is explained by pure increase of the land mass beneath the TPFR. This suggests that the TPFR is formed by lifting by the rigidity of the subducted slab. Furthermore, we found a good positive correlation between the slab age and the intercept of the TPFR gravity against the TPFR elevation. This means that when comparing the TPFR gravity at the sea level, the peak gravity is larger with older slab. This means that older slab pushes up the fore arc more than the younger slab. We concluded that rigidity of the subducting slab is not reflected by the TPFR height, but reflected by holding TPFR up.

Keywords: forearc structure, TPFR, rigidity of slab

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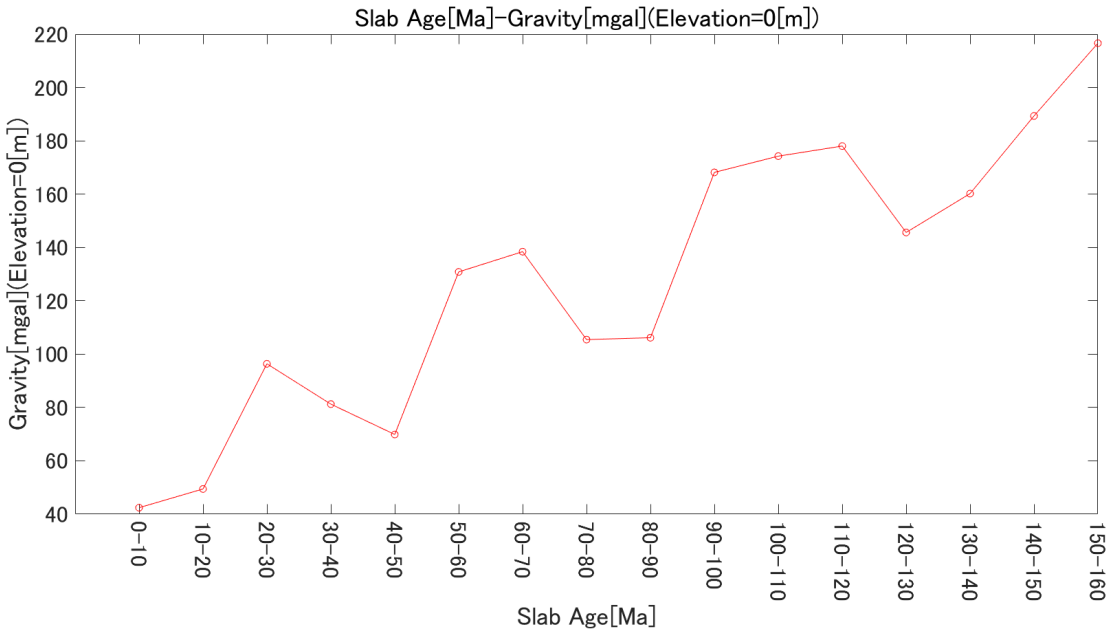

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[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG63] Dynamics in mobile belts

convener:Yukitoshi Fukahata(Disaster Prevention Research Institute, Kyoto University), Ray Y Chuang(Department of Geography, National Taiwan University), Toru Takeshita(Department of Natural History Sciences, Graduate School of Science, Hokkaido University), Hikaru Iwamori(Earthquake Research Institute, The University of Tokyo)

The dynamic behaviors of mobile belts are expressed across a wide range of time scales, from the seismic and volcanic events that impact society during our lifetimes, to orogeny and the formation of large-scale fault systems which can take place over millions of years. Deformation occurs on length scales from microscopic fracture and flow to macroscopic deformation to plate-scale tectonics. To gain a physical understanding of the dynamics of mobile belts, we must determine the relationships between deformation and the driving stresses associated with plate motion and other causes, which are connected through the rheological properties of the materials. To understand the full physical system, an integration of geophysics, geomorphology, geology, petrology, and geochemistry is necessary, as is the integration of observational, theoretical and experimental approaches. In particular, rheological properties, which are physically affected by fluids in the crust and chemical reactions assisted by fluids, can be resolved only through such an interdisciplinary approach. After the 2011 great Tohoku-oki earthquake, large-scale changes in seismic activity and regional scale crustal deformation were observed, making present-day Japan a unique natural laboratory for the study of the dynamics of mobile belts. This session welcomes presentations from different disciplines, such as seismology, geodesy, tectonic geomorphology, structural geology, petrology, geochemistry and hydrology, as well as interdisciplinary studies, that relate to the dynamic behaviors of mobile belts.

[SCG63-19] Separation of Plastic, Viscous, and Elastic Strains From Observed GNSS Data in the Niigata-Kobe Tectonic Zone

*Yukitoshi Fukahata[1], Angela Meneses-Gutierrez[2,3], Takeshi Sagiya[3,4] (1.Disaster Prevention Research Institute, Kyoto University, 2.Institute for Advanced research, Nagoya University, 3.Disaster Mitigation Research Center, Nagoya University, 4.Graduate School of Environmental Studies, Nagoya University)

[SCG63-20] Elasto-plastic behavior of the concentrated deformation zone based on baseline strain rates

*Takeshi Sagiya[1], Angela Meneses-Gutierrez[1,2] (1.Disaster Mitigation Research Center, Nagoya University, 2.Institute for Advanced Research, Nagoya University)

[SCG63-21] Geodetic evidence of time-dependent viscoelastic interseismic deformation driven by megathrust locking in the southwest Japan subduction zone

*Shaoyang Li[1], Jun'ichi Fukuda[1], Onno Oncken[2] (1.The University of Tokyo, Earthquake Research Insititute, 2.German Geoscience Research Center)

[SCG63-22] Horizontal deformation in NE Japan from triangulation, trilateration, and GPS from 1890 to 2010

*Angela Meneses-Gutierrez[1,2], Paul Segall[3], Takeshi Sagiya[2,4] (1.Institute for Advanced Research, Nagoya University, 2.Disaster Mitigation Research Center, Nagoya University, 3.Stanford University, 4.Graduate School of Environmental Studies, Nagoya University)

[SCG63-23] **Interseismic slip of the Shanchiao fault in northern Taiwan from GPS and leveling measurements**

*Yining Ke[1], Wu-Lung Chang[1] (1.Department of Earth Sciences, National Central University)

[SCG63-24] Decomposition of elastic potential energy and the meaning of the energetics-based failure stress criterion

*Mitsuhiro Matsu'ura[1], Toshiko Terakawa[2] (1.Institute of Statistical Mathematics, 2.Nagoya University)

Separation of Plastic, Viscous, and Elastic Strains From Observed GNSS Data in the Niigata-Kobe Tectonic Zone

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We generally consider the following three mechanisms for crustal deformation: elastic, viscous, and plastic deformation. The viscous deformation and the plastic deformation are collectively called inelastic deformation. Geodetic data, which measure crustal deformation, include the deformation due to all these three mechanisms, and the separation to each component has been a challenging problem.

In a simple form, this problem arises in the analysis of crustal deformation after a large earthquake, or more generally, during an earthquake cycle. Fukahata et al. (2004, GJI) developed an inversion method to separately estimate elastic deformation due to slip on the plate interface and viscous deformation due to the viscoelastic relaxation during an earthquake cycle. Yamagiwa et al. (2015, GRL) applied the method to GNSS data associated with the co- and post-seismic deformation of the 2011 Tohoku-oki earthquake. The separation of these components in general form has been more difficult. However, Noda and Matsu'ura (2010, GJI) developed a formulation to separately estimate elastic deformation and inelastic deformation from observed geodetic data. Recently, from the comparison of GNSS data in the northern NKTZ before and after the 2011 Tohoku-oki earthquake, Meneses-Gutierrez and Sagiya (2016, EPSL) have successfully separated inelastic deformation from observed geodetic data. The strain-rate paradox of Japan (Ikeda 1996, Active Fault Res), the geodetically estimated east-west contraction rate is nearly one order faster than the geological one, is also strongly related to this separation problem, because the geodetic data include deformation of all the mechanisms, while the geologically estimated contraction rate only reflects inelastic deformation.

In this study, we succeed in separating plastic deformation as well as viscous deformation in the northern NKTZ using GNSS data before and after the 2011 Tohoku-oki earthquake, under the assumptions that elastic deformation is principally caused by the plate coupling along the Japan trench and that plastic deformation ceased after the Tohoku-oki earthquake due to the stress drop caused by the earthquake. The cessation of plastic deformation can be understood with the concept of stress shadow used in the field of seismic activity. The separated strain rates are about 30 nanostrain/yr both for the plastic deformation in the preseismic period and for the viscous deformation in both the pre- and post-seismic periods, which means that the inelastic strain rate in the northern NKTZ is about 60 and 30 nanostrain/yr in the pre- and post-seismic periods, respectively. This result requires the revision of the strain rate paradox in Japan. The strain rate was exceptionally faster before the Tohoku-oki earthquake due to the effect of plastic strain, and the discrepancy between the geodetic and geologic strain rates is much smaller in usual time, when the plastic strain is off. In oder to estimate the onset timing of plastic deformation, the information on stress history is essentially important.

Keywords: plastic strain, inelastic strain, Niigata-Kobe Tectonic Zone, CFF, strain-rate paradox, Tohoku-oki earthquake

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Elasto-plastic behavior of the concentrated deformation zone based on baseline strain rates

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Along the Japan Sea coast of central-northeasth Japan, a concentrated deformation zone was identified based on GPS observation and named as the Niigata-Kobe Tectonic Zone (NKTZ) (Sagiya et al., 2000). Meneses-Gutierrez and Sagiya (2016) found inelastic deformation occurs within NKTZ through a comparison of preseismic and postseismic deformation of the 2011 Tohoku-oki earthquake. In order to achieve higher spatial resolution of the inelastic deformation and to better understand mechanical properties of NKTZ, we conduct a baseline analysis of GNSS data. By comparing the linear strain rates for the neighboring two baselines in a similar direction, we can obtain a plot representing possible effects of inelastic deformation. From the data plot for two baselines, one across and the other outside the NKTZ, strain rates for the two baselines are proportional each other under extension after 2011. On the other hand, under contraction before 2011, strain rates in NKTZ shows almost a constant value regardless of the strain rate outside. The result implies that the NKTZ behaves as an elasto-plastic body and yielding occurred before 2011. These observations provide a new opportunity to resolve inelastic behavior of the Japanese island arc crust.

Keywords: elasto-plastic behavior, concentrated deformation zone, baseline strain rate

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Geodetic evidence of time-dependent viscoelastic interseismic deformation driven by megathrust locking in the southwest Japan subduction zone

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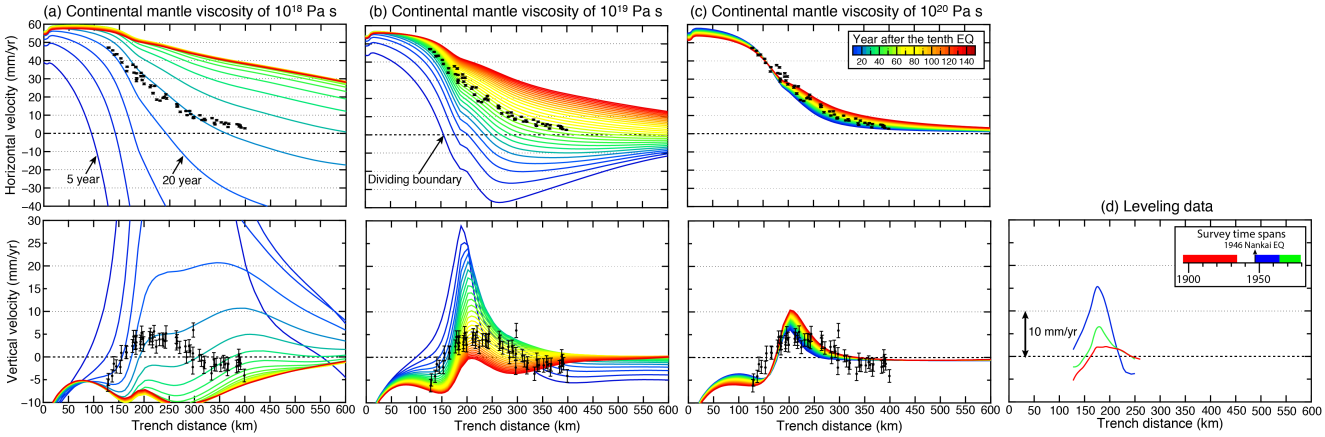
The time-variable features of interseismic deformation in subduction zones are poorly understood and commonly ignored. Here, by incorporating century-long leveling data and contemporary global navigation satellite systems (GNSS) velocities, we investigate the temporal evolution of interseismic deformation in southwest Japan using two-dimensional viscoelastic earthquake-cycle models. We find that a steady-state continental mantle viscosity of 10^{19} Pa s is required to explain these two geodetic datasets. Model with this preferred viscosity predicts significant variations in the surface velocity field throughout the entire interseismic period due to viscous mantle flow driven by ongoing megathrust locking. This finding indicates that the multiyear GNSS-derived velocity field represents a snapshot of time-varying interseismic deformation. Furthermore, we explore the impacts of locking depth and locking time (the duration of megathrust locking) on surface deformation patterns. We find that the horizontal deformation in the backarc region are sensitive to the locking time due to the ongoing interseismic viscoelastic relaxation, and insensitive to locking depth due to the distance to the plate interface. Vertically, the locking depth controls the trench distance of the peak uplift signal, and the locking time primarily influences the magnitude of the vertical velocities. Taken together, our work highlights the importance of the interseismically relaxing mantle and the necessity of considering such an effect in determining the current locking state along the Nankai subduction zone.

Keywords: leveling and GNSS data, interseismic viscoelastic relaxation, time-dependent deformation, earthquake cycle, Nankai subduction zone, interseismic locking



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Horizontal deformation in NE Japan from triangulation, trilateration, and GPS from 1890 to 2010

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Crustal deformation has been transformed in past decades by the availability of continuous GPS data. Time series analysis of GPS data often assumes strain accumulation at a steady rate. In the case of NE Japan, analysis of horizontal GPS data from 1996-2010 revealed crustal accelerations in the decade prior to the 2011 Tohoku-oki earthquake (Mavrommatis et al., 2014). Whether this represented precursory activity before the 2011 Tohoku-oki earthquake is open to debate. The limited duration of the observations makes it difficult to assess how these transients relate to the full interseismic period.

Historical geodetic data are available in Japan since the end of the 19th century. The data consist of two triangulation surveys (1890-1912; 1948-1968) and two trilateration campaigns in the latter half of the 20 th century (1973-1985; 1977-1994). Examination of historical data in combination with the GPS data can provide a way to evaluate the velocity and strain distributions in the last 100 years and elucidate whether the acceleration observed prior to the 2011 Tohoku-oki earthquake represents a short-term transient deformation or not. Thus, we analyze horizontal deformation in NE Japan utilizing all the geodetic sets available.

We estimate horizontal displacement fields in NE Japan for the historical geodetic data using the method developed by Yu and Segall (1996). In this, a denuisancing procedure is performed so that the dependency of the data on station coordinates is projected out of the system of equations and the horizontal displacement fields can be estimated directly. These results are transformed into average velocities by assuming steady deformation over the survey period. The null space inherent in trilateration and triangulation data is constrained by GPS velocities in either the early GPS (1996-2000) period or the period prior to the 2011 Tohoku-oki earthquake (2009-2010).

In this presentation, we will present the horizontal displacement fields for Northeast Japan in the last 100 years. We will offer a comparison of the historical data with the contemporaneous GPS data, as well as an evaluation of the strain state in NE Japan.

Keywords: Crustal deformation, Geodetic data, Interseismic period, Transient deformation

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Interseismic slip of the Shanchiao fault in northern Taiwan from GPS and leveling measurements

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The Shanchiao fault is a major late-Pleistoene active structure responsible for accommodating the extension across the Taipei metropolitan area in northern Taiwan, and its left-lateral normal faulting together with clockwise block rotation have been revealed from regional structural geology, paleomagnetism, and GPS measurements. This study presents Global Positioning System (GPS) measurements for the period 2006–2015 at 106 sites in northern Taiwan and uses horizontal GPS observations and elastic half-space dislocation models to evaluate the interseismic slip of the Shanchiao fault. We first performed model resolution tests for fault slip distribution based on scenarios of subsurface fault geometry that were proposed by previous geologic and geophysical researches. With a dimension of 3×3 km^2 for each fault patch, the results show that our GPS measurements can resolve slips no deeper than 9 km. The method of Tikhonov regularization was then performed to stabilize nonnegative linear inversion for left-lateral normal slip distribution. Our best model suggests two fault planes dipping 75º to SE at depths of 3-6 km, with the north segment having normal slip rates of 1.43±0.71 cm/yr and the south segment having left-lateral normal rates of 0.82±0.75 cm/yr. Moreover, a shallow-dip (25ºSE) plane at depths of 6-15 km with mainly left-lateral slips of ~2.5 cm/yr may correspond to the observed regional clockwise rotation. The residuals of GPS vertical and precise leveling measurements from the best predicted vertical motion reveal uplift at the Linko tableland and the Tatun volcano area and subsidence in the Taipei basin and the northeast coastline in the period of 2006–2015. For future work we will try to include volcanic source model to better resolve the interseismic fault slip from the surface deformation field.

Keywords: Shanchiao Fault, Active fault, Resolution, GPS and Leveling

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Decomposition of elastic potential energy and the meaning of the energetics-based failure stress criterion

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Recently, we proposed an energetics-based failure stress (EFS) and demonstrated that its change (ΔEFS) associated with a main shock gives a new rational metric for evaluating aftershock generation (Terakawa, Matsu'ura & Noda, EPSL, 2020). The EFS is defined in a similar form to the well-known Coulomb failure stress (CFS = shear stress −fault strength), but the shear stress is replaced with the square root of the second invariant of deviatoric stress tensor, which is proportional to the shear strain energy density. The expression of ΔEFS can be reduced to that of ΔCFS in a special case, but the meaning of ΔEFS is essentially different from that of ΔCFS. In this presentation, we make clear the rationale and meaning of EFS through theoretical considerations on the elastic potential energy density and the decomposition of elastic stiffness tensor.

The potential energy density U of linear elastic forces is generally represented in the quadratic form of strain tensor components ε_{ij} as $U = C_{ijkl}\,\varepsilon_{ij}\,\varepsilon_{kl}$, where the fourth-order tensor C_{ijkl} denotes the elastic stiffness. Then, by definition, the stress tensor components σ_{ij} are given by the partial derivative of U with respect to ε_{ij} as $\sigma_{ij} = C_{ijkl}\,\varepsilon_{kl}$. When the medium is isotropic, the stiffness tensor C_{ijkl} is expressible as a linear combination of two independent symmetric tensors (Walpole, Proc. R. Soc. Lond., 1984), and so the elastic potential energy density U can be decomposed into two independent parts; the volumetric part U_v and the shearing part U_s (Matsu'ura, Noda & Terakawa, Tectonophysics, 2019). In such a case, the partial derivative of U_v with respect to volumetric deformation (the first invariant of strain tensor) gives the mean normal stress (one-third of the first invariant of stress tensor). Similarly, the partial derivative of U_s with respect to shearing deformation (the square root of twice the second invariant of deviatoric strain tensor) gives the shear stress (the square root of twice the second invariant of deviatoric stress tensor). These generalized forces to volumetric and shearing deformations in Lagrangian mechanics are used for constructing the energetics-based failure stress EFS.

The elastic property of the Earth's crust is not necessarily isotropic, and so, strictly speaking, we may not decompose the elastic potential energy density into two independent parts. However, even in such a case, it is possible to define the closest isotropic fourth-order tensor to a given anisotropic stiffness tensor (Moakher, Quart. J. Mech. Appl. Math., 2008). Using the closest isotropic fourth-order tensor, we can decompose the elastic potential energy density into two independent parts, and define the generalized forces needed for constructing the EFS in a similar way to the isotropic case.

The expression of ΔEFS, which is a metric for evaluating aftershock generation, can be reduced to the maximum change in shear stress (the square root of the second invariant of deviatoric stress change tensor) recommended by DeVries et al. (Nature, 2018), when the level of background deviatoric stress is zero and the coseismic changes in confining pressure and pore-fluid pressure are negligible. On the other hand, when the level of background deviatoric stress is much higher than the maximum change in stress, it can be reduced to the ΔCFS on the assumption that both the background deviatoric stress and the coseismic deviatoric stress change are in the state of pure shear. From an energetic point of view, however, there is not much meaning in doing such an interpretation of ΔEFS , because the shear stress in the definition of EFS is the generalized force to shearing deformation, and its coseismic change is simply

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evaluated by the inner product of the deviatoric stress change tensor and the normalized background deviatoric stress tensor, which can be estimated from the CMT data inversion of background seismic events (Terakawa & Matsu'ura, GJI, 2008; Tectonics, 2010).

Keywords: Elastic potential energy, Decomposition of elastic stiffness tensor, Energetics-based failure stress, Aftershock distribution

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[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG64] Crust-mantle connections

convener:Yoshihiko Tamura(Research Institute for Marine Geodynamics, Japan Agency for Maine-Earth Science and Technology), Osamu Ishizuka(Geological Survey of Japan, AIST)

The western portion of the Pacific Plate, the oldest oceanic plate in the world, has been drilled several times and, based on Ocean Drilling Program (ODP) Site 801, an understanding of its layers, from pelagic clay through chert to alkali basalts and tholeiitic mid-ocean ridge basalts (MORB), has been established. This oldest oceanic plate is experiencing a renaissance and we propose a strategy to drill the most suitable three sites to recover specific parts of the plate to continue its renaissance. This submitted IODP preproposal is entitled The Renaissance of the Oldest Oceanic Plate: REY (Rare Earth elements and Yttrium) rich Mud, Radiolarite of Jurassic-Cretaceous Boundary (JKB), and Jurassic Oceanic Crust without Moho. The drilling sites, MM, MAT, and MINA, target (1) the most complete sedimentary sequence of pelagic clay including REY-rich mud, (2) newly found outcrops of the Jurassic-Cretaceous boundary (JKB), and (3) MORB tholeiites without Moho, respectively. This session invite scientists who are interested in these exciting drillings.
It is common knowledge that the Moho is the boundary between the crust and the Earths mantle, discovered by and named after the Croatian seismologist Andrija Mohorovicic. The oceanic Moho is defined by seismic reflection images, but seismic profiles generally show that Moho reflections are not universal. Where the Moho can be detected clearly the crust is thicker. A good example is the profile from Kaneda et al. (2010) near Minami-Tori Shima, which is the main motivation for drilling at Site MINA. The session also seeks to explore the crust-mantle connections among ophiolites, at divergent and convergent plate boundaries and ocean island settings based on petrology, geochemistry, geophysics, geochronology, and geodynamics studies.

[SCG64-01] Synmagmatic faulting partly controls fluid-melt-peridotite reaction and lithospheric melts generation at the crust-mantle transition

*Mathieu Rospabe[1], Mathieu Benoit[2], Georges Ceuleneer[2], Mary-Alix Kaczmarek[2] (1.Research Institute for Marine Geodynamics (IMG), Japan Agency for Marine-Earth Science and Technology, 2.Géosciences Environnement Toulouse (GET), Observatoire Midi-Pyrénées, Université de Toulouse, CNRS, IRD)

[SCG64-02] Multi-stage metasomatism and metamorphism of the Mesoarchean Ulamertoq ultramafic rocks in southern West Greenland

*Ikuya Nishio[1], Tomoaki Morishita[1], Akihiro Tamura[1], Juan Miguel Ramirez Guotana[1], Kenichiro Tani[2], Yumiko Harigane[3], Kristoffer Szilas[4], D. Graham Pearson[5] (1.Kanazawa University, 2.Department of Geology and Paleontology, National Museum of Nature and Science, 3.Institute of Geology and Geoinformation Geological Survey of Japan/AIST, 4.University of Copenhagen, 5.University of Alberta)

[SCG64-03] Arc magma genesis: evidence from Kibblewhite Volcanic Complex in the Kermadec arc, New Zealand

★Invited Papers

*Yasuhiro Hirai[1,2], Yoshihiko Tamura[2], Kaj Hoernle[3], Reinhard Werner[3], Folkmar Hauff[3], Christian Timm[4], Bogdan Vaglarov[2], Qing Chang[2], Takashi Miyazaki[2], Jun-Ichi Kimura[2], Takeshi Hanyu[2] (1.Graduate School of Natural Science and Technology, Kanazawa University, Japan, 2.Research Institute for Marine Geodynamics (IMG), Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokosuka, Kanagawa, Japan, 3.GEOMAR Helmholtz Centre for Ocean Research, Kiel, Germany, 4.GNS Science, Lower Hutt, New Zealand)

[SCG64-04] The Atlantis Bank Batholith, SW Indian Ridge, the Link Between Lower Crustal Accretion at High and Low Melt Supply

*Henry J Dick[1] (1.Woods Hole Oceanographic Institution)

[SCG64-05] Oceanic lower crust and uppermost mantle of the Shikoku Basin: insights from expeditions to Mado Megamullion

*Yasuhiko Ohara[1,2,3], Kyoko Okino[4], Norikatsu Akizawa[4], Masakazu Fujii[5], Yumiko Harigane[6], Ken-ichi Hirauchi[7], Osamu Ishizuka[6], Shiki Machida[8], Katsuyoshi Michibayashi[3], Alessio Sanfilippo[9], Sani Camilla[9], Snow E. Jonathan[10], Kenichiro Tani[11], Hiroyuki Yamashita[12] (1.Hydrographic and Oceanographic Department of Japan, 2.Japan Agency for Marine-Earth Science and Technology , 3.Nagoya University, 4.Atmosphere and Ocean Research Institute, University of Tokyo, 5.National Institute of Polar Research , 6.Geological Survey of Japan, AIST, 7.Shizuoka University, 8.Chiba Institute of Technology, 9.University of Pavia, 10.Louisiana State University, 11.National Science Museum, 12.Kanagawa Prefectural Museum of Natural History)

[SCG64-06] Petrological characteristics of serpentinized peridotites dredged from oceanic core complexes in the Shikoku Basin

Izumi Segawa[1], *Ken-ichi Hirauchi[1], Yasuhiko Ohara[2,3], Yui Kouketsu[3], Katsuyoshi Michibayashi[3] (1.Department of Geosciences, Faculty of Science, Shizuoka University, 2.Hydrographic and Oceanographic Department of Japan, 3.Department of Earth & Planetary Sciences, Graduate School of Environmental Studies, Nagoya University)

Synmagmatic faulting partly controls fluid-melt-peridotite reaction and lithospheric melts generation at the crust-mantle transition

*Mathieu Rospabe[1], Mathieu Benoit[2], Georges Ceuleneer[2], Mary-Alix Kaczmarek[2]

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The transition between the upwelling and partially molten peridotitic mantle and the accreting gabbroic lower crust beneath oceanic spreading centres is supposed to be a major interface in terms of chemical and thermal exchanges between the inner part of the Earth and external envelopes. In most ophiolites worldwide as well as at some sites along present-day mid-ocean ridges, the mantle-crust transition is systematically made of dunites developed from reaction between melts and mantle harzburgites and of troctolitic-gabbroic intrusions.

The petrological processes that originate the dunitic mantle-crust transition zone (DTZ) can be studied in the Maqsad area of the Oman ophiolite where is exposed a paleo-mantle diapir that fed with MOR-like melts the former spreading centre. Above the central part of the paleo-diapir, the DTZ reaches 300 to 400 m in thickness. It has been alternatively attributed to a consequence of peridotite reactional melting or to the accumulation of olivine from Mg-rich melts whether a combined origin is also possible (Abily and Ceuleneer, 2013, *Geology*). Variable interstitial minerals fractionation during melt migration between olivine grains (or melt-rock reaction), comprising mainly plagioclase, clinopyroxene, orthopyroxene and pargasitic amphibole, is partly responsible of the high petrological and geochemical variability observed at Moho level (Rospabé et al., 2017, *Geology*; 2018, *Geochem. Cosmochim. Acta*).

The DTZ is frequently cross-cut by faults and minor fractures that seem to have induced a displacement limited to a few meters where measurable. Faults are filled with serpentine and carbonate, and surrounded by a few-meters thick serpentinization aureole. At first glance, it supports a late origin postdating the magmatic accretion of the mantle-crust transition zone. However, the chemical variations observed along the Maqsad DTZ define tendencies with a characteristic vertical scale of few tens of meters, correlated to the distribution of the faults or fracture zones. The fact that (1) not only fluid-mobile elements but also immobile elements (e.g. REE, HFSE) are concerned, and (2) the faults are cross-cut by ridge-trending gabbroic dikes, highlights that the faults were ridge-related and developed at an early, high temperature magmatic stage before the cooling and alteration of this oceanic lithosphere fragment (Rospabé et al., 2019a, *Earth Planet. Sci. Lett.*; 2019b, *Lithos*). In the same area, a well-exposed outcrop of the lowermost oceanic crust likewise recorded strong interplays between ridge-oriented faults and, in the presence of water, crystallizing gabbros (Abily et al., 2011, *Geology*).

We infer that synmagmatic faults may enhance melt migration and extraction from the mantle to the crust and deep hydrothermal fluids introduction down to the Moho level. Faults could be the main places for fluid-melt hybridization and fluid-melt-rock reaction and allowing to the generation of hydrous, lithospheric melts beneath oceanic spreading centres. In other words, synmagmatic faults may directly contribute to the magmatic accretion of the oceanic lithosphere and subsequently significantly impacting the MORB variability and chemical budgets along present-day mid-ocean ridges.

Keywords: Oman ophiolite, dunitic mantle-crust transition zone, synmagmatic faults, fluid-melt-rock reactions

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Multi-stage metasomatism and metamorphism of the Mesoarchean Ulamertoq ultramafic rocks in southern West Greenland

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Archean geological units are widely exposed in southern West Greenland. Ultramafic rocks occur as large, lens-shaped bodies within gneisses and/or granitic rocks. The largest ultramafic body - the Ulamertoq peridotite body (1 km x 1.5 km) - occurs in the Mesoarchean Akia Terrane of the region. The origin of these ultramafic rocks and their tectonic setting remain unclear: (i) residues after partial melting (Friend et al., 2002; Friend and Nutman, 2011), or (ii) ultramafic cumulates formed by mafic mineral accumulation or crystallization from komatiitic melts (Szilas et al., 2018). However, anthophyllite-bearing phlogopitite and amphibole-rich rock layers are observed along the boundary between the host orthogneiss and the ultramafic body. Orthopyroxenite veins/networks are also observed near the country rock contact. These petrological characteristics indicate that the Ulamertoq peridotites experienced metasomatic events involving the surrounding granitic rock/gneiss. Moreover, hydrous minerals such as phlogopite and amphibole, as well as orthopyroxene are not restricted to the boundary areas but are heterogeneously distributed throughout the body. In terms of their geochemistry, HFSEs (Ti and Zr) abundance of whole-rock and minerals of the amphibole-rich rock along the surrounding metamorphic rock are low. On the other hand, an Opx-nite vein near the boundary shows positive Sr, Zr anomalies and TiO_2 contents of amphibole are high. These features suggest that hydrous mineral-rich layers and orthopyroxenite veins/networks were formed by invading hydrous fluids rich in alkalis and by silica-rich melts, respectively. Orthopyroxene in the peridotite main body, far from the contact with the orthogneiss, occurs as fine grained and/or poikilitic aggregates, with low Cr_2O_3 and Al_2O_3 contents, consistent with metasomatic secondary/metamorphosed orthopyroxene (Arai,1974; Ishimaru et al., 2007). Hence, the whole rock chemical trend is likely consistent with metasomatic addition of amphibole and orthopyroxene to the dunitic rocks rather than partial melting trends. On the other hand, titanian clinohumite, ilmenite, magnetite-inclusions in olivine and high forsterite contents of olivines in a dunite indicate their deserpentinized origin. The dehydration process is supported by the similar trace elements abundance of orthopyroxene in titanian clinohumite-bearing dunite and harzburgite to deserpentinized peridotites observed in the Almirez massif (Marchesi et al., 2013). In conclusion, the Ulamertoq peridotites experienced multiple stages of metasomatic and metamorphic events: initial hydration followed by dehydration at 800-900˚ under <2GPa conditions (Nishio et al., 2019), the early stage metasomatism that formed amphibole and orthopyroxene in the main peridotite body, and finally followed by the latest stage of metasomatism related to granitic rock intrusion [600-650˚C and below 1 GPa conditions (Whyatt et al., 2020)]. It should be emphasized that the effect of geochemical and petrological modifications due to multi-stages of metasomatism and metamorphism are required to constrain the origin of the ultramafic body.

Keywords: Ultramafic rock, Metasomatism, Archean, Greenland, Deserpentinization

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Arc magma genesis: evidence from Kibblewhite Volcanic Complex in the Kermadec arc, New Zealand

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It has been proposed that basaltic and andesitic primary magmas could be produced simultaneously in the mantle wedge of subduction zones where the overlying crust is thin (Tamura et al., 2016; 2019). To examine this hypothesis and further investigate arc magma genesis, Kibblewhite Volcanic Complex in the southern Kermadec arc, New Zealand, has been studied. Recent seismic studies reveal that the Kermadec arc is one of the oceanic arcs which have the thinnest crust in the world (9-12 km; Bassett et al., 2016). Dredge surveys during the R/V SONNE SO-255 expedition in 2017 recovered volcanic rocks showing variable SiO_2 contents (48-71 wt.% SiO_2) and degree of differentiation (100*Mg/[Fe+Mg] = 28-78) from the Kibblewhite Volcanic Complex. To investigate arc magma genesis beneath the Kibblewhite Volcanic Complex, extensive studies (petrography, mineral and whole-rock chemistry, and olivine-hosted melt inclusion analyses) have been performed on these samples.

A key conclusion is that both basaltic and andesitic primary melts are produced in the upper mantle beneath Kibblewhite Volcanic Complex. We show that olivine-saturated andesite lavas (magnesian andesites) of the volcano are derived from andesitic primary melts and their origin is closely related to the thin crustal thickness of the Kermadec arc. Primary basaltic melts are also discovered from melt inclusions in forsteritic olivines (Fo_{91-92}). Trace elemental characteristics and fractional crystallization models imply that the two primary melts generate two differentiation trends; basaltic primary melts produce low-Mg andesitic magmas (basaltic andesites to andesites), and andesitic primary melts produce more silicic magmas (dacites to rhyolites) by fractional crystallization processes, respectively. Thus, we suggest that the differentiation of basaltic and andesitic primary melts could result in the bimodal magmatism of the southern Kermadec arc in general.

In the Izu-Ogasawara arc, it has been suggested that the middle crusts have magnesian andesite compositions (Tamura & Tatsumi, 2002). Occurrence of magnesian andesites beneath the arc which has thin crustal thickness could grow the middle crusts in the early stage of arc evolution (Tamura et al., 2016). Therefore, we propose that the magmatic evolution of the Kibblewhite Volcanic Complex represents the development of incipient oceanic arc and the formation of juvenile continental crust.

Keywords: Petrology, Subduction Zone, Arc Magmatism, Kermadec Arc, Kibblewhite Volcanic Complex

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The Atlantis Bank Batholith, SW Indian Ridge, the Link Between Lower Crustal Accretion at High and Low Melt Supply

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Atlantis Bank, an enormous elevated wave-cut platform shoaling to 700-m water depth, exposes a gabbro batholith that accreted in the lower ocean crust at ~18.4 mm/yr from 13.4 to 10.5 Ma on the SW Indian Ridge. It is situated in a region of anomalously elevated topography (~1 km) that extends from the Atlantis II to the Melville Transform (Yu and Dick, 2019). It overlies, and is intruded into fertile mantle lherzolite exposed along the wall of the Atlantis II Transform, representing near steady-state accretion of the lower crust (Dick et al., 2019a). There is a transform parallel three-hole transect extending for 2.2 km down its axis: including recently drilled 809-m deep IODP Hole U1473A, 158-m ODP Hole 1105A, and 1508-m ODP Hole 735B. With extensive seafloor mapping, it provides the first 3-D view of the upper levels of a 660-km^2 section of the lower crust. It is laterally and vertically zoned to dominantly oxide rich gabbros in its uppermost levels, representing a complex interplay of cyclic intrusion, and ongoing deformation, with km-scale upward and lateral permeable migration of interstitial melt. Transform wall dives over the gabbro-peridotite contact found only evolved gabbro intruded directly into the mantle near the transform. There was no high-level melt lens, and dikes cut the gabbros at the dike-gabbro transition. These gabbros crystallized at depth, and then were emplaced into the zone of diking by diapiric rise of a crystal mush, followed by crystal-plastic deformation and faulting. The residues to mass balance the crust to a parent melt composition then lie at depth below the center of the massif –likely near the crust-mantle boundary. Thus, MORB’ s erupted to the seafloor from >1,508 m below seafloor.

The batholith represents dynamic accretion, where extension across the plate boundary is accomplished by a combination of intrusion hypersolidus and sub-solidus crystal-plastic deformation at intermediate depth, and brittle deformation and dike intrusion at higher levels. It has as much in common with crust formed at the East Pacific Rise as it does with typical crust at the Mid-Atlantic Ridge. At the former lower crustal accretion is largely passive by direct intrusion of melt, and likely crystal-mush flow, with extension largely accommodated above the dike-gabbro transition by dike intrusion and brittle deformation. Melt lenses exist at the base of the crust, from where they are intruded to the seafloor with only minor modification occurring in a melt lens overlying a crystal mush zone at the dike-gabbro transition. Due to the melt lens, the dikes are generally cut by the gabbros. Hydrous alteration beneath the axis is very limited. Atlantis Bank is similar to the EPR in that a substantial portion of extension is accommodated by direct intrusion of melt, crystal mush flow, and both the EPR and the Atlantis Bank sections have undergone extensive km-scale late-stage melt transport that modified the overlying gabbros. Like the EPR, magmas are intruded to the seafloor directly from near the base of the crust.

By contrast, MAR lower crust drilled at 23˚N and Atlantis Massif experienced little high-temperature crystal-plastic deformation and limited late-stage melt transport. They contain primitive cumulates, and represent episodic intrusion, melt storage, and crystallization of parental MORB in thin crust below the dike-gabbro transition. Primitive gabbros and therefore storage of primitive melt occurred at all levels. Due to only episodic magmatism, individual intrusions crystallized rapidly, so that unlike Atlantis Bank, there were only short periods where extension could be accommodated by high-temperature crystal-plastic deformation, and tectonic extension was by brittle deformation. Consequently, greenschist facies alteration dominates down Hole 1309D at Atlantis Massif, as compared to largely high-temperature

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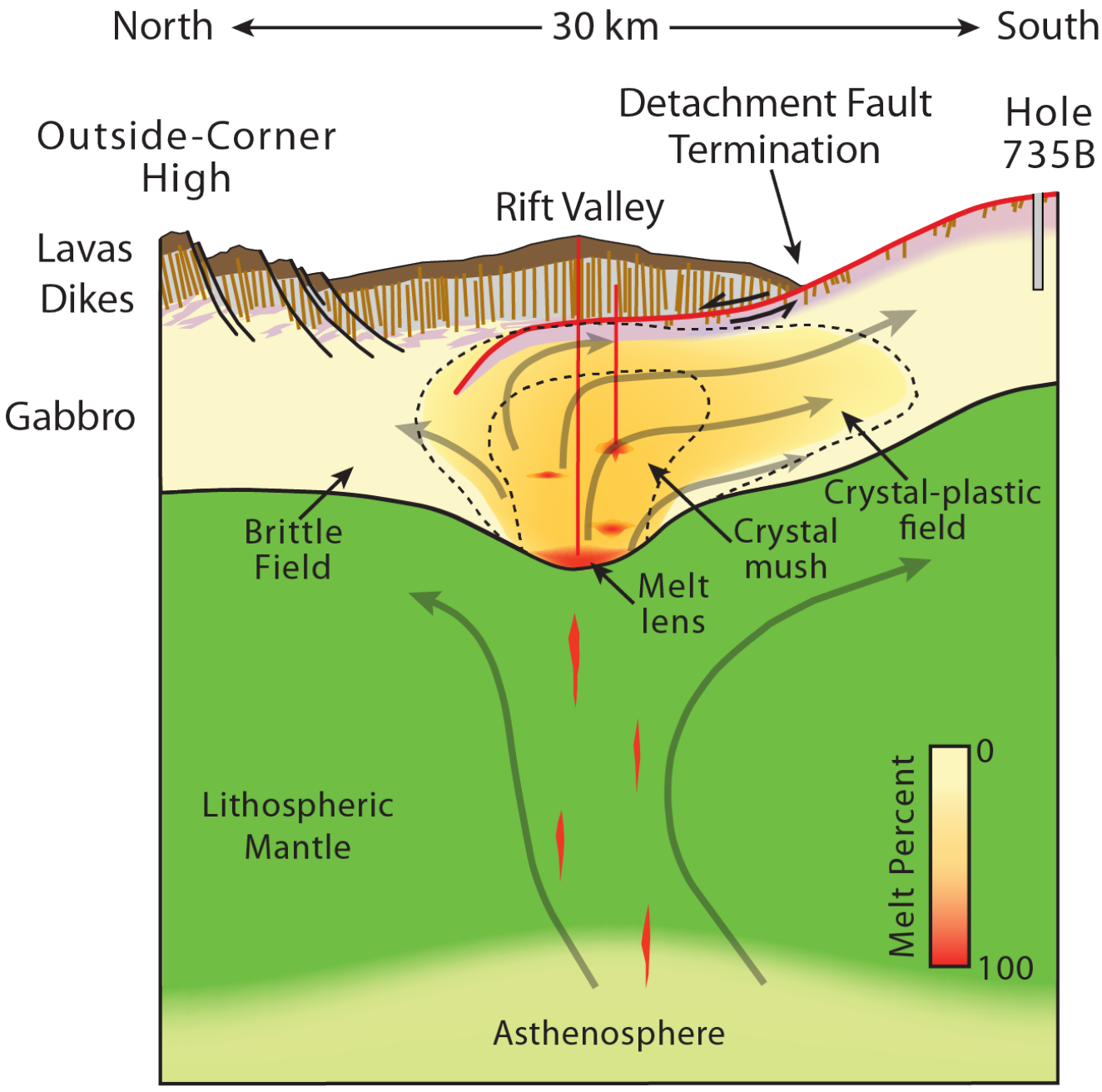
high-level amphibolite to granulite facies alteration at Atlantis Bank. There was no km-scale permeable melt transport and systematic enrichment of the upper levels of the massif in Fe and Ti to form massive oxide gabbros, as found at Atlantis Bank. Like the MAR localities, Atlantis Bank had no melt lens, and the dikes cut the gabbros as a result.

Keywords: Lower Ocean Crust, Gabbro, Melt Transport



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Oceanic lower crust and uppermost mantle of the Shikoku Basin: insights from expeditions to Mado Megamullion

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Oceanic core complexes (OCCs), or megamullions, are domal bathymetric highs with axis-normal corrugations, and with exposure of serpentinized peridotites and gabbroic rocks, interpreted as exhumed footwalls of low-angle detachment faults. OCCs provide a valuable opportunity to directly study the architecture of oceanic lithosphere, together with the tectono-magmatic processes associated with its formation and evolution. A significant fraction of the ocean floor is created in backarc basins where water plays a major role in generating backarc basin basalts, strikingly contrasting to magmatic process at mid-ocean ridges. The opportunity to sample the lower crust and upper mantle at OCCs formed in backarc basins is therefore important for understanding the formation of a large portion of the ocean basins.

The Shikoku Basin is considered as a typical backarc basin that ceased seafloor spreading at ~15 Ma. We noted the presence of OCCs there since early 2000’s. Following the first preliminary dredge survey in 2007, we conducted focused research programs as three cruises in 2018 and 2019 (KH-18-2, YK18-07 and YK19-04S) on the Shikoku Basin axial OCCs. These programs successfully confirmed the presence of two OCCs and a non-transform offset (NTO) massif in the southernmost segment of the Shikoku Basin extinct spreading axis. During these cruises, we performed geophysical mapping, dredging, as well as in situ observation and sampling with the DSV Shinkai 6500. One of the OCCs, named Mado Megamullion, is an ~20 km square domed high with axis-normal corrugations, located at an intersection of a short spreading segment (~30 km) and short transform fault (~45 km). Mado Megamullion and the NTO massif are both associated with high mantle Bouguer anomalies. This observation is consistent with the exposure of deep-seated gabbros and peridotites, commonly sampled with dredge as well as the Shinkai. Overall, the mineral compositions of Mado gabbros define chemical trends interpreted as derivative of melts modified by assimilation of mantle material at the crust-mantle boundary. The Mado peridotites include the plagioclase-bearing lherzolites that suggest melt stagnation and melt-rock reaction in the dying backarc spreading lithosphere. The scheduled YK20-05S cruise in 2020 April will collect more datasets on this OCC.

In this contribution, we will report the preliminary results of YK20-05S cruise, as well as the compilation of the available datasets, to understand the tectono-magmatic characteristics of Mado Megamullion.

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Keywords: Mado Megamullion, Shikoku Basin, Backarc basin, Oceanic lower crust and uppermost mantle

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Petrological characteristics of serpentinized peridotites dredged from oceanic core complexes in the Shikoku Basin

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In order to understand the structure of oceanic lithosphere and the nature of rheological weakening in oceanic detachment faults, we carried out petrographic, petrological, mineralogical analyses of mantle peridotites dredged from oceanic core complexes (Mado Megamullion and Non-Transform Offset Massif at 23°30′N) in the Shikoku Basin. The peridotites consist of harzburgite/lherzolite (H/L-type) or dunite (D-type), and represent refractory residues after low degrees of partial melting (8-14%). Mylonitic deformation at high temperatures leads to the formation of elongated porphyroclasts of pyroxenes and spinel, defining foliation. The mylonitic foliation is cut by gabbroic veins consisting of amphibole, chlorite and diopside. The peridotites undergo significant shallow serpentinization under hydrostatic conditions, which produces lizardite characterized by mesh textures and bastite. The pseudomorphic serpentinites are replaced mainly by talc, resulting in the formation of localized share zone. These results suggest that hydrous minerals formed through hydrothermal and metasomatic alteration of peridotites play a role in contributing to long-term strain localization into a single detachment fault.

Keywords: oceanic core complex, peridotite, metasomatism, serpentinization

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[E] Oral | S (Solid Earth Sciences)：S-CG Complex & General

[S-CG64] Crust-mantle connections

convener:Yoshihiko Tamura(Research Institute for Marine Geodynamics, Japan Agency for Maine-Earth Science and Technology), Osamu Ishizuka(Geological Survey of Japan, AIST)

The western portion of the Pacific Plate, the oldest oceanic plate in the world, has been drilled several times and, based on Ocean Drilling Program (ODP) Site 801, an understanding of its layers, from pelagic clay through chert to alkali basalts and tholeiitic mid-ocean ridge basalts (MORB), has been established. This oldest oceanic plate is experiencing a renaissance and we propose a strategy to drill the most suitable three sites to recover specific parts of the plate to continue its renaissance. This submitted IODP preproposal is entitled The Renaissance of the Oldest Oceanic Plate: REY (Rare Earth elements and Yttrium) rich Mud, Radiolarite of Jurassic-Cretaceous Boundary (JKB), and Jurassic Oceanic Crust without Moho. The drilling sites, MM, MAT, and MINA, target (1) the most complete sedimentary sequence of pelagic clay including REY-rich mud, (2) newly found outcrops of the Jurassic-Cretaceous boundary (JKB), and (3) MORB tholeiites without Moho, respectively. This session invite scientists who are interested in these exciting drillings.
It is common knowledge that the Moho is the boundary between the crust and the Earths mantle, discovered by and named after the Croatian seismologist Andrija Mohorovicic. The oceanic Moho is defined by seismic reflection images, but seismic profiles generally show that Moho reflections are not universal. Where the Moho can be detected clearly the crust is thicker. A good example is the profile from Kaneda et al. (2010) near Minami-Tori Shima, which is the main motivation for drilling at Site MINA. The session also seeks to explore the crust-mantle connections among ophiolites, at divergent and convergent plate boundaries and ocean island settings based on petrology, geochemistry, geophysics, geochronology, and geodynamics studies.

[SCG64-07] Was the Jurassic–Cretaceous boundary a critical event for marine life in the pelagic Panthalassa?

★Invited Papers

*Atsushi Matsuoka[1] (1.Department of Geology, Faculty of Science, Niigata University)

[SCG64-08] The Renaissance of the oldest oceanic plate: Perspective of REY-rich mud as a paleoceanographic archive in a pelagic realm of the Pacific Ocean

★Invited Papers

*Erika Tanaka[1], Kazutaka Yasukawa[2,1,3], Kentaro Nakamura[1], Junichiro Ohta[2,3], Tatsuo Nozaki[4,2,5,3], Yoichi Usui[4], Koichiro Fujinaga[3,2], Koichi Iijima[4], Yasuhiro Kato[2,1,3] (1.Department of Systems Innovation, School of Engineering, The University of Tokyo, 2.Frontier Research Center for Energy and Resources, School of Engineering, The University of Tokyo, 3.Ocean Resources Research Center for Next Generation, Chiba Institute of Technology, 4.Submarine Resources Research Center, Japan Agency for Marine-Earth Science and Technology, 5.Department of Planetology, Faculty of Science, Kobe University)

[SCG64-09] REY-rich mud in the western North Pacific Ocean: An overview and implication for Earth system dynamics

★Invited Papers

*Yasuhiro Kato[1,2], Kazutaka Yasukawa[1,2], Junichiro Ohta[1,2], Erika Tanaka[1], Kazuhide Mimura[1], Koichiro Fujinaga[2,1], Kentaro Nakamura[1] (1.Graduate School of Engineering, University of Tokyo, 2.ORCeNG, Chiba Institute of Technology)

[SCG64-10] The Renaissance of the Oldest Oceanic Plate: Jurassic Oceanic Crust without Moho

*Yoshihiko Tamura[1], Mathieu Rospabe[1], Kentaro Kaneda[2], Alexander Nichols[3], Gou Fujie[1], Eiichi TAKAZAWA[4], Katsuyoshi Michibayashi[5], Shuichi Kodaira[1] (1.Research Institute for Marine Geodynamics, Japan Agency for Maine-Earth Science and Technology, 2.Japan Coast Guard, 3.University of Canterbury, New Zealand, 4.Niigata University, 5.Nagoya University)

[SCG64-11] Magma genesis model of the subduction zones based on hydrous melting experiments of a mantle peridotite

*Eiichi Takahashi[1], Jintuan Wang[1] (1.Guangzhou Institute of Geochemistry, Chinese Academy of Science)

[SCG64-12] The tectonic-magmatic characteristics in the Kamchatka: Implications for the dynamics around the northern edge of Pacific Plate

*Tatsuji Nishizawa[1], Hitomi Nakamura[2,3,4,5], Hikaru Iwamori[3,4,6] (1.Volcanic Fluid Research Center, School of Science, Tokyo Institute of Technology, 2.Institute of Earthquake and Volcano Geology, Geological Survey of Japan, AIST, 3.Department of Solid Earth Geochemistry, Japan Agency for Marine-Earth Science and Technology, 4.Depeartment of Earth and Planetary Sciences, School of Science, Tokyo Institute of Technology, 5.ORCeNG, Chiba Institute of Technology, 6.Earthquake Research Institute, The University of Tokyo)

Was the Jurassic–Cretaceous boundary a critical event for marine life in the pelagic Panthalassa?

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It is an urgent task for Earth scientists to determine the appropriate Global Boundary Stratotype Section and Point (GSSP) for the Jurassic–Cretaceous boundary (JKB) as it is the only GSSP in Phanerozoic not to be anchored yet. The JKB is defined as the base of the Berriasian Stage. In 2016, it was formaly decided by the Berriasian Working Group in the International Subcommission on Cretaceous Stratigraphy to use the base of the *Calpionella alpina* Subzone as the primary marker. This definition can only be satisfactorily applied to shallow marine deposits within the Western Tethys, North Atlantic and central-south America. Unfortunately, the primary marker taxon cannot be found in the Pacific and circum-Pacific regions. We are still looking for an alternative marker suitable for the JKB in the Pacific.

Radiolarians are good candidates for defining the JKB because they are widespread and can be found in both shallow and deep sedimentary facies worldwide. Pelagic sequences across the JKB have been reported in ODP/International Ocean Drilling Program (IODP) sites in the western Pacific and land sections in Japan, the Philippines, southern Tibet, Oman and other locations. The evolutionary first appearance datums (FADs) within firmly recognized lineages are extremely valuable for difining radiolarian zones.

Although the JKB is a boundary between geological periods, no significant turnover of pelagic biota has been reported from the Panthalassa. This is principally because the age of the JKB has not been constrained in the pelagic Panthalassa. Therefore, some key questions have not been tested, such as: 1) Was the JKB a critical event for marine biota in the pelagic Panthalassa? 2) Was the JKB significant in the evolution of marine life through the Phanerozoic? It is highly possible that the radiolarian JKB could be obtained by drilling the tuffaceous rocks near the Jurassic–Cretaceous volcanoes at a site around the outer slope of the Mariana Trench. The new cores at this site will provide critical information for constraining the U–Pb ages of the JKB from zircon grains in the tuff, and provide new insights into the biological evolution among pelagic biota in the Panthalassa across the JKB.

Keywords: Jurassic-Cretaceous boundary, GSSP, Panthalassa, radiolaria

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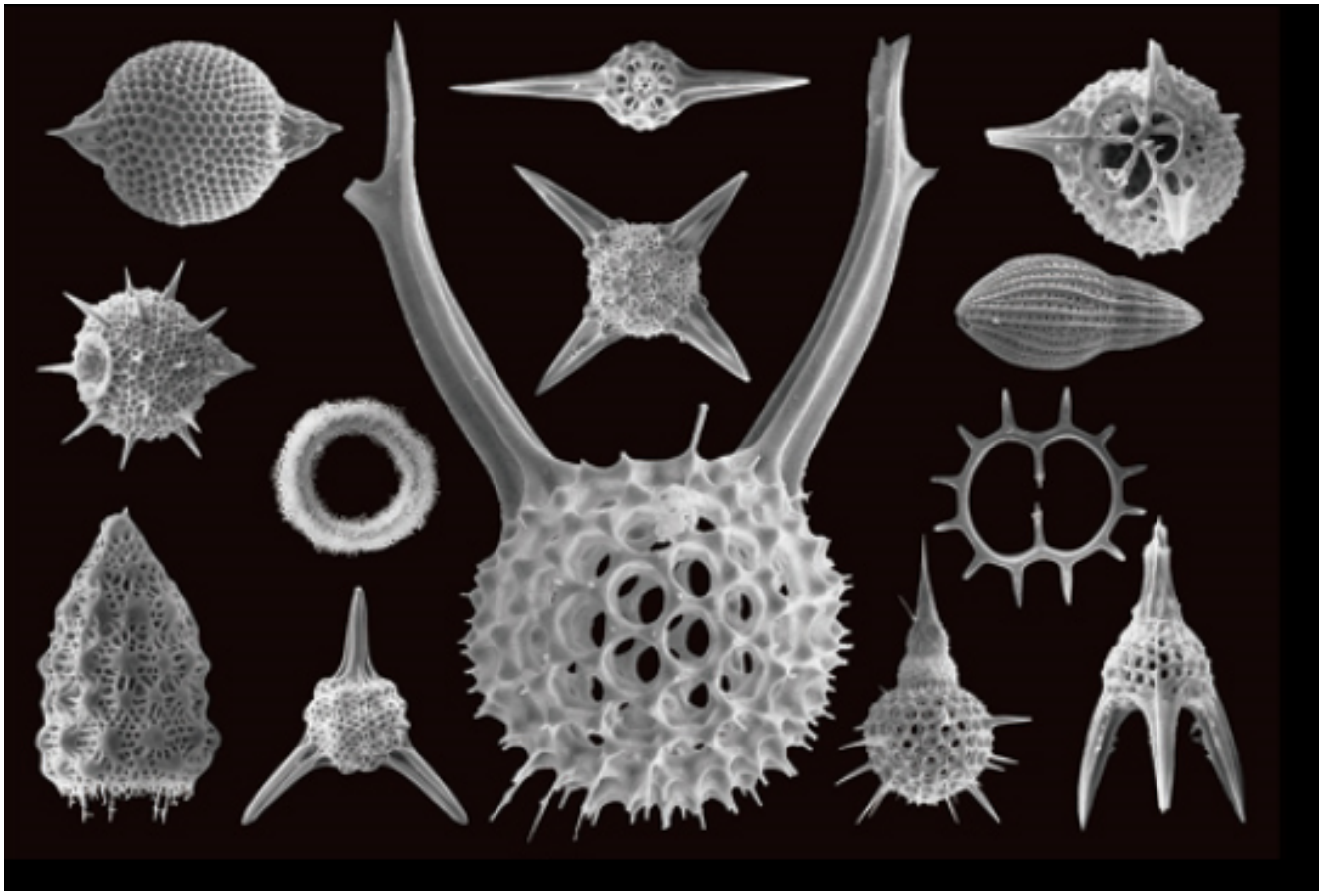

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The Renaissance of the oldest oceanic plate: Perspective of REY-rich mud as a paleoceanographic archive in a pelagic realm of the Pacific Ocean

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Deep-sea sediments showing a high concentration of rare-earth elements and yttrium (REY) are widely distributed in the Pacific Ocean [1]. Recently, the REY-rich mud extremely enriched in REY (up to 8,000 ppm of total REY) was discovered around Minamitorishima Island in the western North Pacific Ocean, and its spatial distribution has been investigated diligently based on 71 piston cores collected by seven research cruises since 2013 [2–7]. These REY-rich muds are composed of pelagic clay, which have characteristic chemical compositions and isotopic ratios reflecting transition of constituents and oceanic environments [1]. In addition, the extremely REY-rich mud is characterized by a significant accumulation of ichthyolith (fish teeth and bones) [2,4]. This suggests that REY-rich mud contains remarkable fluctuations of sedimentary components, implying an important aspect of pelagic clay as an efficient medium for recording some biological and/or sedimentological events in a pelagic realm. We have recently established a method to correlate the apparently homogenous pelagic clay layers based on multi-elemental geochemical features [8], which can provide a key to reveal various (paleo-)environmental information latent in the deep-sea sediments.
However, the piston cores do not cover all the sedimentary history of REY-rich mud because of the short length (~12 m each) [4]. Meanwhile, previous DSDP and ODP cores drilled in the Minamitorishima area (e.g. DSDP Site 198, ODP Sites 800 and 801) captured no sedimentary layer comparable to the extremely REY-rich mud, which is most likely due to poor recovery of the sediment column [9,10].
Here we propose a new scientific drilling of pelagic clay in the western North Pacific Ocean. The purpose of the drilling is (1) to obtain the complete sedimentary sequence of pelagic clay from the late Cretaceous to the present day, (2) to complete the ichthyolith- and REY-enrichment layers lying in the area and (3) to elucidate environmental and ecological factors that related to the formation of REY-rich mud.

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Keywords: REY-rich mud, Minamitorishima Island, paleoenvironmental change, pelagic clay

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REY-rich mud in the western North Pacific Ocean: An overview and implication for Earth system dynamics

*Yasuhiro Kato[1,2], Kazutaka Yasukawa[1,2], Junichiro Ohta[1,2], Erika Tanaka[1], Kazuhide Mimura[1], Koichiro Fujinaga[2,1], Kentaro Nakamura[1]

1. Graduate School of Engineering, University of Tokyo, 2. ORCeNG, Chiba Institute of Technology

Deep-sea mud enriched in rare-earth elements and yttrium (REY), termed as REY-rich mud, has been expected as a novel mineral resource for the industrially critical elements. Moreover, the discovery of extremely REY-rich mud with the maximum total REY content of ~8,000 ppm in the Japanese Exclusive Economic Zone (EEZ) around Minamitorishima Island, in the western North Pacific Ocean, makes it realistic to develop the highly promising deep-sea mineral resource commercially in near future.
Here we overview the progress of our researches on the REY-rich mud within the Minamitorishima EEZ towards the world's first development of deep-sea mineral resources. Moreover, we also discuss the controlling factor(s) of the formation and distribution of the extremely REY-rich mud. Our accumulation and integration of the scientific knowledge strongly suggest an intrinsic linkage between the genesis of deep-sea mineral resources and Earth system dynamics such as climate changes, ocean circulation, plate tectonics, and global geochemical cycles.

Keywords: seafloor mineral resources, rare-earth elements, REY-rich mud, deep-sea sediment, Earth system

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The Renaissance of the Oldest Oceanic Plate: Jurassic Oceanic Crust without Moho

*Yoshihiko Tamura[1], Mathieu Rospabe[1], Kentaro Kaneda[2], Alexander Nichols[3], Gou Fujie[1], Eiichi TAKAZAWA[4], Katsuyoshi Michibayashi[5], Shuichi Kodaira[1]

1. Research Institute for Marine Geodynamics, Japan Agency for Maine-Earth Science and Technology, 2. Japan Coast Guard, 3. University of Canterbury, New Zealand, 4. Niigata University, 5. Nagoya University

The western portion of the Pacific Plate, the oldest oceanic plate in the world, has been drilled several times and, based on Ocean Drilling Program (ODP) Site 801, an understanding of its layers, from pelagic clay through chert to alkali basalts and tholeiitic mid-ocean ridge basalts (MORB), has been established (e.g. Plank et al., 2000; Hauff et al., 2003). This oldest oceanic plate is experiencing a renaissance and we propose a strategy to drill the most suitable three sites to recover specific parts of the plate to continue its renaissance. The drilling sites, MM, MAT, and MINA, target (1) the most complete sedimentary sequence of pelagic clay including rare earth elements and yttrium (REY)-rich mud, (2) newly found outcrops of the Jurassic-Cretaceous boundary (JKB), and (3) MORB tholeiites without Moho, respectively.

Kaneda et al. (2010) conducted seismic surveys across the Marcus-Wake seamount chain. They found two contrasting sub-seafloor structures in the Jurassic lithosphere. The southern basin is underlain by 7.5-8.0 km thick crust with clear Moho reflections (sharp, single, flat and continuous, and of large amplitude. Beneath the northern basin, in contrast, the Moho reflections, if there at all, are extremely weak, and crust is only 6 km thick. The correlation between the strength of the Moho reflections and crustal thicknesses has been observed in other seismic profiles in the Pacific Plate (e.g. Ohira et al., 2017). We suggest that two types of oceanic crust exist; one thick with a Moho and the other thin without a Moho (Tamura et al., in prep). MORB overlying clear Moho reflections have been recovered at Site 801and thus Site MINA has been selected to represent Jurassic oceanic crust without the Moho.

Keywords: Moho reflections, MORB, hydrous melting

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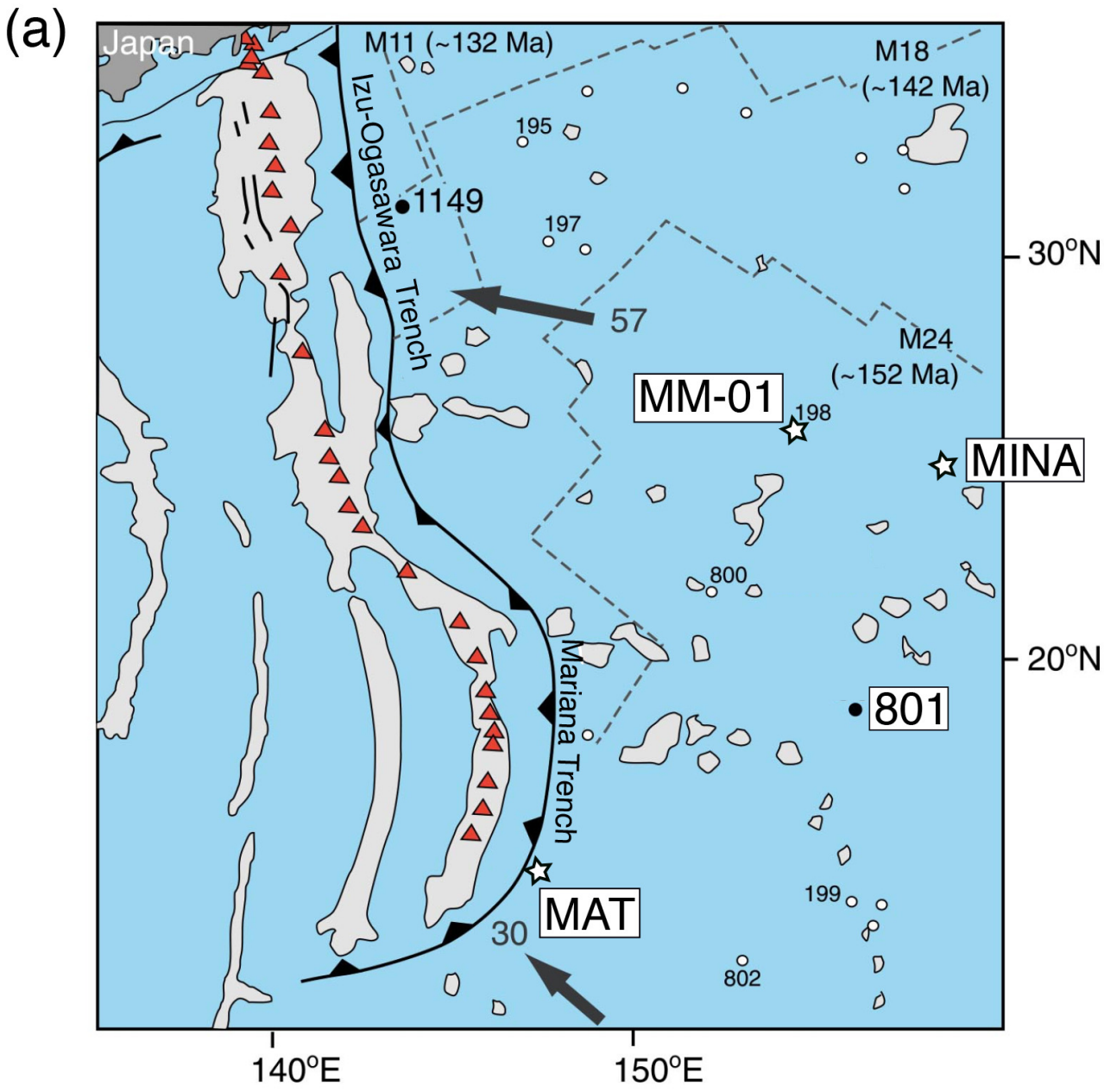

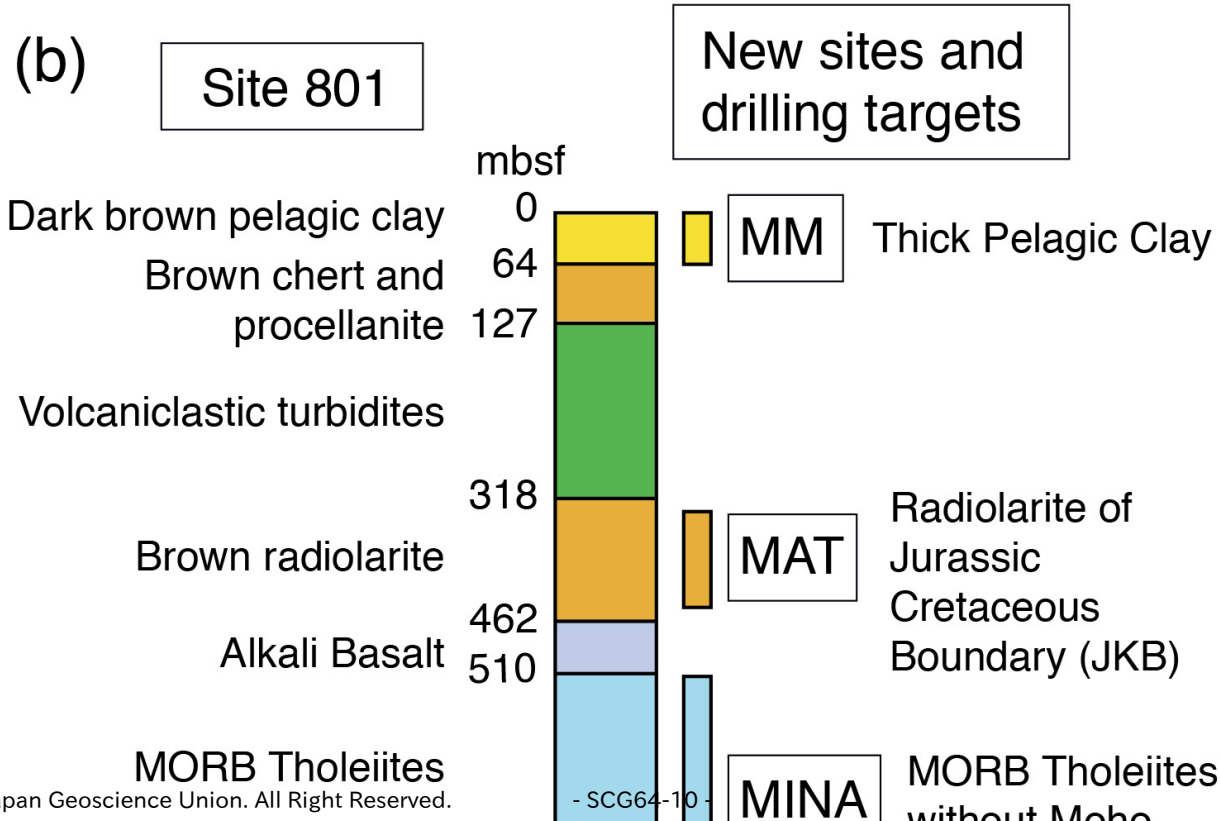

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Magma genesis model of the subduction zones based on hydrous melting experiments of a mantle peridotite

*Eiichi Takahashi[1], Jintuan Wang[1]

1. Guangzhou Institute of Geochemistry, Chinese Academy of Science

In order to understand the magma genesis beneath subduction zones, we carried out melting experiments of fertile peridotite KLB-1 with 10 wt.% H_2O at 3-6 GPa and 900-1200 ˚C using a large volume multi-anvil apparatus at Guangzhou Institute of Geochemistry (Wang et al, 2020, submitted to JGR). Compositions of the changing liquids (fluid + silicate melt at 3 GPa, super critical fluids SCFs at 4 and 6 GPa) have been determined by EDS analysis. At 3 GPa, quenched fluids are very rich in SiO_2 (>73 wt.%) and Al_2O_3 (>12 wt.%), but coexisting silicate melts are similar to boninite (SiO_2 =53-55 wt.%, MgO = 12-18 wt.%, TiO_2 = 0.3-0.5 wt.%) . Compositions of SCFs at 4 GPa are much higher in MgO than the melts at 3GPa, while SCFs at 6 GPa are further enriched in MgO and resembles komatiites or kimberlites (MgO = 22-25 wt.%). We discuss the role of DHPMZ (deep hydrous partial melting zone) and PMZ (partial melt zone in wedge mantle beneath arc volcanoes) in subduction zone magmatism based on our experimental results and some observation in geophysics, geochemistry and petrology in the North Honshu arc Japan.

Fine structures in the mantle wedge and subducted slab beneath North Honshu arc Japan have been studied using RF (receiver function) method by Kawakatsu and Watada (2007 Science), and they found a positive RF plane (indicating low velocity material) locating slightly above the top surface of the subducted plate at the depth of 90-120 km. Although they interpreted this low velocity layer as serpentinite but we propose that this is a hydrous partial melting zone judging from estimated temperature. According to our experiments, water-saturated solidus of mantle peridotite at 90 km depth is approximately 1000 ˚C which is consistent with the estimated mantle wedge temperature by Nakajima & Hasegawa (2003), while serpentinite is only stable below 650 ˚C at this depth.

We propose that the DHPMZ formed just above the subducted plate at 90-120km depth is the driving engine for subduction zone magmatism, although the magma derived from DHPMZ rarely appears on the surface. According to our experiments, melt at the top of the DHPMZ (~90 km depth) should be similar to boninite and is very rich in H_2O (>20 wt.%). As partially molten diapirs separate from DHPMZ and moves upwards and are heated to ~1200 ˚C in the shallower partial melt zone (PMZ), the partial melt compositions may become primitive olivine tholeiite beneath the volcanic front with 4-5 wt% of H_2O or water rich high-alumina basalt with 6-7 wt% H_2O in the rear arc side. It is possible that the location of the VF (volcanic front) is determined by the location of the shallowest end of the DHPMZ. In other word, wet mantle solidus possibly determines the position of VF. The very large volcanic production rate along the VF may be due to the coherent fluid transportation from the shallow end of the DHPMZ to PMZ. Spacing of arc volcanoes (Marsh, 1979) and hot mantle fingering (Tamura et al, 2002) may be explained by the spacing of wet diapirs from DHPMZ. We propose that role of boninite magma in arc magma genesis is significantly larger than previous thoughts. However, boninite magma can migrate to the surface only when PMZ has not been formed in the earliest stage of a subduction zone (e.g., Bonin arc) or PMZ terminates at the edge of a subduction zone (e.g., Tonga arc).

Keywords: subduction zone, magma genesis, wet mantle solidus, boninite magma

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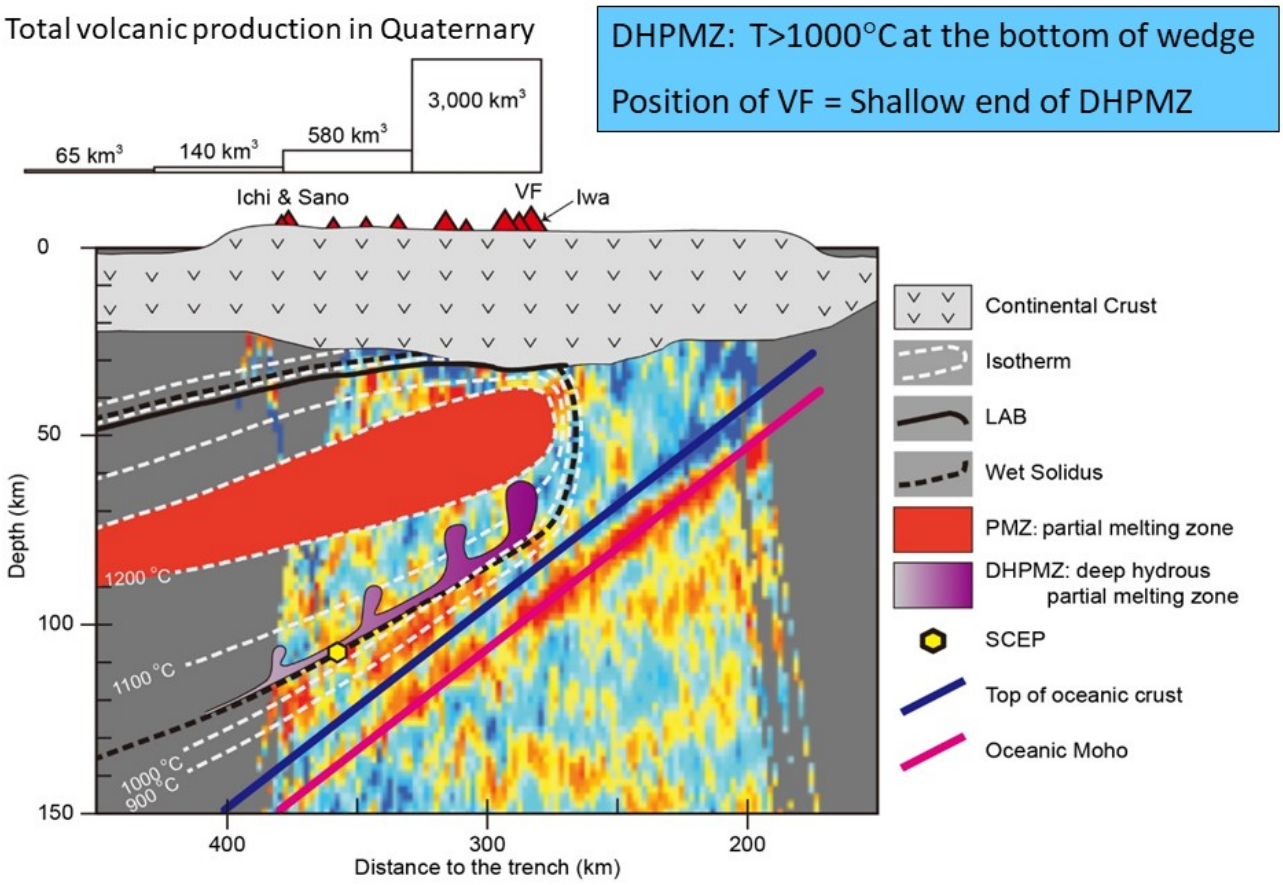

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The tectonic-magmatic characteristics in the Kamchatka: Implications for the dynamics around the northern edge of Pacific Plate

*Tatsuji Nishizawa[1], Hitomi Nakamura[2,3,4,5], Hikaru Iwamori[3,4,6]

1. Volcanic Fluid Research Center, School of Science, Tokyo Institute of Technology, 2. Institute of Earthquake and Volcano Geology, Geological Survey of Japan, AIST, 3. Department of Solid Earth Geochemistry, Japan Agency for Marine-Earth Science and Technology, 4. Depeartment of Earth and Planetary Sciences, School of Science, Tokyo Institute of Technology, 5. ORCeNG, Chiba Institute of Technology, 6. Earthquake Research Institute, The University of Tokyo

The northern slab edge of Pacific Plate (PAP) defined by the transform zones is subducting below Kamchatka and forms a very active volcanic arc, which consists of several volcanic belts: the Eastern Volcanic Front (EVF), the Central Kamchatka Depression (CKD), and the Sredinny Range (SR). In the central part of Kamchatka, the volcanic arc has a width of ~250 km, while in the northern part it decreases to a width of ~50 km, which is associated with transition in several tectonic-magmatic features. The Kamchatka-Aleutian triple junction located off the east coast of Kamchatka is a triple junction where PAP, the Bering Plate (BP), and the Okhotsk Plate meet. Between PAP and BP, three major transform zones with right lateral faults, i.e., Aleutian, Bering and Alpha transform faults, accommodate the differential motion between the two plates (e.g., Kogan et al., 2017; Lay et al., 2017). These right-lateral patchy strike-slip motions are decaying to the northward. In the central part of CKD, an extremely active and massive volcanic group has been formed, which includes the 4750 m high Klyuchevskoy Volcano with a mean eruption rate of 1 m^3/s over the last 10 kyr (Fedotov et al., 1987). The Shiveluch volcano is located in the north of the volcanic group, which defines the northern limit of the currently active volcanoes in Kamchatka, and erupted the adakitic lavas which could indicate slab melting at the edge of PAP slab (e.g., Yogodzinski et al., 2001).
In order to constrain the magmatic-tectonic processes in response to subduction of the norther edge of the PAP, we compiled the published geochemical data of the Quaternary lavas containing more than 5 wt.% MgO in Kamchatka (Churikova et al., 2001; Portnyagin and Manea, 2008; Volynets et al., 2010; 2018). Based on the geochemical data, we estimated the physical-chemical conditions of dehydration of slab and melting in the mantle wedge. As a result, we found several geochemical trends in both along-arc and across-arc directions, which implies that the conditions for fluid-magma processes in the slab and the mantle systematically change in space, particularly along the arc. Combining these analyses with the geophysical observations, tectonic models and numerical simulations, we will discuss the dynamics around the northern edge of PAP.

Keywords: Pacific Plate, volcanic arc, arc lavas, Kamchatka

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[E] Oral | B (Biogeosciences)：B-BC Biogeochemistry

[B-BC03] Earth and Planetary Science Frontiers for Life and Global Environment

convener:Yoshinori Takano(Japan Agency for Marine-Earth Science and Technology (JAMSTEC)), Yohey Suzuki(Graduate School of Science, The University of Tokyo), Shingo Kato(RIKEN), Keisuke Fukushi(Institute of Nature & Environmental Technology, Kanazawa University)

Earth and planetary science is currently capable of sampling from three frontiers: space, deep ocean and deep underground for the study of the origin and evolution of life. Next generation sequencing technology of nucleic acids and nanotechnology driven innovation of solid characterizations are very powerful to expand our understanding of many fields of earth and planetary sciences. It is also important for us to be aware of global warming and climate change that dramatically affect biodiversity, biological activities and elemental cycling. The aim of this session is to cross the border of science sections to explore the frontiers of earth and planetary science.

[BBC03-01] The prebiotic chemistry of Enceladus' hydrothermal systems

*Wataru Takahagi[1,2] (1.Department of Chemistry, Graduate School of Science, The University of Tokyo, 2.Institute for Extra-cutting-edge Science and Technology Avant-garde Research (X-star), Japan Agency for Marine-Earth Science and Technology (JAMSTEC))

[BBC03-02] **Pressure-induced esterification reaction between phosphoric acid and methanol: a possibility of prebiotic formation of alkyl phosphate and phospholipid at high pressure**

*Yuchen Sun[1], Chikako Fujimoto[1], Hiroyuki Kagi[1] (1.Graduate School of Science, The University of Tokyo)

[BBC03-03] **Iron mediated synthesis of thioesters with thioacetic acid and simultaneous formation of FeS clusters in aqueous solution**

*Sebastian Adrian Sanden[1], Shawn Erin McGlynn[1], Masahiko Hara[1], Riquin Yi[1] (1.Tokyo Institute of Technology)

[BBC03-04] Japanese challenges to explore Martian biosphere

*Yohey Suzuki[1], Tomohiro Usui[2], Akihiko Yamagishi[2] (1.Graduate School of Science, The University of Tokyo, 2.Japan Aerospace Exploration Agency (JAXA))

[BBC03-05] Habitable aqueous environment on Early Mars inferred from reconstructed water chemistry at Gale

★Invited Papers

*Keisuke Fukushi[1], Yasuhito Sekine[2,1], Hiroshi Sakuma[3], Koki Morida[4], Robin Wordsworth[5] (1.Institute of Nature & Environmental Technology, Kanazawa University, 2.Earth-Life Science Institute, Tokyo Institute of Technology, 3.National Institute for Materials Science, 4.Division of Natural System, Kanazawa University, 5.Department of Earth and Planetary Sciences, Harvard University)

[BBC03-06] Toward the exploration of habitable Mars: MMX and beyond

*Tomohiro Usui[1] (1.Japan Aerospace Exploration Agency)

The prebiotic chemistry of Enceladus' hydrothermal systems

*Wataru Takahagi[1,2]

1. Department of Chemistry, Graduate School of Science, The University of Tokyo, 2. Institute for Extra-cutting-edge Science and Technology Avant-garde Research (X-star), Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

Enceladus is one the sixth-largest moon of the moons of Saturn, and it has been known to harbor interior ocean beneath the icy crust, which holds important factors necessary for life such as organic compounds, liquid water, and high-temperature condition. While geochemical and other radiation-related processes for the *in situ* production of organics remain elusive, thermally unaltered carbonaceous chondrites, consisting of the main body of Enceladus are known to be enriched with organic matters such as simple amino acids. Due to these characteristics, Enceladus is attracting attention as a habitable area for primitive life, and the prebiotic chemical evolution that occurs in Enceladus ocean is under discussion. Chemical evolution is an abiotic reaction process in which complex organic molecules arise from a combination of simple inorganic and organic chemical compounds. To assess the ongoing chemical evolution at the subsurface ocean of Enceladus, we focused to explore the water-rock reaction and the possibility of peptide formation under the Enceladus hydrothermal environment. We reported that ongoing chemical evolution on Enceladus is likely producing short abiotic peptides from simple amino acids on the porous core surface. Here we show that Enceladus' unique chemical condition linking to prebiotic evolution based on our published report and the latest findings for Enceladus.

Keywords: Enceladus, Hydrothermal System, Prebiotic chemistry

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Pressure-induced esterification reaction between phosphoric acid and methanol: a possibility of prebiotic formation of alkyl phosphate and phospholipid at high pressure

*Yuchen Sun[1], Chikako Fujimoto[1], Hiroyuki Kagi[1]

1. Graduate School of Science, The University of Tokyo

Esterification reaction between phosphoric acid and alcohols is a possible origin of biomolecules with phosphoester bond, such as alkyl phosphate and phospholipid. Especially, studying the prebiotic formation of phospholipid becomes an important task in the discovery of the origin of life because phospholipid acts as a major component of cell membranes. Recently, the existence of organic materials, such as methanol, on ice bodies has been reported[1]. The interiors of ice planets and satellites at high pressure could be places for the prebiotic evolution of biomolecules, since the yield and reaction rate of some organic reactions increase dramatically under high pressure conditions. In this study, we investigated the pressure-induced esterification reaction between phosphoric acid and methanol, and proposed a possibility of the prebiotic formation of phospholipids at high pressure.

A H_3PO_4-CH_3OH-H_2O mixture (molar ratio H_3PO_4:CH_3OH:H_2O =1:5:4) was loaded in an encapsulating gasket and high pressure was applied using a Paris-Edinburgh press. The sample was kept at 6 GPa for 3 days at room temperature. Then, the sample was recovered to ambient pressure and analyzed using LC-MS. The obtained mass chromatograms clarified the formation of monomethyl phosphate and dimethyl phosphate with the yields of 13% and 0.5%, respectively, which were much higher than the yields at ambient pressure (0.5% for monomethyl phosphate and 0 for dimethyl phosphate). The result proved that the high pressure promoted the esterification reaction.

To look into the mechanism of the pressure-induced reaction, we conducted *in situ* observations on the H_3PO_4-CH_3OH-H_2O mixture at high pressure using diamond anvil cells (DAC) with a culet diameter of 600 μm. Samples were loaded into metal gasket holes with the diameters of 200-300 μm, and the pressure was estimated using the ruby fluorescence pressure scale[2]. After increasing the pressure, we observed crystallization of the mixture at 4.3 GPa. From the X-ray diffraction pattern and Raman spectra, we confirmed the existence of ice VII. It suggests that the crystallization of water is likely to be the driving force of this reaction.

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2. Mao HK et al. (1986), *Journal of Geophysical Research: Solid Earth*, 91, 4673-4676.

Keywords: pressure-induced esterification, DAC, methyl phosphate, prebiotic evolution

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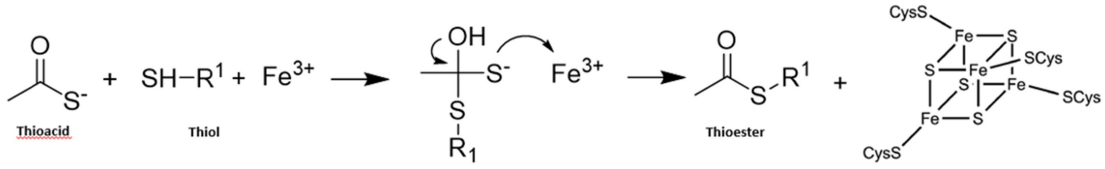
Iron mediated synthesis of thioesters with thioacetic acid and simultaneous formation of FeS clusters in aqueous solution

*Sebastian Adrian Sanden[1], Shawn Erin McGlynn[1], Masahiko Hara[1], Riquin Yi[1]

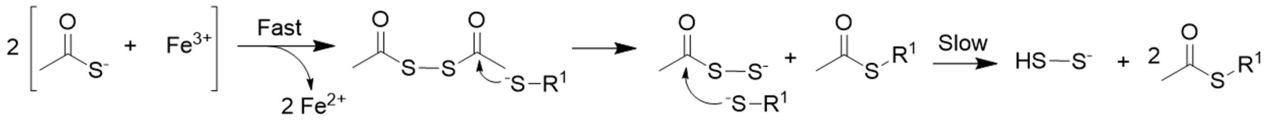
1. Tokyo Institute of Technology

In biological systems, endergonic reactions such as peptide bond formation are coupled to the hydrolysis of phosphoesters (such as ATP) which have a high free energy of hydrolysis. A further hallmark of biology is that the maintenance of high NTP/NDP ratios in the cell is coupled to electron transfer reactions. Here we report new work showing that thioesters can be synthesized from thioacetic acid in a reaction that simultaneously leads to the formation or redox active FeS clusters (Scheme 1).
A pH below 7 and the subsequent degassing of hydrogen sulfide produced during the reaction has been found to drive the otherwise thermodynamically unfavorable reaction, in which a thioacid with a standard free energy of hydrolysis of -15 KJ mol^{-1} is converted to a thioester with a free energy of -37 KJ mol^{-1}. The energy conversion from thioacids to thioesters in terms of free energies of hydrolysis can be as high as 52% if the thiol participating in the reaction incorporates a tertiary amine functional group that additionally accelerates the reaction. When this reaction is then coupled to the oxidation of thioacetate by ferric iron (Scheme 2), thioester yields of up to 47% can be achieved in respect to the amount of thioacetic acid added and the reaction reaches its highest concentration within one hour.
The sulfide produced during the generation of thioesters from thioacids reacts with ferric iron in solution which results in the starting materials for the reconstitution of [4Fe4S] clusters that are frequently employed in biology to facilitate redox reactions; thus providing a possible prebiotic route to ester exchange, polymerization, and electron transfer reactions.

Keywords: Origin of Life, Thioester synthesis, FeS cluster



Scheme 1. Thioester synthesis and simultaneous iron sulfur cluster formation.



Scheme 2. Thioester synthesis via the oxidation of thioacetate

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Japanese challenges to explore Martian biosphere

*Yohey Suzuki[1], Tomohiro Usui[2], Akihiko Yamagishi[2]

1. Graduate School of Science, The University of Tokyo, 2. Japan Aerospace Exploration Agency (JAXA)

It is critical to obtain samples returned from Martian biosphere for demonstrating the existence of extant life and life’ s signatures by high-sensitivity and high-resolution analytical procedures. Rovers named Mars2020 and ExoMars equipped with drilling devices and life-detection instruments will be launched this year. National Aeronautics and Space Administration (NASA) and European Space Agency (ESA) are planning to start Mars Sample Return Mission (MSR) from 2026. From the circumstances, the MSR Science Planning Group (MSPG) is internationalizing the planning for the Returned Sample Science component of MSR, whereas Committee on Space Research (COSPAR) is responsible for establishing analytical protocols with best available technology to determine whether returned materials are biohazard or not.

The presenters are currently serving as Planetary Protection Officer in Japan (JAXA Yamagishi) or as a sole non-US and non-EU member of COSPAR Sample Safety Assessment Protocol Working Group (SSAP WG) (Univ. Tokyo Suzuki) or participating MSPG Workshops (JAXA Usui). In this presentation, it is attempted to share information about the current status of MSR and planetary protection with Japanese scientific communities. More importantly, Japanese enthusiasm and scientific and technological advantages towards future involvement in MSR will be presented.

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Habitable aqueous environment on Early Mars inferred from reconstructed water chemistry at Gale

*Keisuke Fukushi[1], Yasuhito Sekine[2,1], Hiroshi Sakuma[3], Koki Morida[4], Robin Wordsworth[5]

1. Institute of Nature & Environmental Technology, Kanazawa University, 2. Earth-Life Science Institute, Tokyo Institute of Technology, 3. National Institute for Materials Science, 4. Division of Natural System, Kanazawa University, 5. Department of Earth and Planetary Sciences, Harvard University

There is a wealth of geomorphological and mineralogical evidence indicating the presence of liquid water on early Mars. However, the chemical properties of the water such as pH and salinity, which are crucial to habitability on early Mars, have not been clarified so far. The NASA rover Curiosity has conducted a geological survey of Gale crater, a former lake on Mars, and provided mineralogical and geochemical data on the lacustrine sediment. The present study quantitatively estimates the water chemistry of the pore water based on exchangeable cation compositions in the smectite and the salt mineralogy in the sediment. Results show that the liquid water was of Na-Cl type with moderate salinity (0.1-0.5 mol/kg) and circumneutral pH. The estimated Na-Cl concentrations reflect hyposaline lakes developed in 10^4--10^6-year-long semiarid climates. The mild aqueous conditions and redox disequilibria in secondary minerals under this estimated water chemistry suggests that there was a habitable aqueous environment on early Mars.

Keywords: Early Mars, Gale crater, Water chemistry

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Toward the exploration of habitable Mars: MMX and beyond

*Tomohiro Usui[1]

1. Japan Aerospace Exploration Agency

Since Mars has attracted much interest as a potentially accessible habitable planet, the greatest number of spacecraft has been sent to this planet among any of the other extraterrestrial bodies. The Mars exploration has provided evidence for a variety of water-related geological activities: fluvial landforms, paleo-oceans and lakes, and aqueous alteration and weathering of the surface materials. These geologic observations indicated the existence of liquid water on the surface of Mars, while the most recent investigations have uncovered the possible existence of subsurface water (ice) world, which may be more favorable to extant or even present life on Mars. This paper summarizes the heritage of our knowledge on Mars and presents the importance of exploration of habitable Mars including JAXA’s Martian Moon Exploration (MMX).

Keywords: habitable Mars, exploration

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[E] Oral | B (Biogeosciences) : B-BC Biogeochemistry

[B-BC03] Earth and Planetary Science Frontiers for Life and Global Environment

convener:Yoshinori Takano(Japan Agency for Marine-Earth Science and Technology (JAMSTEC)), Yohey Suzuki(Graduate School of Science, The University of Tokyo), Shingo Kato(RIKEN), Keisuke Fukushi(Institute of Nature & Environmental Technology, Kanazawa University)

Earth and planetary science is currently capable of sampling from three frontiers: space, deep ocean and deep underground for the study of the origin and evolution of life. Next generation sequencing technology of nucleic acids and nanotechnology driven innovation of solid characterizations are very powerful to expand our understanding of many fields of earth and planetary sciences. It is also important for us to be aware of global warming and climate change that dramatically affect biodiversity, biological activities and elemental cycling. The aim of this session is to cross the border of science sections to explore the frontiers of earth and planetary science.

[BBC03-07] Isolation and physiological characterization of an archaeon at the prokaryote-eukaryote interface

★Invited Papers

*Hiroyuki Imachi[1], Masaru K Nobu[2] (1.Japan Agency for Marine-Earth Science and Technology, 2.National Institute of Advanced Industrial Science and Technology)

[BBC03-08] Genomic analyses of the closest isolated archaeal relative of eukaryotes reveals novel insights into eukaryogenesis

★Invited Papers

*Masaru Konishi Nobu[1], Hiroyuki Imachi[2], Nozomi Nakahara[2,1,3], Yuki Morono[2], Miyuki Ogawara[2], Yoshihiro Takaki[2], Katsuyuki Uematsu[4], Tetsuro Ikuta[2], Motoo Ito[2], Yohei Matsui[2], Masayuki Miyazaki[2], Kazuyoshi Murata[5], Yumi Saito[2], Sanae Sakai[2], Chihong Song[5], Eiji Tasumi[2], Yuko Yamanaka[2], Takashi Yamaguchi[3], Yoichi Kamagata[1], Hideyuki Tamaki[1], Ken Takai[2] (1.National Institute of Advanced Industrial Science and Technology, 2.Japan Agency for Marine-Earth Science and Technology, 3.Nagaoka University of Technology, Nagaoka, 4.Marine Work Japan Ltd, 5.National Institute for Physiological Sciences)

[BBC03-09] The origin of scaly-foot gastropod's scale and iron sulfide nanoparticles inside

★Invited Papers

*Okada Satoshi[1] (1.Japan Agency for Marine-Earth Science and Technology)

[BBC03-10] Interaction of organic matter and submarine hydrothermal fluids on the early Earth: its importance for origin of proto-enzyme and early microbial activities

*Takeshi Kakegawa[1] (1.Graduate School of Science, Tohoku University)

[BBC03-11] Revised kinetic parameters of the Aps reductase enzyme: effect on microbial sulfur isotope fractionation.

*Shawn E McGlynn[1], Tommy Po-Hsiang Wang[1], Mayuko Nakagawa[1], Yuichiro Ueno[1] (1.Tokyo Institute of Technology)

[BBC03-12] Climate and litter C/N ratio constrain soil organic carbon accumulation

Guoyi Zhou[1], *Shan Xu[2], Ciais Philippe [3], Manzoni Stefano [4,5] (1.Institute of Ecology, Jiangsu Key Laboratory of Agricultural Meteorology, Nanjing University of Information Science & Technology, Nanjing 210044, China, 2.Guangdong Institute of Eco-environmental and Soil Sciences, 3.Institut Pierre Simon Laplace, Laboratoire des Sciences du Climat et de l'Environnement, CEA CNRS UVSQ UPSaclay, 91191 Gif sur Yvette, France, 4.Department of Physical Geography, Stockholm University, Stockholm SE-10691, Sweden, 5.Bolin Centre for Climate Research, Stockholm SE-10691, Sweden)

Isolation and physiological characterization of an archaeon at the prokaryote-eukaryote interface

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The origin of the eukaryotes remains a major enigma in biology. Current data suggest that eukaryotes may have emerged from an archaeal lineage known as “Asgard” archaea. Despite the eukaryote-like genomic features found in these archaea, the evolutionary transition from archaea to eukaryotes remains unclear due to the lack of cultured representatives and corresponding physiological insight. In this presentation, we will introduce the isolation procedure and unique physiological properties of the first cultured representative of Asgard archaea. To effectively cultivate deep marine sediment microorganisms including Asgard archaea, we employed a continuous-flow bioreactor with polyurethane sponges, called down-flow hanging sponge (DHS) bioreactor. We anaerobically incubated deep-sea methane-seep sediment collected from the Nankai Trough, Japan, and fed with methane as the main energy source for more than 2,000 days at 10˚C. During the bioreactor cultivation, the microbial community composition was monitored using 16S rRNA gene-based techniques such as cloning/iTAG, qPCR and fluorescence *in situ* hybridization (FISH). As phylogenetically diverse uncultured microorganisms including Asgard archaea members were increasingly enriched over time, we transitioned towards further enrichment and isolation in glass tubes/vials with simple substrates and selective compounds (*e.g.*, antibiotics). Cultures were incubated for at least 12 months and analyzed for microbial community composition even when no turbidity was observed, as growth was expected to be very slow. One culture amended with casamino acids and antibiotics contained a small population of a novel archaeon (designated strain MK-D1) belonging to the “*Candidatus* phylum Lokiarchaeota” of the Asgard archaea. Through successive *in vitro* cultivation combined with qPCR- and iTag-based cell density and community composition monitoring, we obtained a pure co-culture of the target archaeon and methanogenic archaeon *Methanogenium*– 12 years after the first sampling of deep-sea sediment. Strain MK-D1 is a strictly anaerobic archaeon that degrades amino acids syntrophically with sulfate-reducing bacteria and methanogenic archaea via interspecies hydrogen (and/or formate) transfer. The archaeon has an extremely slow growth rate and low cell yield, i.e., the doubling time was approximately 14–25 days and maximum cell density 10^5 cells/ml, which are thousand-fold lower than a model microorganism *Escherichia coli*. The MK-D1 cells are small cocci (approximately 550 nm in diameter) and generally form aggregates surrounded extracellular polymer substances. Electron microscopic observations revealed that the cells contain no visible organelle-like inclusions, although eukaryote-like intracellular complexes have been proposed for Asgard archaea in previous metagenomic-based studies. Instead, MK-D1 is morphologically complex and unique protrusions that are long and often branching. The MK-D1 cells also produce many membrane vesicles. Based on these unique physiological properties and genetic features (details in the subsequent presentation by Masaru K. Nobu). We proposed the name “*Candidatus* Prometheoarchaeum syntrophicum” for strain MK-D1.

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Keywords: Archaea, deep-sea sediment, Asgard archaea, origin of eukaryotes, syntrophy

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Genomic analyses of the closest isolated archaeal relative of eukaryotes reveals novel insights into eukaryogenesis

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The origin of eukaryotes remains enigmatic. Recent data suggest that eukaryotes may have evolved from an archaeal lineage known as “Asgard archaea”. Despite the eukaryote-like genomic features in these archaea, the evolutionary transition from to eukaryotes remains unclear due to the lack of cultured representatives and corresponding physiological insight. By obtaining an archaeon representing the closest isolated prokaryotic relative of eukaryotes “*Candidatus*Prometheoarchaeumsyntrophicum strain MK-D1”, characterizing the strain and its genome, and further performing comparative genomic analyses, we obtain novel insight into ancestral features of Asgard archaea and eukaryogenesis.

The isolated strain MK-D1 degrades amino acids (AAs) through syntrophic interaction ($H_2$and formate transfer) with methanogenic and sulfate-reducing partners. The strain was also predicted to lack various biosynthetic machinery and depend on the above partners for biosynthesis. A survey of the publicly available Asgard archaea genomes reveals that most also encode AA catabolism and H_2metabolism and lack many biosynthetic pathways. Exhaustive comparative genomics revealed several genes related to AA catabolism and fermentative metabolism conserved across the phylum (*i.e.*, those that form monophyletic clusters in gene trees). In total, we provide the first evidence that Asgard archaea are capable of syntrophic AA degradation, dependent on symbiotic interactions for both catabolism and anabolism (*e.g.*, H_2, formate, and metabolite transfer), and conserve related metabolic features across the superphylum, suggesting that the Asgard archaea ancestor possessed such capacities.

Evolution of this ancestral organism, possibly intracellularly simple (*i.e.*, as observed for MK-D1), towards the last eukaryotic common ancestor likely involved (i) transition from anaerobiosis towards aerobiosis, (ii) acquisition of an endosymbiont capable of O_2respiration and ATP transfer (*i.e.*, mitochondrion), and (iii) transformation to develop elaborate intracellular structures. Based on insight from the isolate and comparative genomics, we propose a new theory for eukaryogenesis –the “Entangle-Engulf-Endogenize (E^3) model” –that sheds light on potential evolutionary scenarios that may have addressed these obstacles and led to emergence of an aerobic organotroph possessing an O_2-respiring ATP-generating endosymbiont.

Keywords: Evolution, Archaea

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The origin of scaly-foot gastropod's scale and iron sulfide nanoparticles inside

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Animals produce hard tissues for skeletal support, protection, and feeding, and inorganic minerals are often utilized as a component. The biologically produced minerals are usually oxygen-containing such as carbonates and phosphates, and other group-16 elements such as sulfur are usually absent in the biominerals. Scaly-foot gastropods (*Chrysomallon squamiferum*), possessing scales on their soft body found in hydrothermal vents on the Cehtral Indian Ridge, Indian Ocean, is a rare exception among animals besides bacteria, and possesses iron sulfide particles such as pyrite ang greigite in their scales only when the vent fluid is rich in iron. The mechanisms of iron sulfide mineralization within the scales of scaly-foot gastropods has been ambiguous for 18 years from their discovery. Here we revealed the mechanisms of iron sulfide mineralization from three viewpoints; origin of sulfur by nanoscale isotopic microanalyses, three-dimensional nanoscopic alignment and elemental distribution by electron microscopy, and pathways of iron incorporation by translocation of dead scaly-foot scales between two vents.
The isotopic analyses revealed that the sulfur isotope ratio ($^{34}S/^{32}S$) in pyrite particles were −9.6 ±0.1‰, which was considerably lower than that of sulfide vent minerals, vent fluids, and soft part of another vent mussel (4.4–7.5‰, 6.8–7.0‰, 3.4–5.6‰, respectively). This clearly shows that the sulfur is of biological origin, and implies several biological processes involved in the sulfur transport to the sulfide minerals in the scales.
Electron microscopic investigation revealed that the sulfide minerals were in columnar alignment along with the longitudinal axis of the scale, and sulfur-rich domains lacking iron were also found. In addition, the cross-sectional lamellar from frozen scales without sulfide minerals revealed the existence of channel-like pores in which fluids can pass through. These results support the sulfur supply to the scales through body fluid.
The iron transport mechanisms is investigated by translocating dead scaly-foot's scales without iron sulfide minerals in the habitat of iron sulfide-bearing scaly foot. The scales collected after 13 days of incubation contained iron only near the surface, indicating the iron diffusion toward inside of the scales.
In conclusion, we have revealed the iron sulfide mineralizaton mechanisms as follows: sulfur-transporting columns are created within scales, and into which sulfur species are supplied through the body fluid. Iron ions are diffused into the scales from the surrounding seawater, and mineralization takes place within the scales. This hybrid mechanism in which only one of the mineral component is spontaneously supplied by an animal is a novel form of biomineralization. In addition, scaly-foot snails may utilize the sulfur transportation mechanisms to discard sulfur waste produced by endosymbionts to adapt to the extreme environment of hydrothermal vent.

Keywords: Chrysomallon squamiferum, Biomineralization, Pyrite nanoparticles, FIB/SEM tomography, Nano-SIMS

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Interaction of organic matter and submarine hydrothermal fluids on the early Earth: its importance for origin of proto-enzyme and early microbial activities

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Prebiotic or biotic organic matter on the early Earth were most likely interacted with submarine hydrothermal fluids intensively. Such interaction may have produced unique chemical species, which could promote chemical evolution and activity of early life, although no data are available. In order to approach such problems, organic matter associated with Archean submarine hydrothermal deposits were studied in the present study.

It is found that sulfide ores at the 2.7 Ga Potterdoal and Schreiber deposits contain various forms of pyrobitumen. Hydrothermally altered basalts also contain various forms of oil-bearing materials. The fluid inclusions in hydrothermal quartz contain methane. Those discovery suggest that submarine hydrothermal activities on the early Earth behaved as geo-reactors to convert and recycle organic matter into various forms. Carbon isotope data of organic matter in sulfide ores suggest that productivities of hydrothermal microbial communities were controlled by products from the geo-reactors.

Such geo-reactors could produce abundant methanethiol, which might be the key molecule for prebiotic enzyme formation. Nano-scale C-S-metal compounds were found in organic matter deposited around Potterdoal and Schreiber deposits. Such metal compounds were similar to enzyme in chemistry and scale. They were most likely produced by using hydrothermal methanethiol. Such discovery from nature leads to propose the new pathway to form proto-enzyme using geo-reactors.

Keywords: Archean, submarine hydrothermal fluid, pyrobitumen

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Revised kinetic parameters of the Aps reductase enzyme: effect on microbial sulfur isotope fractionation.

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1. Tokyo Institute of Technology

The Aps reductase enzyme conducts the first redox reaction of microbial sulfate reduction, and it is the most exergonic under a wide array of conditions. We report a new kinetic characterization of the enzyme under non-inhibited conditions using an assay which specifically removes the inhibitor AMP from the assay solution. The Km, and Vmax properties of the enzyme are dramatically altered, which in turn affects predicted whole cell sulfur isotope fractionation. Whether or not the altered kinetics affect the apparent KIE of the enzyme is under investigation.

Keywords: sulfur isotopes, enzyme kinetics, microbial growth

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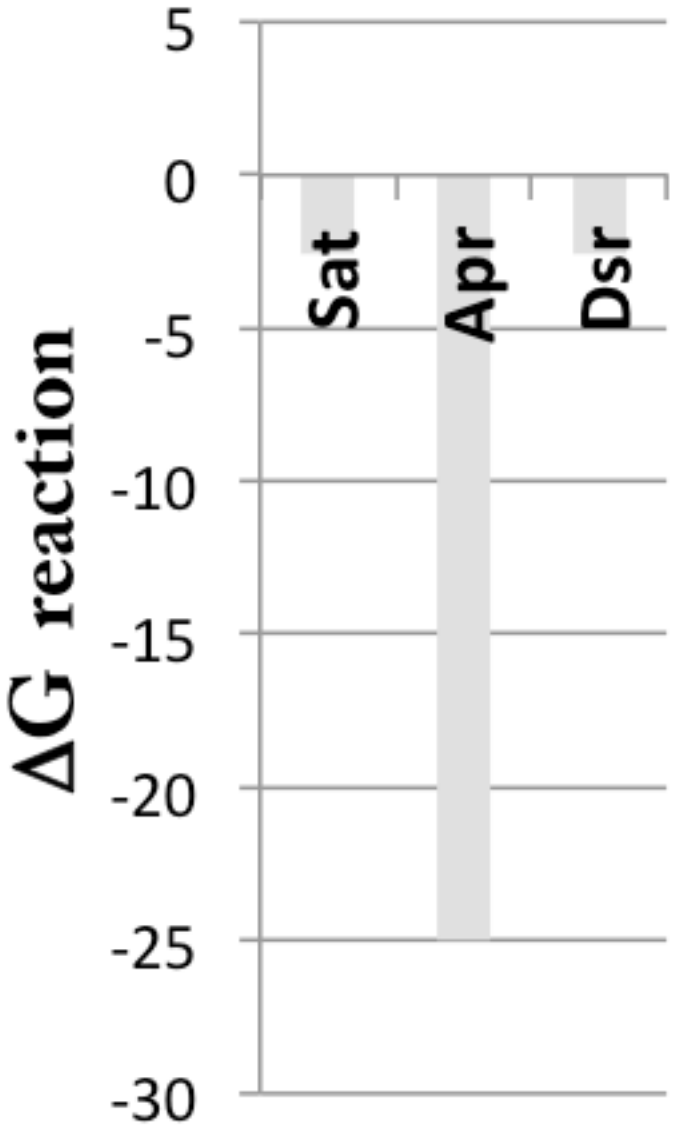

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Climate and litter C/N ratio constrain soil organic carbon accumulation

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Soil organic carbon (SOC) plays critical roles in stabilizing atmospheric CO2 concentration, but the mechanistic controls on the amount and distribution of SOC on global scales are not well understood. In turn, this has hampered the ability to model global C budgets and to find measures to mitigate climate change. Here, based on the data from a large field survey campaign with 2600 plots across China's forest
ecosystems and a global collection of published data from forested land, we find that a low litter carbon-to-nitrogen ratio (C/N) and high wetness index (P/PET, precipitation-to-potential-evapotranspiration ratio) are the two factors that promote SOC accumulation, with only minor contributions of litter quantity and soil texture. The field survey data demonstrated that high plant diversity
decreased litter C/N and thus indirectly promoted SOC accumulation by increasing the litter quality.We conclude that any changes in plant-community composition, plant-species richness and environmental factors that can reduce the litter C/N ratio, or climatic changes that increase wetness index, may promote SOC accumulation. The study provides a guideline for modeling the carbon cycle of various ecosystem scales and formulates the principle for land-based actions for mitigating the rising atmospheric CO2 concentration.

Keywords: litter carbon-to-nitrogen, wetness index, annual litterfall, soil texture, soil organic carbon

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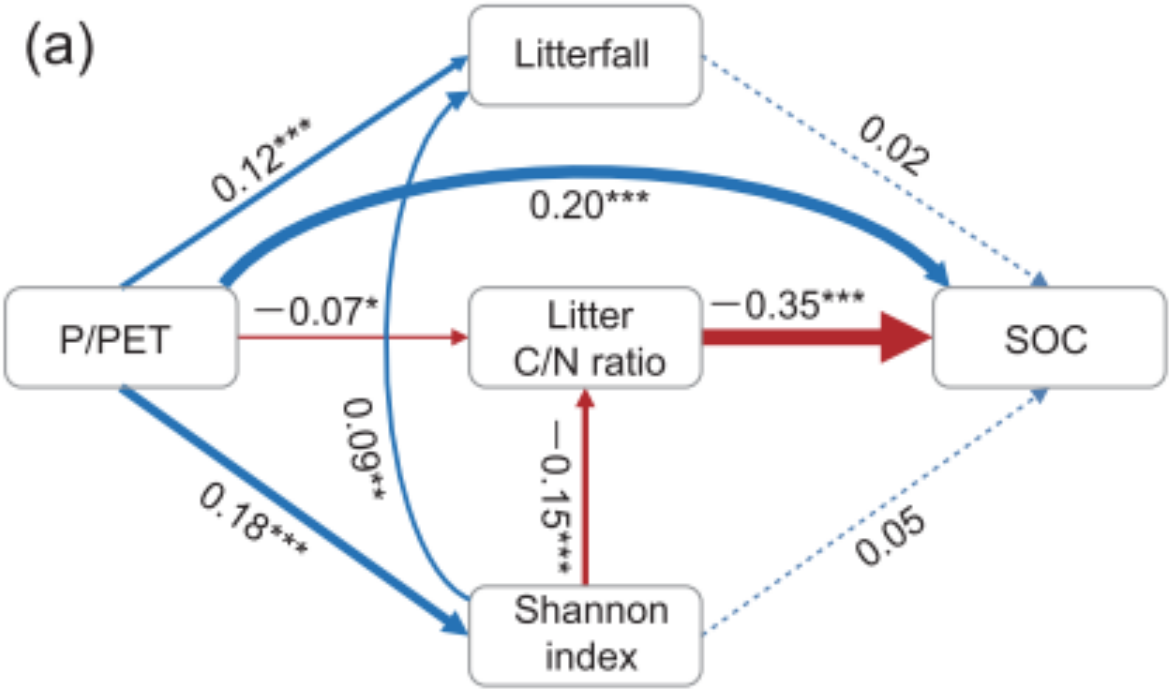
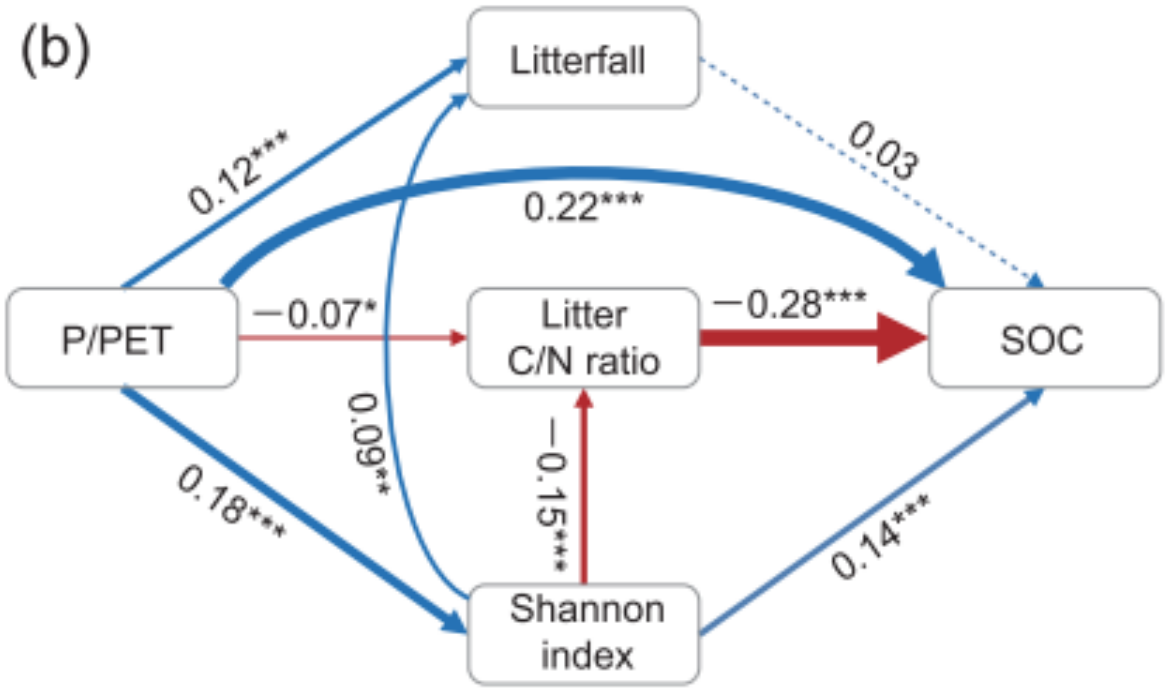


0-100 cm, χ^2=1.51, P=0.22, df=1, n=1519



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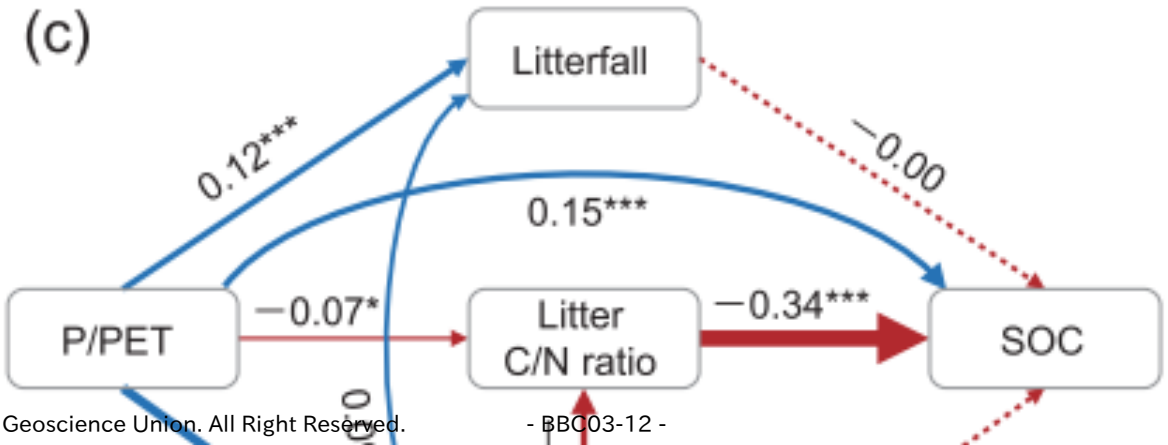

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[E] Oral | B (Biogeosciences)：B-PT Paleontology

[B-PT04] Biomineralization and Geochemistry of Proxies

convener:Takashi Toyofuku(Japan Agency for Marine-Earth Science and Technology (JAMSTEC)), Jelle Bijma(Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung), Hiroshi Kitazato(Tokyo University of Marine Science and Technology (TUMSAT)), Kotaro Hirose(Faculty of Science and Engineering, Waseda University)

In order to reconstruct the Earth climate system, marine paleoclimatologists resort to transfer functions or geochemical proxies, which are produced or affected by organisms. The relationships used for reconstructions are generally based on field calibrations or derived from laboratory experiments. The danger of these so-called empirical relationships is that they may be valid only within the restricted parameter space of their calibration. Application of proxy relationships to very different environmental settings (e.g. high vs. low latitude or glacial vs. interglacial) requires a mechanistic understanding of these relationships. Much progress can be expected by a better understanding of the biomineralization mechanisms and the incorporation of proxy signals.
In this session we facilitate contributions related to the biomineralization, calibration and validation of marine proxies from field study, laboratory culture experiment and paleo-environmental reconstruction.

[BPT04-01] Shell formation of foraminifera -marine unicellular calcifiers-

*Takashi Toyofuku[1,2], Yukiko Nagai[1,3] (1.Japan Agency for Marine-Earth Science and Technology (JAMSTEC), 2.Tokyo University of Marine Science and Technology (TUMSAT), 3.National Museum of Nature and Science,Tokyo (NMNS))

[BPT04-02] Effect of euxinic conditions on planktic foraminifers: results from laboratory culture experiments and implications for oceanic anoxic events

*Azumi Kuroyanagi[1], Takashi Toyofuku[2], Yukiko Nagai[2], Katsunori Kimoto[2], Hiroshi Nishi[1], Reishi Takashima[1], Hodaka Kawahata[3] (1.The Center for Academic Resources and Archives, Tohoku University, 2.JAMSTEC, 3.Atmosphere and Ocean Research Institute, The university of Tokyo)

[BPT04-03] Effects of larger benthic foraminifers from global warming analysed by Micro-X-ray CT

*Shunichi Kinoshita[1], Azumi Kuroyanagi[2], Hiroshi Nishi[2], Osamu Sasaki[2], Kazuhiko Fujita[3], Atsushi Suzuki[4], Hodaka Kawahata[5] (1.Tohoku University, Graduate School of Science, 2.The Tohoku University Museum, 3.University of the Ryukyus, 4.Geological Survey of Japan National Institute of Advanced Industrial Science and Technology, 5.the University of Tokyo)

[BPT04-04] Foraminiferal calcification, CO_2, precipitation rates and element incorporation

*Lennart Jan de Nooijer[1], Takashi Toyofuku[2], Esmee Geerken[1], Gert-Jan Reichart[1] (1.Netherlands Institute for Sea Research, 2.JAMSTEC)

[BPT04-05] The coral reef-dwelling *Peneroplis pertusus* brought to light: recalcification during culture experiments

*Laurie Charrieau[1], Takashi Toyofuku[1], Yukiko Nagai[1], Katsunori Kimoto[2], Kazuhiko Fujita[3] (1.X-STAR, JAMSTEC, 2.RIGC, JAMSTEC, 3.Department of Physics and Earth Sciences, University of the Ryukyus)

[BPT04-06] Variations in carbon and oxygen isotope composition and trace element concentrations of the modern brachiopod shells collected off Okinoshima

*Kazuma Oikawa[1], Hideko Takayanagi[1], Ryuichi Shinjo[2], Kazuyoshi Endo[3], Masa-aki Yoshida[4], Yasufumi Iryu[1] (1.Institute of Geology and Paleontology Graduate School of Science Tohoku University, 2.Department of Physics and Earth Sciences, University of the Ryukyus, 3.Department of Earth and Planetary Science, Tokyo University, 4.Shimane University Faculty of Life and Environmental Science)

Shell formation of foraminifera -marine unicellular calcifiers-

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Foraminifers are unicellular eukaryotes that mainly live in the ocean. Calcareous foraminifera forms a shell of calcium carbonate. Calcareous shells are stored in sediments for long periods and are therefore used as geological records as environmental indicators. However, the processes required for foraminifer shell formation have not been well studied. Therefore, we investigated how calcium and carbonate ions are taken up by biological processes at the site of calcification. It also shows the microstructure of the calcified site where the shell formation process proceeds. In this study, after optically observing the shell formation process, fluorescence imaging was performed to record the environment inside and outside the calcification site. Besides, the morphology of the shell formation site was described in detail by electron microscopy, revealing the relationship between the cytoplasm and calcareous structure. For decades, these relationships have been largely ignored. By obtaining samples at various stages during shell formation through laboratory culture experiments, we were able to study the mechanism of chamber formation.

Keywords: foraminifera, calcification, shell formation

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Effect of euxinic conditions on planktic foraminifers: results from laboratory culture experiments and implications for oceanic anoxic events

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The oceanic redox state is a critical determinant for life on Earth, and “anoxic events” may have substantially impacted the oceanic biosphere. However, we do not know much about the sensitivity of living planktic foraminifers to conditions of anoxia or euxinia (anoxia in the presence of free H_2S).We examined the biological response of planktic foraminifers to euxinic conditions (free H_2S) by culturing six species of planktic foraminifers (n = 31) in three treatments: ~2 mg hydrogen sulfide (H_2S) L^{-1}, ~9 mg H_2S L^{-1}, and a control, without H_2S. No planktic foraminifers survived more than 48 hr in the presence of H_2S, the gametogenesis percentage was extremely low, and the time to gametogenes was very short. These results show that the biological impact of euxinia is fundamentally different from that of dysoxic conditions. Two foraminiferal species survived euxinia for 24 hr, suggesting a species-specific, varying tolerance to H_2S. If the exposure to H_2S was restricted to a relatively short time (i.e., <24 hr; e.g., linked to a tidal cycle), some species of foraminifers (i.e., *Neogloboquadrina dutertrei*) might be able to survive. We argue that disappearance of planktic foraminifers from sediments deposited during anoxic events could be the result of the absence of planktic foraminifers in the photic zone to euxinia (free H_2S), rather than due to carbonate dissolution in the water column and sediment. If this is confirmed, the presence/absence and abundance record of planktic foraminifers might record the oceanic redox state in the euphotic zone and contribute to the evaluation of results of modeling studies. The variability in species-specific response suggests that future changes in foraminiferal assemblages are possible, linked to ocean deoxygenation.

Keywords: planktic foraminifers, culture experiments, hydrogen sulfide, oceanic anoxic event (OAE)

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Effects of larger benthic foraminifers from global warming analysed by Micro-X-ray CT

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Studying calcification organisms are essential for understanding environmental changes in the tropical to subtropical seas. Although symbiont-bearing larger benthic foraminifers (LBF) is one of important calcification organism with complex calcium carbonate shells living in coral reefs. They produce plentiful calcium carbonate following to reef corals and calcareous algae in coral reef area. However, the relationships between foraminiferal shell calcification and SST are not cleared yet because it was difficult to measure and calculate foraminiferal shell volume accurately, due to the tiny size and complexity of their shell form. Thus, this study tried to analyze responses of the symbiont-bearing LBF to global warming by culturing experiment in laboratory with means of Micro-X-ray CT investigations.

In this study, we cultured asexually reproduced individuals of *Sorites orbiculus* under six different temperature conditions to examine the effects of SST on calcium carbonate producing of LBF. Experimental results with 12 weeks culturing indicated that increasing rates of shell weight, shell volume and the number of chambers added were generally increase with temperature increasing from 19 ˚C to 27 ˚C. On the other hand, calculated shell density is in constant in whole range of experiment temperature. Due to these results, it was suggested that shell weight was most closely dependent upon their shell volume. Their increasing rates of shell weight and shell volume were reversed their trends and decreasing at 29 ˚C, despite their growth rate of number of chambers added was still in constant from 27 ˚C to 29 ˚C. Therefore, the optimum temperatures for their chamber growth rate and calcification rate might be showed some deviation. This deviation might be caused by deviation of optimum temperatures of LBF and their photosynthesis symbionts. Finally, in future predicted global warming will be disturbed LBF calcification.

Keywords: larger benthic foraminifer, micro CT, foraminiferal shell, laboratory experiments, global warming

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Foraminiferal calcification, CO_2, precipitation rates and element incorporation

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1. Netherlands Institute for Sea Research, 2. JAMSTEC

Ongoing burning of fossil fuels increases atmospheric CO_2, elevates marine dissolved CO_2 and decreases pH and the saturation state with respect to calcium carbonate. Intuitively this should decrease the ability of $CaCO_3$-producing organisms to build their skeletons and shells. The response of foraminifera to changes in [CO2] is shown to be contradictory, which may result from their calcification strategy. Here we show that foraminifera form their calcium carbonate by active proton pumping. This elevates the internal pH and acidifies the direct foraminiferal surrounding. This also creates a strong pCO_2 gradient and facilitates the uptake of DIC in the form of carbon dioxide. This finding uncouples saturation state from calcification and predicts that the added carbon due to ocean acidification will promote calcification by these organisms. In addition, a series of experiments was conducted to determine the preciptation rate at which foraminifera produce their calcite. These rates are relatively high and may explain, together with their ability to regulate their internal pH, the incorporation mechanism of elements during biomineralization.

Keywords: foraminifera, biomineralization

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The coral reef-dwelling *Peneroplis pertusus* brought to light: recalcification during culture experiments

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Ocean acidification is a consequence of current global climate changes. The concomitant decrease in pH and carbonate ion concentration in sea water may have severe impacts on calcifying organisms. Coral reefs were among the first ecosystems to be recognized as vulnerable to ocean acidification. On coral reefs, large benthic foraminifera are among the major calcium carbonate producers.

The aim of this study was to evaluate the effects of a lower pH and presence or absence of light on large benthic foraminifera. We performed culture experiments reproducing ocean acidification conditions to study the shell (test) resistance to dissolution of the miliolid and symbiont-bearing species *Peneroplis pertusus*. Furthermore, resilience of decalcified specimens under dark or light treatments was documented.

We found that after four days, small signs of test decalcification were observed on the specimens kept at pH 7.2, and severe test decalcification was observed on specimens kept at pH 6.9. All the specimens were alive, even the strongly decalcified ones, which demonstrates the resistance of *P. pertusus* to a lowered pH, at least on the short-term. After being partially decalcified, some of these living specimens were placed back at higher pH 7.8. After around 10 days, test recalcification occurred, but only on individuals that were daily exposed to light. These results highlight the crucial role of the symbionts that are able of photosynthesis, which provides the required energy for the recalcification process. Moreover, the newly formed chambers were abnormal, and the ultrastructure of their walls was altered. We conclude that even if symbiont-bearing large benthic foraminifera show some resistance and resilience to lowered pH, they will stay strongly affected by ocean acidification conditions.

Keywords: Ocean acidification, Large Benthic Foraminifera, Culture experiments

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Variations in carbon and oxygen isotope composition and trace element concentrations of the modern brachiopod shells collected off Okinoshima

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The carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotope composition of Rhynchonelliform brachiopods (hereafter, called ‘brachiopods’) have been regarded as useful for paleoceanographic conditions throughout the Phanerozoic. However, recent studies have revealed that the isotopic composition and minor element concentrations in modern brachiopod shells are not only influenced by environmental changes in ambient seawater but also by biological effects such as the chemical composition of calcification fluid and the growth process (e.g., growth rates, metabolism). In order to improve our knowledge on the calcification mechanism of brachiopod shells and to make the isotopic composition and the chemical composition more reliable paleoenvironmental proxies, it is necessary to accumulate data on them from various modern brachiopod species. In this study, we measured $\delta^{13}C$ and $\delta^{18}O$ values and minor element concentrations of the primary (PL) and secondary (SL) shell layers of three (one male and two female) specimens of *Pictothyris picta* collected at a water depth of ~61 m off Oki Island. We performed a high-resolution micrometer-scale sampling along the maximum growth axis, corresponding to time resolution of 3 days to 8 months. Samples were also collected from the innermost shell surface. We examined whether there are differences in isotopic composition and minor element concentrations between male and female specimens. The $\delta^{13}C$ and $\delta^{18}O$ values of calcite precipitated in equilibrium with surrounding seawater ($\delta^{13}C_{EC}$ and $\delta^{18}O_{EC}$) were calculated using oceanographic data (e.g., temperature, salinity) and isotopic composition of dissolved inorganic carbon ($\delta^{13}C_{DIC}$) and seawater ($\delta^{18}O_{SW}$) at the brachiopod growth site to compare with the shell $\delta^{13}C$ and $\delta^{18}O$ values.

The $\delta^{18}O$ values of three *P. picta* of the SL are mostly close to oxygen isotope equilibrium with ambient seawater. The $\delta^{13}C$ values of the PL and SL show clear seasonal variations. There are no differences in shell $\delta^{13}C$ and $\delta^{18}O$ values between male and female specimens. Whereas, intraspecific (inter-specimen) differences in $\delta^{13}C$ and $\delta^{18}O$ values are not negligible. There is no significant correlation between Mg/Ca and $\delta^{18}O$ values. Whereas Sr/Ca and $\delta^{13}C$ values are negatively correlated.

Keywords: brachiopod, carbon and oxygen isotope, trace metal element concentrations

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[E] Oral | B (Biogeosciences)：B-PT Paleontology

[B-PT04] Biomineralization and Geochemistry of Proxies

convener:Takashi Toyofuku(Japan Agency for Marine-Earth Science and Technology (JAMSTEC)), Jelle Bijma(Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung), Hiroshi Kitazato(Tokyo University of Marine Science and Technology (TUMSAT)), Kotaro Hirose(Faculty of Science and Engineering, Waseda University)

In order to reconstruct the Earth climate system, marine paleoclimatologists resort to transfer functions or geochemical proxies, which are produced or affected by organisms. The relationships used for reconstructions are generally based on field calibrations or derived from laboratory experiments. The danger of these so-called empirical relationships is that they may be valid only within the restricted parameter space of their calibration. Application of proxy relationships to very different environmental settings (e.g. high vs. low latitude or glacial vs. interglacial) requires a mechanistic understanding of these relationships. Much progress can be expected by a better understanding of the biomineralization mechanisms and the incorporation of proxy signals.
In this session we facilitate contributions related to the biomineralization, calibration and validation of marine proxies from field study, laboratory culture experiment and paleo-environmental reconstruction.

[BPT04-07] **Validation and calibration of proxies to reconstruct past oxygenation using foraminifera: Shell Mn/Ca and porosity.**

*Inge van Dijk[1,2], Christine Barras[2], Aurelia Mouret[2], Grit Steinhöfel[1], Emmanuelle Geslin [2], Jelle Bijma[1] (1.Marine Biogeosciences, Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung, Bremerhaven, Germany, 2.LPG UMR CNRS 6112, University of Angers, UFR Sciences, Angers, France)

[BPT04-08] Development of new proxies using macromolecular structures of marine palynomorphs

*Takuto Ando[1], Kazumi Matsuoka[2], Karin Zonneveld[3], Gerard Versteegh[3,4] (1.Estuary Research Center, Shimane University, 2.Institute for East China Sea Research, Nagasaki University, 3.Center for Marine Environmental Sciences (marum), Bremen University, 4.Department of Earth and Environmental Science, Jacobs University Bremen)

[BPT04-09] Lipid biomarker analysis of culture samples of genus *Tetraparma* of the Parmales (Bolidophyceae)

*Ken Sawada[1], Yuki Hattori[1], Mutsuo Ichinomiya[2], Akira Kuwata[3] (1.Department of Earth and Planetary Sciences, Faculty of Science, Hokkaido University, 2.Prefectural University of Kumamoto, 3.Tohoku National Fisheries Research Institute)

[BPT04-10] Seasonal variation in assemblage of planktic foraminifera from the sediment trap samples in the Bay of Bengal

*Ayumi Maeda[1,2], Azumi Kuroyanagi[3], Hiroshi Nishi[3], Birgit Gaye[4], Hodaka Kawahata[2,1] (1.Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, 2.Atmosphere and Ocean Research Institute, The University of Tokyo, 3.The Tohoku University Museum, Tohoku University, 4.Institute of Biogeochemistry and Marine Chemistry, University of Hamburg)

[BPT04-12] Recent changes of the diatom assemblages in relation to human-induced pollution in Baltic Sea coastal inlets.

*Kotaro Hirose[1], Hanna Nilsson[3,2], Karin Rengefors[3], Olof Berglund[3], Filipsson F. Helena[2] (1.Faculty of Science & Engineering, Waseda University, 2.Dept. of Geology, Lund University, Lund, Sweden, 3.Dept. of Biology, Lund University, Lund, Sweden)

Validation and calibration of proxies to reconstruct past oxygenation using foraminifera: Shell Mn/Ca and porosity.

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The extent of oxygen minimum zones have been increasing since the 1960s due to ongoing climate change and eutrophication, and has led to dramatic ecological and economic consequences that will most likely be amplified in the near future. However, the timing and extent of future deoxygenation is still uncertain, since processes and feedback mechanisms involved in the formation of oxygen depleted zones are relatively unknown. The paleo-record provides the opportunity to study the processes involved in the onset and evolution of low oxygen events, leading to a better understanding of the mechanisms causing and consequences following anoxic and hypoxic events. Unfortunately, there is still a need to develop robust and reliable proxies to reconstruct past oxygenation accurately. This knowledge is crucial to predict the extent, intensity and development of low oxygen areas in the future. A number of proxies have been proposed in the last decade. The incorporation of redox sensitive element manganese in foraminiferal calcite and shell porosity has been studied as a potential proxy for paleo-oxygenation reconstructions. So far, these proxies have not been tested nor calibrated in controlled laboratory conditions. In this study we investigate the potential impacts of decreased oxygen concentration on foraminifera, including different levels like biological parameters, i.e. survival and chamber addition rate as well as shell porosity (gas exchange surface), and shell chemistry. This allows for the validation of these proposed proxies for past oxygenation, and at the same time assesses the impact of a decreasingly deoxygenated environment on the viability and success of foraminifera. Our preliminary results show that, while hypoxia negatively impacts shell growth, foraminiferal shell chemistry and porosity varies with oxygen concentration. All in all, these foraminiferal based proxies show to be a potential worthy addition to the paleo oceanographers toolbox as indicators of low oxygen conditions.

Keywords: Foraminifera, biomineralization, oxygen, Mn/Ca, shell porosity

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Development of new proxies using macromolecular structures of marine palynomorphs

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Palynomorphs are the microscopic organic remains of organisms. These microfossils are composed of resistant macromolecules and preserved in the sedimentary rocks even after thermal maturation. They are important sources of information for (paleo)environment, stratigraphy, fisheries, forensic science, honey origin, pollen allergy etc. Marine palynomorphs are characterized by organic-walled shells and membranes originated from marine organism. Dinocyst, ciliate cyst/lorica, foraminiferal lining, prasinophycean phycoma and acritarch are major components of marine palynomorphs. This information is extracted from differences in morphology. However, it is not always easy to link the palynomorph to a single source organism. First, different species may produce morphologically identical palynomorphs. One aspect here of is that we cannot always separate toxic from non-toxic taxa. Second, for several recent and fossil palynomorphs we do not know their biological origin.
Like morphology, chemical composition is the result of adaptation of the source organism to its environment, both over the course of evolution (genotypic) and in reaction to its living conditions. Exploring palynomorph chemistry may not only help to resolve the problems of attributing palynomorphs to their source organisms, but may also provide new information on the evolution and adaptation of the source organisms to their environment. Recently, we have suggested that the macromolecular analyses of marine palynomorphs using by micro-FTIR and pyrolysis GC-MS are useful methods for differentiating these palynomorphs chemotaxonomically. For example, Bogus et al. (2014, *Journal of Phycology*) reported that difference of macromolecular structures between autotroph and heterotroph dinocysts. Moreover, palynomorph chemistry may differ due to factors independent of the source organism such as diagenesis. Analysis of palynomorph chemistry therefore may prove to provide important insight in the diagenetic history and preservation of sedimentary organic matter, and through this, the functioning of the global carbon cycle.
Blooming (red-tide) of dinoflagellate, especially toxic/harmful species, in coastal waters adversely impact on both marine ecosystem and human life. Formation and preservation of dinocysts in the sediments are important for understanding the mechanism of red-tide. *Alexandrium catenella/pacificum* are toxic and form the elliptical transparent cysts. On the other hand, palynomorphs with unknown origin, called as acritarch, are also frequently observed in sediment. The plankton cells of some spherical dinocysts and ciliate cysts are still unknown and these palynomorphs are conventionally belong to sphaeromorph acritarchs. It is also possible that these spherical palynomorphs are the fragments of foraminiferal linings. The records of these processes are possibly remained as difference in macromolecular structure of same species of palynomorphs.
Here, we present the results of micro-FTIR analyses by means of attenuated total reflection (ATR) of individual cyst-walls of toxic and non-toxic, morphologically similar to identical *Alexandrium* species including *A. catenella* and *A. pacificum* from the surface sediments of Osaka Bay, Japan. In addition, we show the results and discuss the potential of new proxies using macromolecular structures of marine palynomorphs.

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Keywords: palynomorph, Palynochemistry, macromolecule, Organic Geochemistry, Micropaleontology

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Lipid biomarker analysis of culture samples of genus *Tetraparma* of the Parmales (Bolidophyceae)

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Parmales is picoplankton that has siliceous tests, and may be closely related to diatom, which is a main important primary producer in the Cenozoic ocean. There have been no reports for siliceous fossil of Parmales. It is known to well preserve siliceous diatom fossil in ancient sediment, and however, such fossil is frequently lost through its dissolution by diagenesis after deposition. Therefore, very small siliceous tests of Parmales must be easily dissolved by diagenesis, and it cannot evaluate the timing of first appearance and reconstruct productivity of Parmales by using its siliceous fossil. Thus, we clarified the Parmales biomarkers and their compositions, and these biomarkers are used as molecular fossils for giving understanding evolution processes and historical variations of productivity of this alga. We have reported the lipid biomarkers from the isolated culture strains of genus *Triparma* (Kanou et al., 2013). In the present study, we analyzed the lipid biomarkers, especially steroids, of newly isolated genus *Tetraparma*, and to give understanding for their taxonomic variability for steroid compositions and concentrations.

We use culture strains of genus *Tetraparma*, *Tetraparma gracilis* and *Tetraparma pelagica*, and no species name, Scaly parma, for analysis of the lipid biomarkers. Wet culture samples were extracted with methanol/ dichloromethane, and the extracts were fractionated by silica gel chromatography. Polar fraction was silylated by BSTFA before analyses using GC/MS (Sawada and Shiraiwa, 2004).

We can identify C21:6 *n*-alkene, C20:5 and C22:6 *n*-alkenoic acids as well as C27-C29 sterols in all samples of genus *Tetraparma* and scaly Parma. These lipids have been detected from diatom and genus *Triparma* cultures as reported previously (e.g. Rampen et al., 2010, Kanou et al., 2013). In particular, *Te. gracilis* and *Te. pelagica* strains is found to be characterized by overwhelmingly abundance of C29 stigmasterol. However, the scaly parma have abundant C29 β-sitosterol rather than C29 stigmasterol, which agree with the results of genus *Triparma* previously. The steroid compositions of genus *Tetraparma* are significantly different from the other Parmales. These results clearly indicate that there is possibly interspecies variability in sterol compositions within Parmales (Bolidophyceae).

The genus *Tetraparma* and scaly parma have been found to be more primitive parma by genomic analysis (Ban et al., 2019). Their lipid biomarkers may give understandings for the relationship between these primitive Parmales and diatom, and have potentials for chemotaxonomic indicators of siliceous microalgae.

Keywords: Parmales, biomarker, chemotaxonomy, evolution of siliceous algae, steroid

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Seasonal variation in assemblage of planktic foraminifera from the sediment trap samples in the Bay of Bengal

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The monthly resolution of sediment trap samples revealed the shell fluxes and the composition of the assemblages of planktic foraminifers in the Bay of Bengal in the three periods (November 1988 to October 1989, December 1990 to October 1991, and January 1993 to October 1993). The shell fluxes and the distribution patterns of planktic foraminifers varied between each experimental period. The highest values of shell fluxes were observed in either or both of summer and winter monsoon periods, while the lowest values were observed from March to May. The strong seasonality is possibly caused by the phytoplankton bloom in monsoon periods and the strong surface stratification in spring.
We identified 25 species of planktic foraminifers in the samples and 7 species constitute more than 80% of foraminiferal assemblage. The 7 species are divided into three populations: carnivorous spinose species (*G. ruber*, *T. sacculifer* and *G. siphonifera*), herbivorous non-spinose species (*G. menardii* and *N. dutertrei*), and opportunistic/upwelling species (*G. glutinata*, *G. bulloides*). In the summer and winter monsoon periods, the orders of the increase for foraminiferal species are similar. At first, non-spinose species increase and nearly at the same time opportunistic species become dominant. Subsequently spinose species increase in assemblage which shows the opposite pattern on relative contribution of spinose species and opportunistic species. In winter monsoon periods, the first presence of more opportunistic species in the same living depths may be caused by the deeper mixed layers where the phytoplankton bloom is observed in both of surface and subsurface layers. In contrast to winter monsoon periods, the increase for foraminifers start from subsurface-dwelling non-spinose species and then, surface-dwelling spinose species are dominant in summer monsoon periods. The orders of increase for foraminifers possibly reflect the initiation of the primary and the secondary production in subsurface layer under cloudiness and strong stratification inhibiting the surface propagation.

Keywords: planktic foraminifera, Bay of Bengal, sediment trap

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Recent changes of the diatom assemblages in relation to human-induced pollution in Baltic Sea coastal inlets.

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The Baltic Sea, one of the world's largest semi-enclosed water bodies in northern Europe, is naturally vulnerable to hypoxia due to estuarine hydraulic characteristics (Zillén et al. 2008). Moreover, the ca 85 million people living in the drainage area are causing severe pressures on the ecosystem, resulting in environmental deterioration and one of the most polluted seas in the world (Leppäranta and Myrberg, 2009).

Diatoms are dominant primary producers in coastal ecosystems, and are sensitive to the environmental change. In this study, we present temporal changes of diatom assemblages in the core (c.l. 49 cm) from coastal fjord-like inlets Gropviken (site Gp2) on the Swedish southeast coast, and discuss the temporal variation of the ecosystem on the basis of primary producers.

Using the vertical variations of diatom assemblages of the past 130 years (^{210}Pb and ^{137}Cs age information), core Gp2 was classified into 4 diatom zones: DAZ1 (50-36cm; C.E. 1888-1952), relatively low and constant content of dominant species. DAZ2 (36-19cnm; C.E. 1952-1989), intense dominance of *Skeletonema marinoi*intermittently and strong dominance of *Pauliella taeniata*in the lower horizons (39-33cm). DAZ3 (19-2cm; C.E. 1989-2014): strong dominance of *Cyclotella choctawhachiana*, and DAZ4 (2-0cm; C.E. 2014-2017): Strong dominance of *Skeletonema marinoi*, similar assemblage to DAZ2.

Based on the ecological features of diatoms and their fluxes (valves/cm^2/yr), the change in the primary producers in Gropviken (Gp2) during the 1950's, is considered to be caused by the acceleration of human-induced eutrophication. Recent records (CE 2014-2017), suggest a potential recovery from the initial change (CE 1952-1989).

[reference]
Zillén, L., Conley, D., Andrén, T., Andrén, E. & Björck, S. (2008) Past occurrences of hypoxia in the Baltic Sea and the role of climate variabil ity, environmental change and human impact, Earth-Science Reviews 91, 77-92.Leppäranta, M., and Myrberg, K. (2009). Physical Oceanography of the Baltic Sea. Berlin: Springer/Praxis Pub.

Keywords: diatom assemblages, anthropogenic impact, eutrophication, coastal inlets, Baltic Sea, past 130 years

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[E] Oral | B (Biogeosciences)：B-PT Paleontology

[B-PT05] Biotic History

convener:Isao Motoyama(Faculty of Science, Yamagata University), Takao Ubukata(Division of Geology & Mineralogy, Department of Earth & Planetary Sciences, Kyoto University), Kazuyoshi Moriya(Department of Earth Sciences, Faculty of Education and Integrated Arts and Sciences, Waseda University)

The Biotic History session covers all aspects of ancient life and the history of biosphere through the geologic time. The study of ancient life is essential for unveiling mysteries of our planet earth. It also provides evidence for evolution of oceans, continents and island arcs. Modern progress in this field has been enhanced by interdisciplinary collaboration with allied sciences, such as paleoceanography and evolutionary biology. Our session intends to be a hub of communication amongst all earth scientists studying the biosphere; we welcome biological and biogeochemical approaches toward the understanding of the history of life.

[BPT05-01] Adaptive evolution of marine cyanobacteria to the climate in the Neoproterozoic inferred from ancestral proteins

*Nao Masuda[1], Mariko Harada[2], Sota Yagi[3], Ryutaro Furukawa[4], Akihiko Yamagishi[5], Shin-ichi Yokobori[5] (1.Department of Biological Sciences, Graduate School of Science, The University of Tokyo, 2.Faculty of Life and Environmental Sciences, University of Tsukuba, 3.Center for Biosystems Dynamics Research, RIKEN, 4.Faculty of Human Sciences, Waseda University, 5.Department of Applied Life Sciences, Tokyo University of Pharmacy and Life Sciences)

[BPT05-02] Ontogenetic transformations and re-interpretation of Ediacaran Trilobozoa

*Maria Zakrevskaya[1], Andrey Ivantsov[1] (1.Paleontological Institute of the Russian Academy of Sciences, Moscow, Russia)

[BPT05-03] Natural assemblages of the platform-type conodont in lowermost Triassic deep-sea black claystone from northeastern Japan, with probable soft-tissue impressions

*Satoshi Takahashi[1], Satoshi Yamakita[2], Noritoshi Suzuki[3] (1.Department of Earth and Planetary Science, University of Tokyo, 2.Department of Earth Science, Faculty of Culture, Miyazaki University, 3.Institute of Geology and Paleontology, Graduate school of Tohoku University)

[BPT05-04] Tephrochronological study of the Yezo Group (uppermost Albiane-basal Campanian) in Hokkaido, Japan

*Hiroshi Nishi[1], Reishi Takashima[1], Keiichi Hayashi[2], Kuwabara Sato[2], Yuji Orihashi[3], Toshiro Yamanaka[4] (1.The Center for Academic Resources and Archives, The Tohoku Museum Tohoku University, 2.Geological Survey of Hokkaido, 3.Hirosaki University, 4.Tokyo University of Marine Science and Technology)

[BPT05-05] **Molecular mechanism which controls the shell microstructure depending on environmental changes in the Japanese pearl oyster**

*Kei Sato[1], Davin H.E. Setiamarga[2], Hiroshi Yonemitsu[2], Keita Higuchi[3], Yasunori Iwahashi[3], Kiyohito Nagai[3] (1.Faculty of Education and Integrated Arts and Sciences, Waseda University, 2.National Institute of Technology, Wakayama College, 3.MIKIMOTO Pearl REsearch Laboratory)

[BPT05-06] From artisanship to amateur: the challenge to identify large fossils using deep learning

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Adaptive evolution of marine cyanobacteria to the climate in the Neoproterozoic inferred from ancestral proteins

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The Neoproterozoic (ca. 1000–542 million years ago) must have been a remarkable period for life on Earth, marked by severe global glaciations, the oxidation of the atmosphere and ocean, and the emergence of diverse large multicellular organisms. Understanding the climatic conditions in the Neoproterozoic and their effect on life is necessary for comprehending the co-evolution of life, biogeochemical cycles, and environments during this period. Based on the $\delta^{18}O$ and $\delta^{30}Si$ compositions of marine cherts, the global seawater temperature was ~30 ºC in the Neoproterozoic, which is ~15 ºC warmer than global average temperature today. During the snowball earth events at 730-700 Ma and 665-635 Ma, the global average temperature has dropped to around -40 ºC. However, how life adapted to such warm interglacial and severe glacial periods has been poorly understood.

In the present study, aiming to clarify the temperature adaptation of life to climatic changes, we estimated the optimum growth temperatures of ancestral marine cyanobacteria lived 1.7-0.4 billion years ago based on temperature-dependent stability of experimentally “resurrected” ancestral NDK (nucleoside diphosphate kinase) proteins. NDK is the enzyme that synthesizes a nucleoside triphosphate by adding a phosphate from ATP to a nucleoside diphosphate, which denaturation temperature is known to have a strong correlation with the optimum growth temperature of its host organism. Thus, the optimum growth temperatures of the ancestral cyanobacteria can be estimated by examining the denaturation temperatures of ancestral NDKs.

10 ancestral NDKs from two monophyletic marine groups of cyanobacteria were reconstructed. The ancestral amino acid sequences were statistically estimated by Maximum Likelihood method, based on extant sequences and given two phylogenetic trees. The ancestral NDKs were expressed in *Escherichia coli* and purified to analyze denaturation midpoint temperatures (T_ms). As a result, T_ms of 8 NDKs from an ancestral marine group α-cyanobacteria diverged 1.7-0.5 Ga consistently ranged from ~65 ºC to ~70 ºC, which correspond to the optimal growth temperatures of around 33-48 ºC. On the other hand, T_ms of 2 NDKs from another marine group of cyanobacteria were ~70 ºC (~400 Ma) and ~85 ºC (~800 Ma), which correspond to the optimal growth temperatures of 37-49 ºC and 53-62 ºC, respectively.

The results suggest that the ancestors of marine cyanobacteria adapted to the sea temperatures of interglacial periods and/or the temperatures that are higher than the environments. The difference in the growth temperatures between the two lineages may indicate latitudinal difference of their habitat, or the variation in the way of adaptation between lineages. We could not find any signs of adaptation to the temperature drops during global glaciations including snowball Earths, which suggest that ancestral marine cyanobacteria may have survived the snowball Earths maintaining high/mid-temperature tolerance, with cold tolerance and suppressed growth rates.

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Keywords: Cyanobacteria, Ancestral protein reconstruction

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Ontogenetic transformations and re-interpretation of Ediacaran Trilobozoa

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One of the most noticeable groups of Precambrian Metazoa is trilobozoans (Trilobozoa Fedonkin, 1985 s.str. along with informal synonyms Tribrachiomorpha and Triradialomorpha). Their remains are common in marine sedimentary sediments of Australia and Vendian of Eastern Europe. To date, 6 monospecific genera of Trilobozoa have been described. These were small organisms, with a body diameter up to 4 cm and a height up to 5 mm. The shield-like body of trilobozoans consisted of three identical lobes (antimeres) located around the central axis which goes through the top of the shield. An extensive network of grooves separated by ridges covered the shield from the upper side. The classic Ediacaran organism, *Tribrachidium heraldicum*, is one of Trilobozoa. It had strongly curved antimeres and the appearance of a regular three-lobed swastika (migi mitsudomoe, figure). A separate cluster of grooves of the outer surface and an elongated inner cavity belonged to each antimere of *Tribrachidium*. The grooves of one cluster diverged from a small area at the top of the shield and were divided multiple times on the way to its edge. One of the ends of the internal cavity approached the same area and supposedly opened here, and this way became connected with the grooves. The branched grooves, which evenly covered the outer surface of the shield, could be lined with ciliary epithelium and form an organ responsible for collecting and transporting food. The elongated internal cavities associated with this net of grooves are considered digestive. Microparticles suspended in water could be a trilobozoan food item.
We can observe an interval of individual development of *Tribrachidium* in the preserved fossil remains. Thus, in the size interval up to 2 mm, the outer surface of the shield was smooth, and the inner space was not differentiated. While the disc diameter was from 2 to 4 mm, the internal cavities, the ridges of the sculpture, and, accordingly, the grooves of the outer surface appeared. In the interval from 4 to 5 mm, distal parts of the internal cavities were formed. Then, with growth in diameter up to 15 mm, the number of furrows and their branches increased. Further, up to the largest sizes, significant changes in the morphology of the disc did not occur. The sharp change in morphology that occurred at the beginning of the observed interval of ontogenesis can be associated with a change in the feeding method from the absorption of nutrients by the body surface to the capture of particles from the water column and their digestion in the internal cavities. Fossil remains of Trilobozoa are preserved *in situ* in the localities. However, some samples show signs that trilobozoans were not attached organisms. The loose attachment of *Albumares* to the substrate is indicated by specimens with one of the antimeres raised above the fossilization plane. Indirect indications of the mobility of *Tribrachidium* are provided by the specimens overlapping the structures of paleopascichnids, giant protozoans, spread along the surface of microbial mats. A single specimen of a trace of trilobozoan movement associated with the body imprint of *Tribrachidium* is known. The trace demonstrates a short, slightly curved depression laterally extending from the shield. The depression is covered with numerous ridges, representing casts from the grooves covering the shield. The trace was presumably left by an animal that crawled under a thin layer of silty sediment before its death. Thus, we believe that the trilobozoans were less mobile benthic seston-feeders that had gastric cavities closed at their ends and developed ciliary epithelium, but did not have tentacles. According to this body plan, they can be considered Coelenterata s. l. However, they belonged neither to the Ctenophores nor to the Cnidarians but represented a special ancient branch of Coelenterata, which probably became extinct by the beginning of the Paleozoic. This study is supported by RSF grant No. 19-14-00346.

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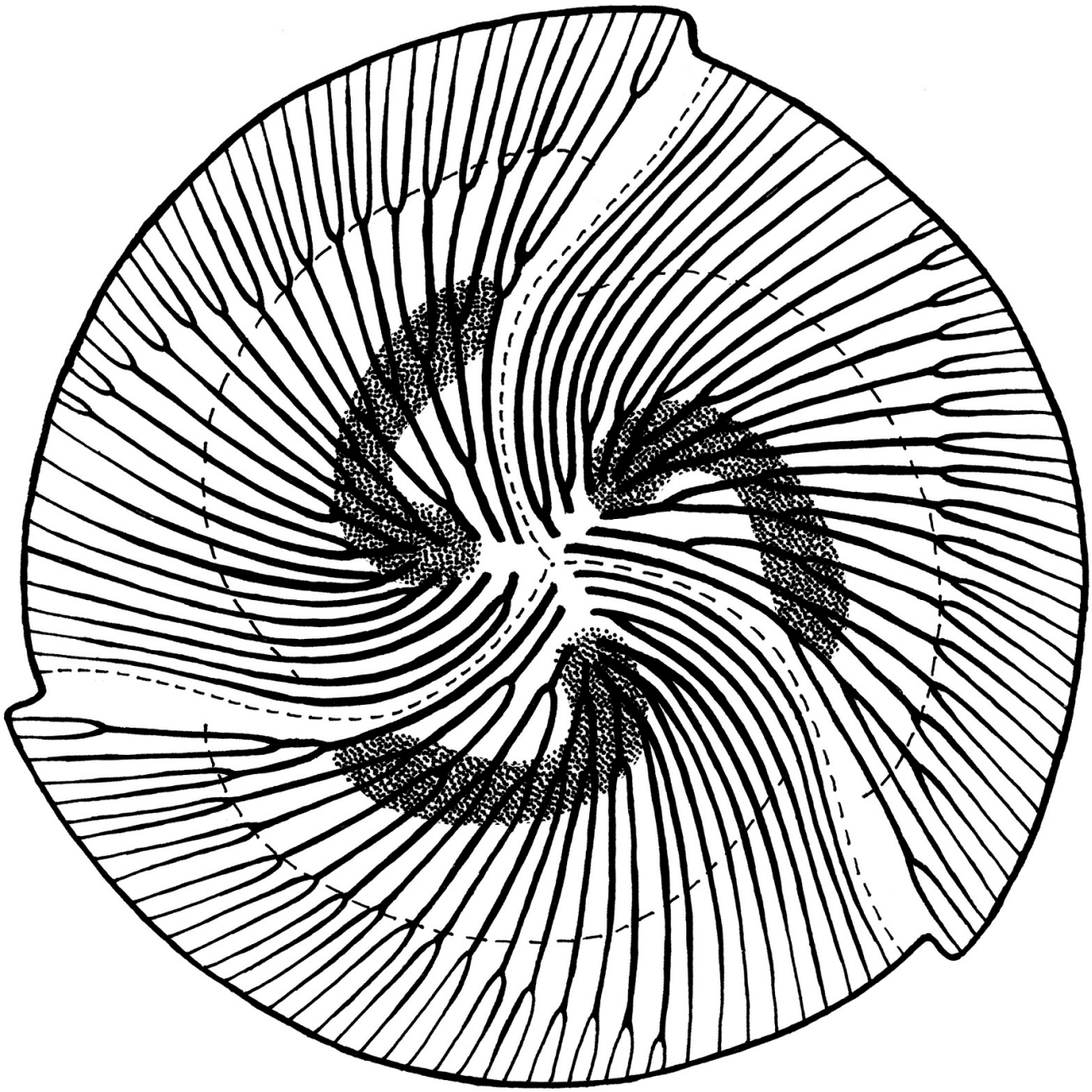
Keywords: Ediacaran, macrofossils, Trilobozoa , Tribrachidium, Coelenterata, ontogenesis



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Natural assemblages of the platform-type conodont in lowermost Triassic deep-sea black claystone from northeastern Japan, with probable soft-tissue impressions

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This presentation reports the Lower Triassic conodont assemblages which belong to genus of *Clarkina* from the Lower Triassic (Griesbachian) pelagic black claystone bed of the North Kitakami Belt in northeastern Japan (Akkamori section-5; Takahashi et al., 2019). In this horizon, four fossil assemblages include a paired segminiplanate-formed P1 element (*Clarkina*) yielded.

These fossil assemblages preserve probable impressions of ‘eye’ like sensory organs which were replaced by aggregations of silicate, phosphate, and sulphide minerals. Fossilization process of these soft-tissue impressions of conodont animals could be explained in the following. (1) Soft tissue buried in the sediments starts to decay, decreasing the pH via agents such as organic acids and sulphur reduction. (2) In such low-pH regional environments, silica clastic materials (e.g. quartz and clay) then attach to organic soft tissue surfaces, which then became coated with silicates. Authigenic minerals such as phosphate, clay, and sulphides also formed under these acidic and reductive conditions. (3) Following the maturation process (diagenesis), the replication of soft tissue was stabilised, and most of the organic materials are lost.

The occurrence of several sets of fossils that retain the original positioning of the conodonts' elemental apparatuses, as well as the original presence of soft tissue, may be attributed to the process by which the conodonts' bodies were transported to the deep seafloor, and by which the activity of agents of decomposition was inhibited in near-abiotic sediments under anoxic conditions in the pelagic deep sea during the earliest Triassic.

Reference

Takahashi et al., 2019. Palaeogeogr. Palaeoclimatol. Palaeoecol. 524, 212–229.

Keywords: Conodont, Triassic, Pelagic deep-sea

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Tephrochronological study of the Yezo Group (uppermost Albiane-basal Campanian) in Hokkaido, Japan

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The Yezo Group consists of siliciclastic marine sequence that deposited in the forearc region of the active Asian continental margin in the northwest Pacific during the Cretaceous interval. This group is the most important for the Cretaceous stratigraphy in Japan because the detailed geological ages of the group have been determined by numerous bio- and chemo-stratigraphic studies that is associated with many radiometric dating of tuff beds. Here we report the results of tephrostratigraphy in the middle to upper parts of the Yezo Group (the uppermost Albian -basal Campanian interval) based on the trace-element composition of apatite contained in tuffs, and improve the regional stratigraphic correlation of the Cretaceous sequences in the northwest Pacific region.

Our results demonstrate that the geochemical analysis of apatite grains are very useful for correlation of individual tuff beds in the Yezo Group. In particular, three widely distributed tuff beds are recognized, and they are intercalated in the lower Cenomanian, Turonian/Coniacian boundary and the Santonian/Campanian boundary. These tuff beds give the suggestion for local biostratigraphic problem where the datum plane of age-diagnostic fossils is sometimes diachronous across areas, which is attributed to the sporadic occurrences of fossils and/or different depositional settings.

Keywords: tephrostratigraphy, Cretaceous , correlation

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Molecular mechanism which controls the shell microstructure depending on environmental changes in the Japanese pearl oyster

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The shell microstructure is the micro-scale morphological trait of molluscan shells and this character closely links to the shell property such as the mechanical strength and production cost of the shell. Some studies pointed out that shell microstructural evolutions may have contributed as driving force for adaptive radiations in some molluscan taxa (e.g. Vendrasco et al., 2013; Sato & Sasaki, 2015). In addition to the paleobiological study, assessing how genetic constraints and environmental factors affect the expression of shell microstructural characters is an intriguing research topic to understand the evolution of molluscan biomineralization.

In this study, we focused on the phenotypic plasticity in Japanese pearl oyster’ s shell microstructure. Pearl oysters form unusual microstructures within their nacreous shell layer during the time they restart their shell formations (Wada, 1990). Therefore, we collected living specimens in three times; the period when animals stop their shell formations (January), the period animals restarting shell formation (April), and the normal shell formation period (August). The shell microstructures of each specimen were described using scanning electron microscopy, and also their mantle gene expressions of seven known shell matrix proteins were quantified by realtime PCR. We anew recognized the unusual microstructure which is consist of fine granular crystals from the samples collected in April. Besides, we identified the gene expression increasing of a shell matrix protein which inhibits $CaCO_3$ precipitation in the April specimens. These microstructural and molecular results are consistent with each other and imply that molluscs regulate their shell microstructure by controlling the shell matrix gene expression depending on environmental conditions.

Keywords: shell microstructure, shell matrix protein, gene expression, nacreous structure, pearl oyster

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From artisanship to amateur: the challenge to identify large fossils using deep learning

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1. The University of Tokyo, 2. The Kyushu University Museum, 3. The Mikasa City Museum

Deep Learning is a machine learning technique that allows computers to process raw data effectively. Specifically, Deep Convolutional Neural Networks (CNNs) lead to the recent success of Deep Learning in the computer vision field and achieve near-human or super-human performance on various image recognition tasks, such as image classification. CNNs learn from data to how to process data and have surpassed previous hand-crafted methods, which are carefully designed by experts. Large fossils are generally identified based on 3D morphological characters, and these characters are difficult to find except for specialists of the specific taxon of large fossils. Therefore, the identifications of fossils are treated as “artisanship.”

An extinct bivalves clade of Inoceramidae is abundant from the upper Cretaceous in Japan. More than 450 occurrences of inoceramids (paleoDB Feb.2020) were reported from Japan. These inoceramids are classified into more than 4 genera, 6 subgenera, and >50 species. Almost all species have a very short stratigraphic range, and therefore inoceramids are favorable for index fossils.

However, morphological differences between some species are small and sometimes indistinguishable for non-experts. Diagnostic features are not limited to a specific region or structure in a shell and are not defined quantitatively. Thus, learning the identification skill of inoceramids requires many years of experience and mentors who can correctly discriminate one’s identifications.

Unfortunately, the specialists of inoceramid taxonomy are at risk of “extinction” in Japan. Only one or two active researcher(s) struggle for classification or systematics of inoceramids. In contrast, for the majority of paleontologists, fossil identification was a “tool” for other research. These researchers cannot spare their time in learning the identification of inoceramids.

To overcome this situation, we will propose to use CNNs for the automatic classification of inoceramids. For this purpose, we collected 2D images of several species of Inoceramidae from 3D surfaces models for reducing their fossil color effects. After the collection, we will train CNNs to identify the species of images correctly. Because the number of available images of fossils is limited compared to other domains, we will also study methods to virtually increase the amount of data for better classification accuracy.

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[E] Oral | B (Biogeosciences)：B-CG Complex & General

[B-CG06] Decoding the history of Earth: From Hadean to the present

convener:Tsuyoshi Komiya(Department of Earth Science & Astronomy Graduate School of Arts and Sciences The University of Tokyo), Yasuhiro Kato(Department of Systems Innovation, Graduate School of Engineering, University of Tokyo), Katsuhiko Suzuki(Submarine Resources Research Center, Japan Agency for Marine-Earth Science and Technology), Kentaro Nakamura(Department of Systems Innovation, School of Engineering, University of Tokyo)

The latest results of Earth's evolution and geological processes through 4.6 billion year
s from Hadean to Modern, based on various approaches including fieldworks, chemical
analyses, experiments and computer simulation, will be presented. In this session, we ai
m to discuss and understand causal relationships and interplay among the evolution of
Earth's deep interior, changes in the surface environments, and development and evolut
ion of life. Wide-ranging topics are accepted.

[BCG06-01] REY-rich mud in the modern and past oceans

*Yasuhiro Kato[1,2], Kazutaka Yasukawa[1,2], Junichiro Ohta[1,2], Koichiro Fujinaga[2,1], Kentaro Nakamura[1] (1.Graduate school of Engineering, Univ. of Tokyo, 2.ORCeNG, Chiba Institute of Technology)

[BCG06-02] Fish debris and rare-earth deposition caused by topographically induced upwelling in the latest Eocene

★Invited Papers

*Junichiro Ohta[1,2,3], Kazutaka Yasukawa[1,3,2], Tatsuo Nozaki[3,1,4,2], Yutaro Takaya[5,2,3], Kazuhide Mimura[1], Koichiro Fujinaga[2,1], Kentaro Nakamura[1], Yoichi Usui[3], Jun-Ichi Kimura[3], Qing Chang[3], Yasuhiro Kato[1,2,3] (1.The University of Tokyo, 2.Chiba Institute of Technology, 3.Japan Agency for Marine-Earth Science and Technology, 4.Kobe University, 5.Waseda University)

[BCG06-03] Diversity of acritarchs from the 3.0 Ga Farrel Quartzite, Pilbara Craton, Western Australia

*Kenichirio Sugitani[1] (1.Nagoya University)

[BCG06-04] The MIF-Sulfur record suggests the oxygenated atmosphere and sulfate-rich oceans through geologic time

*Hiroshi Ohmoto[1] (1.The Pennsylvania State University)

[BCG06-05] Mantle data imply that secular oxidation can drive oxygenation of the atmosphere

★Invited Papers

*Shintaro Kadoya[1], David C Catling[1], Robert W Nicklas[2], Igor S Puchtel[3], Ariel D Anbar[4] (1.Department of Earth and Space Sciences / cross-campus Astrobiology Program, University of Washington, 2.Geosicence Research Division, Scripps Institution of Oceanography, 3.Department of Geology, University of Maryland, 4.School of Earth and Space Exploration and School of Molecular Sciences, Arizona State University)

[BCG06-06] Ankaramite-andesite-basalt (ANANBA) model of arc evolution

*Yoshihiko Tamura[1], Tomoki Sato[1], Osamu Ishizuka[1], Yasuhiro Hirai[1], Takashi Miyazaki[1] (1.Research Institute for Marine Geodynamics, Japan Agency for Maine-Earth Science and Technology)

REY-rich mud in the modern and past oceans

*Yasuhiro Kato[1,2], Kazutaka Yasukawa[1,2], Junichiro Ohta[1,2], Koichiro Fujinaga[2,1], Kentaro Nakamura[1]

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The potential of deep-sea “REY-rich mud” in the Pacific Ocean as a novel source for rare-earth elements and yttrium (REY) was reported in 2011 [1]. Based on a hemisphere-scale geochemical dataset of deep-sea sediments and a multivariate statistical approach using independent component analysis, we have clarified three key components as the origins of REY-rich mud: hydrogenous Mn-oxides, biogenic Ca-phosphates (fish remains), and hydrothermal Fe-oxyhydroxides [2]. Along the spreading axis, scavenging of REY dissolved in seawater by highly absorptive hydrothermal Fe-oxyhydroxide particles causes REY-rich mud with high Fe concentrations [1, 2].

Owing to plate tectonics, deep-sea sediments deposited in the past now constitute accretionary complexes along subduction margins. Therefore, REY-rich mud in the past ocean is expected to be found in the accretionary complexes. One of such a counterpart of REY-rich mud is a metalliferous sedimentary rock called “umber.” In the presentation, we will provide an overview of REY-rich mud from a modern seafloor deposit to an ancient analogue.

[1] Kato, Y. et al. (2011) *Nat. Geosci.* **4**, 535–539.

[2] Yasukawa, K. et al. (2016) *Sci. Rep.* **6**, 29603.

Keywords: seafloor mineral resources, rare-earth elements, REY-rich mud, umber, seafloor hydrothermal activity, deep-sea sediment

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Fish debris and rare-earth deposition caused by topographically induced upwelling in the latest Eocene

*Junichiro Ohta[1,2,3], Kazutaka Yasukawa[1,3,2], Tatsuo Nozaki[3,1,4,2], Yutaro Takaya[5,2,3], Kazuhide Mimura[1], Koichiro Fujinaga[2,1], Kentaro Nakamura[1], Yoichi Usui[3], Jun-Ichi Kimura[3], Qing Chang[3], Yasuhiro Kato[1,2,3]

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Microscopic fish skeletal debris (fish teeth, denticles, and bones) are the only fossil remains well preserved in pelagic brown clay in which calcareous and siliceous nannofossils are hardly preserved. Since pelagic brown clay deposited in world wide areas of open ocean, fish debris can be a biological proxy in these areas. In addition, fish debris highly concentrates rare earth element after deposition. Thus, fish debris-rich deep-sea sediment is now recognized as a new deep-sea resource for rare earth elements [1].

In 2013, a deep-sea sediment extremely enriched in fish skeletal debris and rare earth elements was found in western North Pacific [2,3]. The maximum contents of fish debris and rare earth elements were reported to be ~30% and ~7000 ppm, respectively [2,3]. To unravel the causes of the anomalous accumulation of fish debris and rare earth elements, we determined the depositional age of this fish debris-rich sediment based on osmium isotope stratigraphy. Depositional ages of sediment samples can be obtained by comparing the measured osmium isotope ratios ($^{187}Os/^{188}Os$) in the samples with the reconstructed seawater $^{187}Os/^{188}Os$ curve [4].

Our osmium isotope measurement and age assignment revealed that the deposition of the fish debris-rich sediment was contemporaneous with the first appearance of the Antarctic ice-sheet in the latest Eocene. At this time, the ice-sheet cooled high southern latitude and could have invigorated Antarctic bottom water formation [5]. The enhanced northward flow of bottom water would have stirred nutrient-rich deep ocean and led to nutrient upwelling on topographic barriers such as seamounts [6], which resulted in flourishment of pelagic organisms
including fish. Consequently, an anomalous amount of fish debris has deposited and now constitutes a huge storehouse for rare-earth elements.

[1] Takaya et al. (2018) *Sci. Rep.* **8**, 5763. [2] Iijima et al. (2016) *Geochem. J.* **50**, 557-573. [3] Ohta et al. (2016) *Geochem. J.* **50**, 591-603. [4] Peucker-Ehrenbrink & Ravizza (2012) In *Geologic Time Scale 2012*, 145-166. [5] Goldner et al. (2014) *Nature* **511**, 574-577. [6] Hein et al. (1993) *Paleoceanography* **8**, 293-311.

Keywords: Fish skeletal debris, Rare-earth elements, Osmium isotope

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Diversity of acritarchs from the 3.0 Ga Farrel Quartzite, Pilbara Craton, Western Australia

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1. Nagoya University

Among reported Archean microfossils, assemblages from the 3.0 Ga Farrel Quartzite and the 3.4 Ga Strelley Pool Formation in the Pilbara Craton of Western Australia are particularly important. They are morphologically diverse, including small and large spheroids (5~60 μm in diameter), "films" up to 300 μm across, thin and thick filaments (1~10 μm in width), and lenses from 20 to 100 μm across. The biogenicity of these microfossils, particularly lenses, has long been subjected to skepticisms, as their size and morphological complexity are unexpected for the early Archean "primitive" life. However, through multidisciplinary studies performed by over 20 researchers from 6 countries have demonstrated the biogenicity of lenticular microfossils. Here new image data of the Farrel Quartzite microfossils obtained by acid maceration are presented, providing further evidence for biogenicity and morphological diversity. Extracted microfossils include large flexible spheroids with thick or thin wall, paired lenses, linearly arranged multiple lenses, two dimensionally arranged lenses, three-dimensionally connected small rigid spheroids, and others. Their Raman spectra are identical to those obtained for carbonaceous clots and microfossils in petrographic thin sections, indicating that they are not contaminants. Abundant paired lenses corresponding to sequence of ordinary binary fissions are consistent with biogenicity and inconsistent with alternative interpretation that they are lenticular colony or biofilm-coated volcanic vesicles. This study also provides firm evidence for that each morphological type (e.g., small spheroid, large spheroid, and lens) is composed of multiple taxa as implied from examination of petrographic thin sections. Biotic diversity and preservation of the Farrel Quartzite microfossils are outstanding and may transform our images of Archean life.
Figure 1. a) Large spheroid with thick flexible wall; b) Two dimensionally arranged colony of lenses; c) Paired lenses; d) Tripled lense; e) Cluster of rigid small spheroids; f) Paired lenses associated with small spheroids. Scale bars = 50 μm.

Keywords: Archean, acritarch, Pilbara Craton

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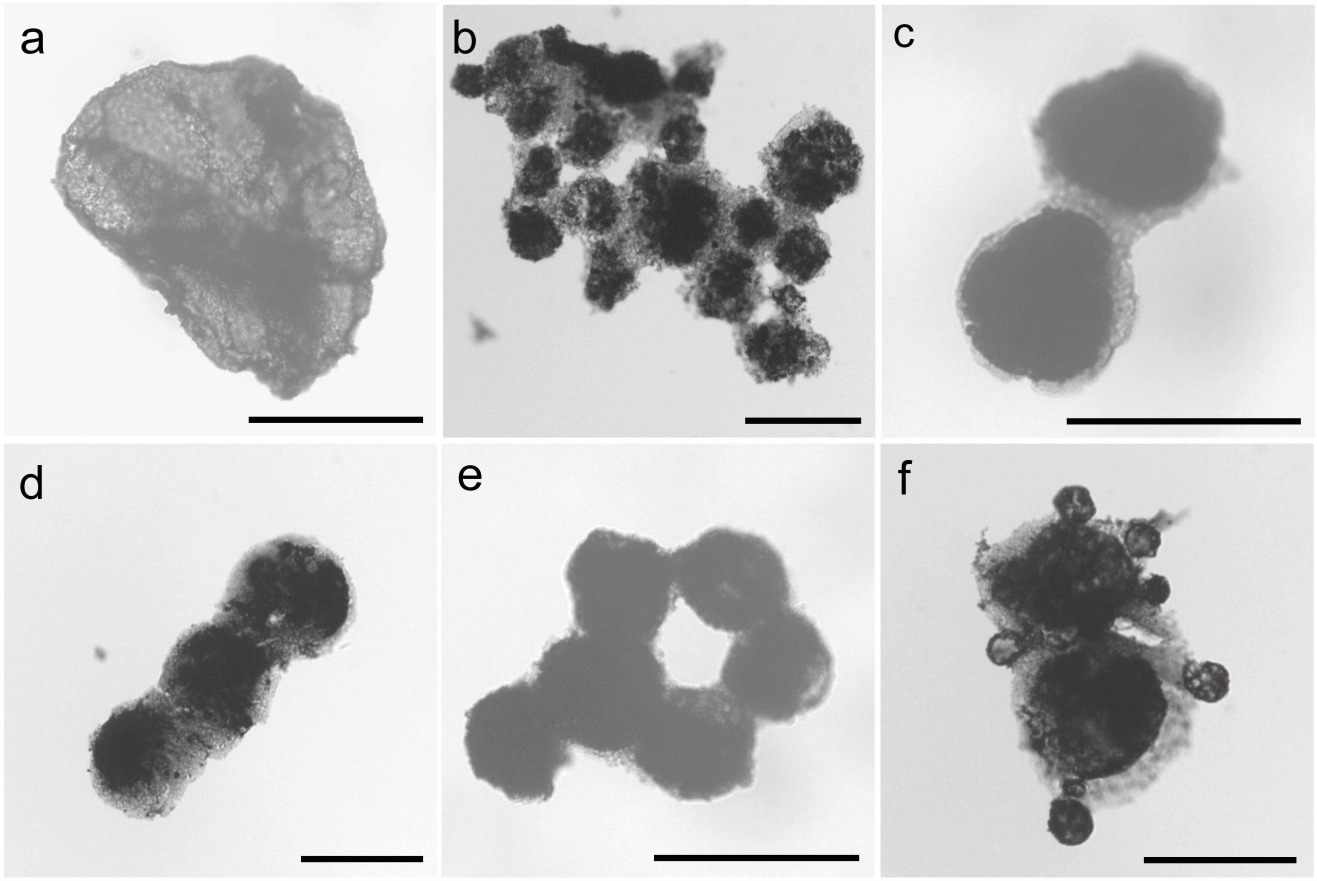

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The MIF-Sulfur record suggests the oxygenated atmosphere and sulfate-rich oceans through geologic time

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1. The Pennsylvania State University

The presence of mass-independently-fractionated sulfur isotopes (MIF-S) in Archean-aged sedimentary rocks, and the scarcity of MIF-S in younger rocks, have been accepted by most geoscientists as unequivocal evidence for an anoxic Archean atmosphere and the G.O.E. at ~2.5 Ga. This theory has been based on an (unspoken) assumption that the MIF-S was created mostly near the Earth surface by the UV photochemical reactions of volcanic SO_2. UV with wave lengths 190-350 nm, which are responsible for the photochemical reactions of SO_2, would be largely blocked by the ozone shield if the P_{O2} had been greater than 10^{-5} PAL in the troposphere[1]. Here I suggest that the MIF-S signatures in Archean-aged sedimentary rocks were generated by: (1) the UV photochemical reactions in the stratosphere (> ~15 km above sea level) over an oxygenated troposphere of the SO_2 emitted by Plinian-type explosive volcanic eruptions, and/or (2) high temperature (> ~150˚C) heterogenous reactions between SO_4^{2-} and highly-reactive organic matter (solid or liquid) in marine basins where abiotic, cell-free organic matter was abundantly produced by submarine hydrothermal processes. Both processes (atmospheric and oceanic) for MIF-S creation would have been important on early Earth when the Earth was hotter and magmatism was more intensive and extensive on land and in oceans than today.

The above suggestions are based on the following discoveries: (i) the MIF-S in sulfates associated with volcanic ashes from Plinian-type explosive volcanic eruptions (e.g., Mt. Pinatubo and Mt. Agung)[2]; (ii) the abundance of ash layers in MIF-S-bearing Archean shales[3]; (iii) the abundance of MIF-S-free Archean-aged sedimentary rocks[4]; (iv) the experimental evidence for the creation of MIF-S by UV-induced photochemical reactions of SO_2 in O_2-rich atmospheres[5]; (v) the evidence in 2.7 Ga-old Fe-micro meteorites of an O_2-rich upper atmosphere[6]; (vi) the MIF-S in sulfate associated with aerosols that were generated from the burning of pyrite-rich coals[7]; (vii) the experimental evidence for the creation of MIF-S during thermochemical sulfate reduction by amino acids[8]; (viii) the sub-nanometer-sized particles of hydrothermally-synthesized organic matter in 3.46 Ga-old jasper beds[9]; and (ix) the various lines of evidence for an O_2-rich atmosphere and O_2- and sulfate-rich oceans during the Archean[10], including, but not restricted to the following: (a) the abundance ratios of redox-sensitive elements in paleosols, sedimentary rocks, and deep-submarine volcanic rocks; (b) the abundance of pyrite and barite in sedimentary rocks and submarine hydrothermal deposits; (c) the $d^{34}S$ and $D^{33}S$ records of submarine hydrothermal deposits and sedimentary rocks; (d) the scarcity of detrital kerogen in Precambrian-aged sedimentary rocks; (e) the $d^{13}C$ records of carbonates and kerogen; and (f) the abundance of magnetite-series (i.e., oxidized-type) granitoids.

References: 1: Farquhar et al. (2000), Kasting et al. (1989). 2: Savarino et al. (2003), Baroni et al. (2007). 3: Unpublished data. 4: Ohmoto et al. (2009). 5: Whitehill et al. (2015). 6: Tomkins et al. (2016). 7: Romeo & Thiemaens (2003), Han et al. (2017). 7: Watanabe et al. (2008), Oduro et al. (2011). 9: Graham et al. (2018). 10: Ohmoto et al. (in prep.).

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Keywords: Atmospheric evolution, MIF-Sulfur, Volcanic eruptions

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Mantle data imply that secular oxidation can drive oxygenation of the atmosphere

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One of the major components of the modern Earth’ s atmosphere is O_2, which is produced by photosynthesis and is necessary for aerobic lifeforms, including humans. However, according to geological evidence, such as mass-independent sulfur isotope fractionation, O_2 levels in the atmosphere were low during the Archean, even after the emergence of oxygenic photosynthesis around 3.2 - 2.8 Ga. It took several hundreds of millions of years before the O_2 level increased around 2.4 Ga, which is the start of the Great Oxidation Event (GOE) from ~2.4 to ~2.1 Ga.

In a majority of the literature, a delay of atmospheric oxygenation has been attributed to a secular decrease in O_2 sinks rather than a secular increase in O_2 sources. However, the actual mechanism for the decrease in O_2 sinks is still uncertain. One possibility is the secular oxidation of the mantle, which decreases the proportion of reducing gases in volcanic emissions and therefore, lowers the O_2 sinks relative to CO_2 fluxes, where CO_2 is a substrate for O_2 production. Although secular mantle oxidation has been long dismissed, two new studies reveal that the oxygen fugacity of the mantle increased by ~ 1.3 log $_{10}$ units from the Archean onward. These studies qualitatively suggest that the new trend of the mantle redox state would cause the oxygenation of the atmosphere.

Here, we quantitatively examine the possibility of atmospheric oxygenation caused by mantle oxidation using the data from the new studies. We calculate a ratio of O_2 sources to rapid O_2 sinks: the oxygenation parameter, K_{oxy}. As explained in the previous studies, K_{oxy} less than unity indicates a reducing atmosphere, while K_{oxy} larger than unity indicates an oxic atmosphere. The effect of secular mantle oxidation increases K_{oxy} with time: K_{oxy} shifts from < 1 to > 1 at ~ 2.5 Ga. Hence, mantle oxidation would trigger the GOE around 2.5 Ga. On the other hand, if we model the mantle with a constant oxidation state, a shift of K_{oxy} from < 1 to > 1 never occurs.

These results do not exclude the possibility that other processes proposed previously contributed the GOE, such as a shift from the submarine to subaerial volcanoes, a secular increase in the degassing ratio of carbon and/or sulfur to hydrogen, and/or a decrease in hydrogen flux via serpentinization. The exact timing of the GOE (~2.4 Ga) is probably explained by combining these processes with the effect of mantle oxidation on the atmosphere. However, our results show that mantle oxidation alone could drive the oxygenation of the atmosphere.

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If secular oxidation of the mantle ultimately controlled the timing of the GOE, then the cause of mantle oxidation is ultimately important for setting the tempo of biological evolution. Possible drivers of mantle oxidation are the mixing of a redox heterogeneous mantle and/or the escape of hydrogen to space. Such processes could also apply to other Earth-like planets and would determine whether such planets could be habitats for aerobic lifeforms.

Keywords: GOE

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Ankaramite-andesite-basalt (ANANBA) model of arc evolution

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1. Research Institute for Marine Geodynamics, Japan Agency for Maine-Earth Science and Technology

Primitive and phenocryst-rich ankaramitic basalts were recovered from the old submarine knolls near Nishinoshima (Tamura et al., 2019), Doyo seamount 50 km north of Nishinoshima, and Kibblewhite volcano in the Kermadec arc (Hirai, 2020 PhD thesis). We suggested that lithospheric mantle was thicker before the development of andesite volcano like Nishinoshima. Primary basaltic magmas could have been generated at depth beneath the thicker lithospheric lid, and these magmas might have interacted with the lithospheric uppermost mantle during their ascent and have resulted in the unique ankaramite magmas. The temperature of the upper part of the mantle wedge increases with frequent passage of magmas through it, and continuous subduction beneath it will drench the whole mantle wedge, thus, the thickness of the lithosphere will decrease and approach the thickness of the curst in mature arcs. Doyo Seamount could represent the early stage of Nishinoshima volcano, and thus, ankaramite magma is deemed to be a precursor of andesitic magmas.
Olivine-bearing phenocryst-poor andesites found in older submarine lavas from the flanks of the volcano have been used to develop a model for the genesis of andesitic lavas from Nishinoshima (Tamura et al., 2019). Primary andesite magmas originate directly from the mantle as a result of shallow and hydrous melting of plagioclase peridotites. Andesites erupted from Nishinoshima that were produced in the recent history of the volcano have been generated by olivine fractionation of primary andesitic magmas (Tamura *et al.*, 2019).
When crust becomes thicker than 30 km like northern parts of the Izu-Ogasawara arc (Izu-Oshima volcano, Miyake-jima volcano etc), only basalt magmas are produced in the mantle wedge of subduction zones.We present here the evolution model of oceanic arc volcanoes, which start from ankaramites through andesites to basalts (ANANBA model).

Keywords: ankaramite, andesite, basalt

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[E] Oral | B (Biogeosciences)：B-CG Complex & General

[B-CG06] Decoding the history of Earth: From Hadean to the present

convener:Tsuyoshi Komiya(Department of Earth Science & Astronomy Graduate School of Arts and Sciences The University of Tokyo), Yasuhiro Kato(Department of Systems Innovation, Graduate School of Engineering, University of Tokyo), Katsuhiko Suzuki(Submarine Resources Research Center, Japan Agency for Marine-Earth Science and Technology), Kentaro Nakamura(Department of Systems Innovation, School of Engineering, University of Tokyo)

The latest results of Earth's evolution and geological processes through 4.6 billion year
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analyses, experiments and computer simulation, will be presented. In this session, we ai
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Earth's deep interior, changes in the surface environments, and development and evolut
ion of life. Wide-ranging topics are accepted.

[BCG06-07] Hydrogen isotope analysis of apatite inclusions in the Hadean to early Archean zircon

Daiki Tanaka[1], *Shinji Yamamoto[1], Shoichi Itoh[2], Shuhei Sakata[3] (1.Graduate School of Environment and Information Sciences, Yokohama National University, 2.Graduate School of Faculty of Science, Kyoto Uiversity, 3.Earthquake Research Institute)

[BCG06-08] Occurrence and chemical composition of carbonate rocks in the Nuvvuagittuq supracrustal belt, Quebec, Canada: Implications for chemical composition of the Eoarchean hydrothermal fluid

★Invited Papers

*Yoshida Satoshi[1], Yusuke Sawaki[2], Tsuyoshi Komiya[2] (1.Department of Earth & Planetary Science, Graduate School of Science, The University of Tokyo, 2.Department of Earth Science & Astronomy, Graduate School of Arts and Sciences, The University of Tokyo)

[BCG06-09] Depositional setting and biological activity highlighted by Cr concentration, 3.2 Ga Moodies Group, Barberton Greenstone Belt

*Yoko Ohtomo[1], Daizo Yamauchi[1], Tsubasa Otake[1], Tsutomu Sato[1] (1.Faculty of Engineering, Hokkaido University)

[BCG06-10] Effect of Hydrocarbon Haze on Climate Stability under Mildly Oxidized Late-Archean Environment

★Invited Papers

*Yasuto Watanabe[1], Eiichi Tajika[1], Kazumi Ozaki[2], Peng Hong[3] (1.The University of Tokyo, 2.Toho University, 3.Chiba Institute of Technology)

[BCG06-11] The demise of the positive carbon isotope excursion in the Paleoproterozoic Francevillian Basins, Gabon

*Tomohiko Sato[1], Yusuke Sawaki[2], Shigenori Maruyama[1], Karen Bakakas[3], Mathieu Moussavou[3], Ambroise Edou-Minko[3] (1.Tokyo Institute of Technology, 2.The University of Tokyo, 3.University of Sciences and Technology in Masuku)

[BCG06-12] Sponge-like grains and negative excursion of carbon isotopes in late Cryogenian

*Akihiro Kano[1], Yuki Eguchi[1] (1.Graduate School of Science, The University of Tokyo)

Hydrogen isotope analysis of apatite inclusions in the Hadean to early Archean zircon

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We measured hydrogen isotopic composition of apatite inclusions trapped in Hadean to early Archean igneous zircons from sedimentary rocks in Jack hills greenstone belt and tonalitic rocks in Acasta gneiss, Labrador gneiss, and Tanzawa tonalite in order to compare the isotopic ratio of ancient ocean with that of modern oceanic water.

Hydrogen isotope analysis with SIMS show the data sets with the range about δD=-50 to -340 from Jack Hills zircons (3.3 to 4.3 Ga), -15 to -265‰ from Acasta (3.5 to 4.0 Ga) and Labrador (3.8 to 3.9 Ga), and -57±19‰ from Tanzawa tonalite (4.5 Ma) samples. In addition, we evaluated the micro-cracks in zircon to exclude the negative possibility of secondary hydrogen interaction of apatite inclusions. Assuming the magma type the apatite crystalized, Arc-type apatite have the composition δD= -106 to -170‰, and Mantle-type have δD= -232±27‰ and -338±22‰, respectively. The data set above-mentioned result in the Archaean ocean δD= -84±19‰ and mantle water δD= -232±27‰ and -338±22‰.

Keywords: Hadean-early Archean, zircon, apatite, hydrogen isotope analysis

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Occurrence and chemical composition of carbonate rocks in the Nuvvuagittuq supracrustal belt, Quebec, Canada: Implications for chemical composition of the Eoarchean hydrothermal fluid

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The Earth is a unique planet where liquid water and life exist through the geologic time. Therefore, an estimate of surface environmental conditions of the surface environment of the early Earth is an important issue to reveal early life. However, we know little about the early Earth, because the first 500-million-year records of the Earth was almost lost.
Recent studies suggested that the Nuvvuagittuq supracrustal belt (NSB) in Quebec, Canada, was formed 4.28 billion years ago (O'Neil et al., 2008). Therefore, the NSB has gained attention in the decoding of the early Earth history.
Previous studies showed that the origin of BIF occurred in the NSB is originated from chemically sedimentary rock based on their Post-Archean Average Shale (PAAS)-normalized rare earth element (REE) patterns, including positive La, Eu, and Y anomalies (Mloszewska et al., 2012; 2013). The La and Y positive anomalies are recognizable in the modern seawater, and the positive Eu anomaly is a diagnostic signature of hydrothermal fluid. Therefore, these features are regarded as powerful proxies in discussing the origin of metamorphosed and altered Archean sedimentary rocks (e.g. Bolhar et al., 2004). In particular, it is considered that the positive Y anomaly is mainly formed by precipitation of iron oxides in the ocean (e.g. Nozaki et al., 1997). Mloszewska et al. (2013) also described occurrence of carbonate rocks in the NSB, and argued that it was formed through metasomatic alteration based on its occurrence. However, they did not estimate the chemical compositions of hydrothermal fluids that caused metasomatic alternation. Therefore, we try to decode the Eoarchean hydrothermal fluid chemical composition using the carbonate rocks in the NSB.
In 2018, we found some new outcrops of carbonate rocks in the NSB. Most of the carbonate rocks in the NSB occur as vein within mafic rocks or silicic sedimentary rocks. As suggested by the previous study, it is considered that the carbonate rocks were formed through metasomatism. We analyzed major and trace element (e.g. REE and Zr) contents of whole rocks of the carbonate rocks using X-ray Fluorescence for major elements and High-Resolution Inductively Coupled Plasma Mass Spectrometry for trace elements at the University of Tokyo, respectively. Some carbonate rocks have high SiO_2, Al_2O_3, and Zr contents, possibly due to involvement of detrital and volcanic materials with/without silicification. We selected the carbonate rocks with low SiO_2, Al_2O_3, and Zr contents in order to remove influence of the silicification and contamination of the detrital materials. The PAAS-normalized REE patterns of the almost all of the carbonate rocks show LREE-depleted patterns with positive La, Eu (Eu/Eu*: 1.01-2.87) and Y (Y/Ho: 34.3-48.1) anomalies and some samples show a negative Ce anomaly.
Generally speaking, positive La and Y anomalies of carbonate rocks indicate that they originate from chemical sediments precipitated from seawater (e.g. Webb and Kamber, 1999; Bolhar et al., 2004). Although the carbonate rocks in the NSB have the La and Y anomalies, their geologic occurrence suggests that these carbonate rocks were formed through metasomatism. Namely, their chemical signatures are inconsistent with the geological occurrence. The inconsistency may indicate that the Y and La anomalies are not necessarily robust proxies for origins of the Eoarchean sedimentary rocks. A combination of their chemical composition and geological occurrence is essential for the estimate of origins.

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In general, it is considered that a Ce anomaly can be formed by oxidation of trivalent Ce to less soluble tetravalent Ce and then the subsequent absorption of Ce to Fe oxide. However, our result suggests that metamorphic fluids have the Ce anomaly because the carbonate rocks in the NSB have the negative Ce anomaly. If the hydrothermal fluids in the Eoarchean were more alkaline than previously expected, the Ce would be tetravalent. Also in this case, Ce is adsorbed to iron oxide and removed as described above. Hofmann and Harris (2008) reported the negative Ce anomaly from the Eoarchean altered basalt in the Barberton greenstone belt, and interpreted that Ce was removed by iron oxides in the hydrothermal system. Our result supports the mechanism.
A negative Y anomaly have been reported in carbonated or weathered basalts (e.g. Nakamura and Kato, 2004; Babechuk et al., 2015), but generation processes of the anomaly is still unknown. Therefore, further studies of causes of the positive Y anomaly in the Eoarchean carbonated basalt will be required.

Keywords: Nuvvuagittuq supracrustal belt, Carbonate rock, Eoarchean

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Depositional setting and biological activity highlighted by Cr concentration, 3.2 Ga Moodies Group, Barberton Greenstone Belt

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Previous studies suggest that atmospheric oxygen increased by emergence of cyanobacteria at 2.45 Ga Great oxidation event (GOE). Fluctuation of microbial activities prior to prosperity of cyanobacteria and oxidation state might be expected in shallow ocean before GOE. 3.2 Ga Moodies Group, Barberton Greenstone belt, South Africa, is focused as a significant archive of shallow ocean environment before GOE which consists of detrital sedimentary rocks including Banded Iron Formations (BIFs), chemical deposits associated with microbial activities in terms of the Fe oxidation process. In such a transitional environment, behavior of redox-sensitive elements can be important factors to evaluate oxidation state. In this study, we performed detail observation of Cr-bearing minerals as an indicator of redox state together with geological, petrological and geochemical investigation to understand fluctuation of depositional setting and biological activity on 3.2 Ga shallow BIFs of Sheba gold mine, Moodies Group.

Rock samples were classified into Sandy-siltstone (6.1–16.3 wt% Fe_2O_3), Carbonate rich (Carb-) siltstone (21.6–32.8 wt% Fe_2O_3) and Magnetite rich (Mgt-) siltstone (18.9–50.2 wt% Fe_2O_3) based on petrographic observations. Modal analysis indicates that grain size ratio of <30 : > 30 (μm diameter) without chemical precipitates are almost identical in all rock types, suggesting they deposited at identical sedimentary depth although Fe host minerals are different from each other (Sandy- and Carb-siltstone: carbonate and silicate, Mgt-siltstone: magnetite). Contents and stable isotope ratios of organic carbon in these samples indicate 0.03–0.29 wt% and ~−27 per mil, suggesting the biogenic origin. Carbon stable isotope ratio of carbonate ranges −12.5 to −3.4 per mil, which indicates isotopic contribution of organic carbon to carbonate. Morphologies of organic materials extracted by acid-treatment are classified into three types: 30–50 μm flake, > 100 μm filament and ~50 μm indeterminate grain. Carb-siltstone is rich in filaments compared to Mgt-siltstone although Carb-siltstone and Mgt-siltstone deposited in identical sedimentary settings. The result suggests multiple microbial species and fluctuation of the microbial activities in 3.2 Ga shallow oceans.

Host mineral of Cr is ~50 μm chromite surrounded by magnetite in Mgt-siltstone, on the other hand, chromite is rare in Sandy- and Carb-siltstone and it is not accompanied by magnetite. Point counting of thin sections indicates that Mgt-siltstone contain ~60-130 chromite grains/cm^2, whereas Sandy and Carb-siltstone contain < 20 chromite grains/cm^2, although bulk Cr concentrations are almost identical (Mgt-siltstone: 166-1341ppm, Sandy- and Carb-siltstone: 455-1449ppm). FE-EPMA analysis showed that main host minerals of Cr in Sandy- and Carb-siltstone are biotite and chlorite which contain 1.22± 0.66wt% and 1.54±0.58wt% Cr_2O_3 respectively, whereas biotite and chlorite in Mgt-siltstone contain 0.26±0.40wt% Cr_2O_3. The variation of Cr host minerals coupled with rock facies cannot be explained by simple Cr source such as detrital chromite supply from weathered igneous rocks under anoxic condition. Our results suggest Cr^{6+} was dissolved in 3.2 Ga shallow oxic ocean and distributed to silicate or concentrated in magnetite during early diagenesis after coprecipitation with iron hydroxide. Bulk Cr/TiO_2 ratio showed positive correlation with Fe_2O_3/TiO_2 ratio in all rock types and high values in Mgt-siltstone, which also supports coprecipitation of Cr and Fe.
In summary, our data indicates that fluctuation of multiple microbial activities and subsequent changes of mineral assemblages including host minerals of Fe and Cr in 3.2 Ga shallow ocean: when microbial

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activities were low, iron hydroxide coprecipitated with Cr ($Cr^{6+} + Fe^{2+} + 3OH^- \rightarrow Cr^{3+}$, $Fe^{3+}(OH)_3$) at the redox boundary and converted to magnetite-chromite during early diagenesis. When microbial activities were high, iron hydroxide coprecipitated with Cr and converted to carbonate using parts of organic carbon buried together during early diagenesis. Cr was then distributed to surrounding biotite and chlorite due to the lack of the available sites in crystal structure of carbonate.

Keywords: Moodies Group, Chromite, Organic matter

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Effect of Hydrocarbon Haze on Climate Stability under Mildly Oxidized Late-Archean Environment

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The atmospheric oxygen level (pO_2) is suggested to have been lower than 10^{-5} PAL (present atmospheric level) based on an existence of mass-independent isotope fluctuation of sulfur in the Archean (e.g. Pavlov and Kasting, 2002). During the Late Archean (3.0-2.5 Ga), temporal increases of pO_2 are suggested from concentrations of redox sensitive trace elements (e.g. Anbar et al., 2007), which might have been associated with the onset of oxygenic photosynthesis in the ocean. On the other hand, there is a record of co-variation of carbon and sulfur isotopes, which might have reflected a transient formation of hydrocarbon haze, meaning a transient appearance of very reducing atmosphere in the Late Archean (Zerkle et al., 2012; Izon et al., 2017). These records suggest that the atmospheric composition in the Late Archean could have significantly varied. Previously, how the rise of oxygen in the atmosphere affects the global carbon cycle has been discussed in various context and in different ages. However, how the formation of haze has affected global carbon cycle in the Late Archean has not been investigated considering the atmospheric and marine microbial reactions. Here we used a coupled model of atmospheric photochemimstry-marine microbial ecosystem-global carbon cycle, in which the photochemical model "Atmos" (Arney et al., 2016) is included, to investigate how the production of the hydrocarbon haze affected the global carbon cycle and climate stability under mildly oxygenized condition in the Late Archean ($f(O_2)$ ~10^{-6} PAL) and under completely anoxic condition in the Middle Archean ($f(O_2) < 10^{-10}$ PAL). In both cases, hydrocarbon haze is formed in the atmosphere when CH_4/CO_2 is more than around 0.2, consistent with Arney et al. (2016). We found that, the formation of hydrocarbon haze works as a CO_2 consumption pathway in the atmosphere under completely anoxic condition, because the formation/removal rates of hydrocarbon haze increase according to the decreasing pCO_2. This means that, hazy climate state is unstable under anoxic condition. In the mildly oxidized world, on the other hand, the formation/removal rates of hydrocarbon haze were not affected significantly by the change in pCO_2, so that the hazy condition becomes stable by the silicate weathering negative feedback. This result suggests that there is a negative feedback mechanism concerning the formation rate of hydrocarbon haze under mildly oxidized atmosphere, through changes in the UV flux in the atmosphere and atmospheric redox condition. Our result is consistent with the geological records that suggests the transient formation of hydrocarbon haze in the Late Archean.

Keywords: Archean, Early Earth, Carbon Cycle

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The demise of the positive carbon isotope excursion in the Paleoproterozoic Francevillian Basins, Gabon

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In the history of the carbon cycle on the Earth, ~2.2-2.1 Ga was an unprecedented interval with positive $\delta^{13}C_{carb}$ (>5‰) recorded in carbonate rocks all over the world (Martin et al., 2013). It is called the Lomagundi-Jatuli event (LJE) and interpreted as the result of high rate of organic-carbon burial in the same period (Karhu & Holland, 1996); however, how it ended still remains unexplained. The Paleoproterozoic sedimentary sequence of the Francevillian basins in Gabon has a negative shift of $\delta^{13}C_{org}$ (Gauthier-Lafaye & Weber, 2003), which is assumed to correspond to the end of the LJE (Kump et al., 2011). In addition, it also has fossil horizons of possible eukaryotes (Albani et al., 2010) or large colonial organisms (Edou-Minko et al., 2017). Thus, the Francevillian basins are the key to clarify the relation between the changes of ecosystem and carbon cycle of the period; however, $\delta^{13}C_{carb}$ stratigraphy has not been well established because carbonate rocks are minor in the main Franceville basin. We focused on the neighboring Lastoursville basin, which has carbonate-rich facies, and investigated the detailed $\delta^{13}C_{carb}$ stratigraphy. The Paleoproterozoic sequence in the Lastoursville basin consists of FA (sandstones; >30 m), FB (carbonates and mudstones; ~200 m), FC (cherts; ~10 m), and FD (mudstones and carbonates; >80 m) formations in ascending order. We analyzed $\delta^{13}C_{carb}$ and $\delta^{13}C_{org}$ of the samples (carbonates and mudstones in FB-FD) obtained from the outcrops and the drill cores. As a result, we identified the negative shift of $\delta^{13}C_{carb}$ from +5‰ to -2‰ in the middle of the FB formation as the demise of the stable positive excursion (+5‰~+8‰). At the same interval, the carbon isotope fractionation ($\Delta = \delta^{13}C_{carb} - \delta^{13}C_{org}$), changed from ~30‰ in the lower FB, suggesting carbon fixation by the Calvin cycle, to ~45‰ in middle FB, suggesting methanotrophic activity. By the stratigraphic correlation with the Franceville basin, the $\delta^{13}C_{carb}$ negative shift apparently underlies the fossil horizons at the uppermost FB. It means that the major change in the carbon cycle preceded the appearance of the macroscopic organisms in the Francevillian basins.

Keywords: Paleoproterozoic, carbon isotope, Gabon

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Sponge-like grains and negative excursion of carbon isotopes in late Cryogenian

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Multicellular animals have evolved when the Earth experienced the Neoproterozoic Snowball Events. The oldest and currently well-accepted multicellular animals are the Ediacaran embryos, but biomarker and fossil records imply that sponges already evolved in Cryogenian. One of the examples is the sponge-like grains reported from South Australia, which have an internal channel system (Maloof et al. 2010). However, other researches considered that they are fragments of lithified microbial mat (Anticliff et al. 2014).

The Trezona Formation in Flinders Ranges, which yields the sponge-like grains, is 156 m thick sequence consisting of alternation of shallow-marine limestone and shale. Carbon isotopic values of limestone is in a range from −9 to −7‰ and correlated with the Trezona negative excursion just before the Marinoan glaciation. The grains of less than 2 cm in diameter exhibit various colors and textures. Among them, dark brown grains with an internal pore system and curved configuration are the sponge-like grains of Maloof et al. (2010). Internal pores are 0.1−0.2 mm thick and 1−2 mm wide, and complicated intersection forms a honeycomb structure.

EPMA and XRD analyses indicate hematite scattering within the sponge-like grains. This is similar with occurrence known from the Phanerozoic echinoderm grains, which were formed by iron oxide precipitation in a μm-sized pore system called steroem. Thus, the sponge-like grains has such smaller-sized pore system. A possible interpretation is that this corresponds to Ostia of sponges, and that the honeycomb structure is Osculum of sponges. This animal secreted platy skeletons like the Paleozoic stromatoporoids, and this could be the oldest biomineralization.
The Tresona excurtion in this time and the Shrum excursion during late Ediacaran were likely formed by re-mineralization of organic matter suspended in water column. There is a hypothesis that sponges were responsible for the re-mineralization of organic matter (Sperling et al. 2018). The animal of the oldest biomineralization had extinct by the Marinoan Snowball, and non-skeletal sponges became abundant in late Ediacaran. Biomineralization resumed 80 myr later by the latest Ediacaran *Cloudina* group.

Keywords: Cryogenian, sponges

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[E] Oral | B (Biogeosciences)：B-CG Complex & General

[B-CG07] Phanerozoic biodiversity change: radiation and extinction

convener:Yukio Isozaki(Department of Earth Science and Astronomy, Multi-disciplinary Sciences - General Systems Studies, Graduate School of Arts and Sciences, The University of Tokyo), Yusuke Sawaki(The University of Tokyo)

This session explores the latest progress in the paleobiodiversity studies, particularly about the final 500 m.y.-long history of life during the Phanerozoic. All paleo-environmental, stratigraphic, and paleotological studies are welcome.

[BCG07-01] Hierarchy in mass extinction causes: from direct kill mechanism to ultimate cause

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[BCG07-02] A relationship between paleomagnetic data and biodiversity during the Phanerozoic

*Yasushi Harada[1], Yuto Kikuzawa[1] (1.School of Marine Science and Technology, Tokai University)

[BCG07-03] The oldest arthropod body fossils from the Cambrian Stage 1 (Fortunian) in South China

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[BCG07-04] Graptolite biostratigraphy of the Ordovician to Silurian boundary succession in the Khao Nui area, southern peninsular Thailand

*Ippei Katakura[1], Sachiko Agematsu[1], Apsorn Sardsud[2] (1.University of Tsukuba, 2.Department of Mineral Resources)

[BCG07-05] Permian Panthalassan Sr budget change

*Tomomi Kani[1], Yukio Isozaki[2], Keiji Misawa[3], Akira Ishikawa[4], Shigekazu Yoneda[5] (1.Department of Earth and Environmental Sciences, Kumamoto University, 2.The University of Tokyo, 3.National Institute of Polar Research, 4.Tokyo Institute of Technology, 5.National Museum of Nature and Science)

[BCG07-06] Marine osumium isotope records during the Carnian (Late Triassic) “pluvial episode” in the pelagic bedded cherts

*Yuki Tomimatsu[1], Tatsuo Nozaki[2,3,4,5], Honami Sato[5], Yutaro Takaya[6], Jun-Ichi Kimura[7], Chang Qing[7], Hiroshi Naraoka[8], Manuel Rigo[9], Tetsuji Onoue[8] (1.Graduate school of Science and Technology, Kumamoto University, 2.Submarine Resources Research Center, Research Institute for Marine Resources Utilization, Japan Agency for Marine-Earth Science and Technology, 3.Frontier Research Center for Energy and Resources (FRC- ER), Graduate School of Engineering, Tokyo University, 4.Department of Planetology, Graduate School of Science, Kobe University, 5.Ocean Resources Research Center for Next Generation, Chiba Institute of Technology, 6.Department of Resources and Environmental Engineering School of Creative Science and Enginerring, Waseda University, 7.Department of Solid Earth Geochemistry, Japan Agency for Marine-Earth Scienc and Technology, 8.Department of Earth and Planetary Sciences, Faculty of Sciences, Kyushu University, 9.Department of Geosciences, University of Padova)

Hierarchy in mass extinction causes: from direct kill mechanism to ultimate cause

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Causes of extinction can be grouped into four categories in hierarchy, from small to large scale: i.e., Category 1 –direct kill mechanism for each local biota, Category 2 –background change in global environment, Category 3 –major geological phenomenon on the planet’ s surface, and Category 4 –ultimate cause from the interior and exterior of the planet (Isozaki, 2019). Previous discussions on bolide impact and/or LIP are limited solely to Category 3. Bolide fall-out and/or LIP formation have been regarded as accidental phenomena; however, these likely have appeared under strong controls of agents of Category 4. The study of mass extinctions on the Earth is entering a new stage with a new astrobiological perspective. The Paleozoic era experienced 4 major mass extinctions; i.e., end-Ordovician, Late Devonian, end-Guadalupian, and end-Permian episodes. For causing significant biodiversity decline, non-biological environmental change on global scale is needed for a trigger; nonetheless, popular claims on bolide impact and/or large igneous province (LIP) with too much *ad-hoc* assumptions have not yet been accepted as common/universal explanation for the Paleozoic extinctions. New perspectives of cosmoclimatology are emerging for introducing an alternative extinction scenario; e.g. 1) increased flux of galactic cosmic radiation (GCR) and solar/terrestrial responses in planetary magnetism, and 2) encounter with dark nebula. Both can bring profound impacts on Earth’ s climate, in particular, global cooling by extensive cloud coverage and/or dust screen (irradiance shutdown) over the globe. It is noteworthy that the past star-burst events detected in the Milky Way Galaxy by astronomical observations apparently coincide in timing not only with the cooling-associated major extinctions of the Paleozoic (Ordovician, Devonian, and Permian) but also with the Neoproterozoic snowball Earth episodes. Recently our research group detected for the first time the signature of increased flux of extraterrestrial ^{3}He from the slowly accumulated deep-sea P-TB beds immediately below the extinction horizon of the Late Permian radiolarians (Onoue et al., 2019). The same analyses are needed for other extinction cases to prove or disprove this working hypotheses.

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Keywords: Phanerozoic, mass extinction, kill meachnism, extraterrestrial, global environmental change, non-bolide cause

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A relationship between paleomagnetic data and biodiversity during the Phanerozoic

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Crain, 1971 claimed a good relation between paleomagnetic reversal rate (McElhinny, 1971) and extinction rate (Simpson, 1966) during Phanerozoic. But the correlation factor was not so high (0.36) and those data he used was not sufficient. We used recent data sets, "A Concise Geologic Time Scale 2016", and Hounslow et al., 2018 for the reversal rate, and Alroy, 2010, Rohde and Muller, 2005 for genus diversity. We digitized the paleomagnetic reversals from "A Concise Geologic Time Scale 2016", and from Shaviv, 2003 for samples of cosmic radiation exposure ages of iron meteorites. First, the direct comparison showed positive relations between the magnetic and the biodiversity data at 250Ma and 375Ma when the biggest and the second biggest extinction occured, whereas at the 170Ma reversal maximum, there was no relation between the two. We also found that there are coeval abrupt change between the biodiversity and the cosmic radiation at 250Ma and 375Ma. Second, we performed 100Myr running mean analysis for both biodiversity and magnetic reversals, and we found one local minimum and two local maximums are synchronized between the two data sets. This indicates that the earth's magnetic field and biodiversity related each other for the scale of 100Myr, and the cosmic radiation at 250Ma and 375Ma caused the mutations of life forms.

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The oldest arthropod body fossils from the Cambrian Stage 1 (Fortunian) in South China

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The oldest arthropod body fossils hitherto known are trilobite (*Abadiella*) and bradoriid (*Kunmingella)* in the Chengjiang fauna from Lower Cambrian Stage 3 (ca. 517 Ma) in Yunnan, South China. In contrast, no arthropod fossil was reported in diversified small shelly fossils (SSFs) from the lowermost Cambrian (Fortunian and Stage2). Our latest litho- and bio-stratigraphical study on the lowermost Cambrian at the Hongjiachong section in the Chengjiang area identified for the first time 2 different types of bivalved arthropod body fossils. These 2 types with 2 specimens for each, occur from the Fortunian phosphorite (Zhongyicun Mb.), around the boundary horizon between the *Anabarites trisulcatus-Protohertzina anabarica*SSF Assemblage Zone and *Paragrobolilus subglobosus-Purella squamulosa*Assemblage Zone. Type A: subtriangular, 0.4 mm long, anterior/posterior asymmetric, dorsal outline straight, outlines of ventral, posterior, and anterior margins slightly curved outward, carapace with reticulate ornamented, two segmented. Type B: 1.7 mm long, anterior/posterior asymmetric, oval shaped, carapace with smooth surface. The former type is similar to Cenozoic ostracods in general form and size, and in having reticulate ornamented two segments. The oldest ostracod was reported previously from the lowermost Ordovician (Tremadocian) in central England. On the other hand, the latter type is similar to bradoriid in general size and form, but without lobes. The oldest bradoriid was reported from the Cambrian Stage 3 in South China. The present new finding of the oldest (Fortunian) arthropod body fossils demonstrates that arthropod has appeared at least 18 Myr earlier than previously believed.

Keywords: Cambrian, Fortunian, oldest, arthropod, SSF, Chengjiang

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Graptolite biostratigraphy of the Ordovician to Silurian boundary succession in the Khao Nui area, southern peninsular Thailand

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The Ordovician to Silurian boundary (OSB) is characterized by the second largest mass extinction in the Phanerozoic. Graptolites are the most useful index fossil of the OSB interval and it is important for studies on OSB to establish the graptolite biostratigraphy. In this study, we investigate graptolite taxonomy and litho-/biostratigraphy of the upper Ordovician to lower Silurian section in the Khao Nui area, southern peninsular Thailand. The Wang Tong Formation, consisting of upper Ordovician to Silurian clastic rocks, are distributed in the study area. The study section is composed of black to grey mudstone and sandstone, 10 m in thickness, and divided into the lower, middle, and upper parts: the lower part (2 m thick) is made up of the black bedded mudstone which conformably overlies the Middle to Upper Ordovician Pa Kae Formation; the middle part is 5.5 m-thick, grey sandstone and black bedded mudstone; black bedded mudstone intercalated with thin white limestone layers constitutes the upper part (2.5 m in thickness). Sixteen rock samples are collected from this section for graptolite examination and 8 species belonging to 10 genera are identified. The result of the biostratigraphic correlation shows that the lower and middle parts of the study section correspond to the Hirnantian stage, the uppermost Ordovician, and the upper part to the Rhuddanian stage, lowermost Silurian. This is consistent with a result led by a macrofossil assemblage occurred from the lower part of the section, including trilobites and brachiopods. On the basis of the microscopic observation of thin sections, the depositional environment of the study section is interpreted as follows: the black mudstones were accumulated on a continental shelf, until the Hirnantian age; at the end of Hirnantian, a sea-level fall caused a deposition of coarse-grained sandstones; in early Silurian, the sea-level rose again and mudstones restarted to deposit.

Keywords: graptolite, Khao Nui, Wang Tong Formation, Ordovician to Silurian boundary

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Permian Panthalassan Sr budget change

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The radiogenic Sr isotopic composition ($^{87}Sr/^{86}Sr$) of the Phanerozoic seawater has been fluctuated according to global tectonics and/or climate change. The major Sr fluxes to drive $^{87}Sr/^{86}Sr$ in seawater are three-fold; i.e., weathering of highly radiogenic continental silicates, non-radiogenic submarine hydrothermal fluid, and weathering of less radiogenic carbonates and basalts from island arc/oceanic island. During the Phanerozic, seawater $^{87}Sr/^{86}Sr$ changed most dramatically around the Middle/Late Permian boundary marked by a major mass extinction. Stable Sr isotope ($\delta^{88}Sr$) in seawater is recently recognized as an useful proxy for estimating ancientburial/dissolution of marine carbonate. The $\delta^{88}Sr$ values were consistently low in the Middle Permian and began to increase during the Late Permian. The timing of thistrend change across the G-LB corresponds to that of $^{87}Sr/^{86}Sr$. This significant change of ocean Sr budget in the Phanerozoic might be explained by increase/decrease of carbonate weathering on continental shelves with respect to the long-term cooling/warming associated with global sea level change.

Keywords: δ88Sr, 87Sr/86Sr, carbonate, seawater

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Marine osumium isotope records during the Carnian (Late Triassic) “pluvial episode” in the pelagic bedded cherts

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The Carnian Pluvial Episode (CPE) is considered as a global environmental change and biotic crisis that occurred during the Carnian (Late Triassic). The climate during the CPE is characterized by a short-lived period of extreme rainfall caused by the maximal development of the Megamonsoon, and an extinction of marine taxa is known to have occurred during uppermost Julian (lower Carnian). Although these events have been considered caused by the Wrangellia Flood Basalt (FB) volcanism, existing studies have found little directly evidence to support this. Here, to clarify the linkage between the eruption of Wrangellia FB and the timing of environmental crises during the CPE, we investigate high-resolution microfossils biostratigraphy and paleo-seawater Os isotope profiles in an Upper Triassic bedded chert succession from the Jurassic accretionary complex of Japan. Our biostratigraphic based on conodonts and radiolarians and osmium isotope data show (i) a continuous decline in the early Julian, (ii) a persistence of lower steady-state in the late Julian, and (iii) an abruptly increase in the end of Julian. The decrease phase of initial $^{187}Os/^{188}Os$ ratios throughout the Julian indicates an increased delivery of unradiogenic Os from the eruption of the Wrangellia FB. Moreover, our geochemical data suggest that enrichment factors of the redox sensitive elements, such as V_{EF} and U_{EF}, abruptly increased and recovered in the end of the Julian, which presents first evidence of ocean anoxia in the latest Julian in the pelagic deep-sea Panthalassa. The ocean anoxia in the late Julian has been recognized from widespread deposition of black shales and organic rich marls in from intermediate to shallow water setting of Tethyan sections. Thus, this observation suggest that the ocean anoxia occurred between shallow continental margin and deep-Panthalassa basin at the end of the Wrangellia FB volcanism, and that was likely to have triggered extinction.

Keywords: Carnian Pluvial Episode, Osmium isotope analysis, Late Triassic, Jurassic accretionary complex, microfossils, Geochemistry

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[E] Oral | B (Biogeosciences)：B-CG Complex & General

[B-CG07] Phanerozoic biodiversity change: radiation and extinction

convener:Yukio Isozaki(Department of Earth Science and Astronomy, Multi-disciplinary Sciences - General Systems Studies, Graduate School of Arts and Sciences, The University of Tokyo), Yusuke Sawaki(The University of Tokyo)

This session explores the latest progress in the paleobiodiversity studies, particularly about the final 500 m.y.-long history of life during the Phanerozoic. All paleo-environmental, stratigraphic, and paleotological studies are welcome.

[BCG07-07] Upper Triassic (Rhaetian) conodont biostratigraphy of the Panthalassa Ocean and the final extinction of conodonts at the end-Triassic

*Tetsuji Onoue[1], Kanna Yamasaki[2], Yuki Tomimatsu[2,1], Yixing Du[3], Daisuke Yamashita[4], Katsuhito Soda[2], Manuel Rigo[3] (1.Kyushu Univ., 2.Kumamoto Univ., 3.Univ. Padova, 4.Satsumasendai City Office)

[BCG07-08] **The Carbon-Silicon cycle coupling: insight from in situ δ^{30}Si in Mesozoic radiolarites.**

*Maximilien Bole[1], Masayuki Ikeda[1], Rie Hori, S.[2], Peter O. Baumgartner[3] (1.Department of Earth and Planetary Sciences, Tokyo University, Japan, 2.Department of Earth Science, Ehime University, Japan, 3.Institute of Earth Science (ISTE), Université de Lausanne, Switzerland)

[BCG07-09] Geology and paleontology of the Tetori Group distributed in the Shokawa area, Gifu prefecture

*WATABE SERIE[1], Sachiko Agematsu[1] (1.University of Tsukuba)

[BCG07-10] Marine Os isotopic evidence for multiple submarine volcanic activities during Aptian, mid-Cretaceous

*Hironao Matsumoto[1], Junichiro Kuroda[1], Rodolfo Coccioni[2], Fabrizio Frontalini[2] (1.Department of Earth and Planetary Science, The University of Tokyo, 2.DiSPeA, University of Urbino)

[BCG07-11] Cu- or Ag-enriched grains in the K-Pg boundary clays: New evidence for acid rain immediately after the meteorite impact

*Teruyuki Maruoka[1], Yoshiro Nishio[2], Tetsu Kogiso[3], Katsuhiko Suzuki[4] (1.University of Tsukuba, 2.Kochi University, 3.Kyoto University, 4.Japan Agency for Marine-Earth Science and Technology)

Discussion

Upper Triassic (Rhaetian) conodont biostratigraphy of the Panthalassa Ocean and the final extinction of conodonts at the end-Triassic

*Tetsuji Onoue[1], Kanna Yamasaki[2], Yuki Tomimatsu[2,1], Yixing Du[3], Daisuke Yamashita[4], Katsuhito Soda[2], Manuel Rigo[3]

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The Rhaetian stage of the Triassic was characterized by intense biological, climatic, and environmental changes, ending with the break-up of the supercontinent Pangaea and the end-Triassic mass extinction (ETE). Notably, the ETE appears to be associated with significant $d^{13}C$ perturbations, commonly linked to the CAMP (Central Atlantic Magmatic Province) eruptive phases. The stratigraphic record of these environmental changes has been documented in Upper Triassic bedded chert successions in Japan, deposited within a Paleo-Pacific (Panthalassa) deep basin. The chronology of the Rhaetian pelagic sediments in the Panthalassic Ocean is based on radiolarian zones, which are well established in the Upper Triassic bedded chert successions in the Mino Belt, central Japan. Although accurate calibration of the chronostratigraphic stages and substages is based mainly on ammonites and conodonts, most of the Japanese radiolarian zones have been calibrated through correlation with zonal schemes established in other regions, and do not have a calibrated conodont biostratigraphy.
Here we present the Upper Norian to Rhaetian conodont biostratigraphy of an Upper Triassic bedded chert succession from the Mino belt, central Japan, where the radiolarian biostratigraphy has been investigated. Based on the stratigraphic distributions of marker species, four conodont zones are defined: the *Mockina bidentata*, *Misikella hernsteini*, *M.posthernsteini*, and *M. ultima*zones (in stratigraphic order). The conodont biostratigraphy established here calibrates the radiolarian zones in Japan with standard chronostratigraphic stages and substages, which allow us to compare the bio- and chemostratigraphicdata of other Triassic-Jurassic boundary sections from different areas in Tethys and Panthalassa oceans.Our analysis suggests that the final extinction of conodonts was asynchronous: the group first tried to take refuge from shallow water to open marine environments before becoming extinct.

Keywords: Triassic, Jurassic, Chert, Panthalassa Ocean, Conodont, Extinction

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The Carbon-Silicon cycle coupling: insight from in situ $\delta^{30}Si$ in Mesozoic radiolarites.

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Long-term (>105 yr) changes in Earth's climate are regulated by the global carbon and silicon cycles through the negative feedback between silica weathering followed by carbonate and BSi precipitation trapping CO_2 and SiO_2, respectively. The silica weathering depends on the kind and amount of silica rock exposed on continents and to climate, which is it-self induced by atmospheric CO_2 and astronomical cycles (Milankovitch cycles). However, many works need still to be done to constrain the temporal relation between the carbon and silicon cycles due to poorly constrained proxy record for the past controlling factors.
Radiolarian and other biosiliceous organisms incorporate preferentially lighter ^{28}Si from the ocean implicating that $\delta^{30}Si$ is, at least partially, a proxy of productivity for biosiliceous organisms similar to $\delta^{13}C$. Other parameters influencing $\delta^{30}Si$ are the isotopic ratio of the sources, the weathering intensity and the Si recycling in the water column. As silicon is commonly undersaturated in the water column, this proxy is very sensitive to input/output fluxes but has also fever pools that carbon at the Earth's surface. In addition, silica is more resistant to isotopic resetting/homogenisation than carbonates.
Here, we show $\delta^{30}Si_{radiolaria}$ of Triassic to Cretaceous bedded chert with bio-astrochronology, in Franciscan, Japan, Italy and Turkey. We found an overall inverse correlation between $\delta^{30}Si$ and biogenic silica (BSi) burial flux on 10-Myr timescale, which contradicts with a conventional interpretation of $\delta^{30}Si$ as paleoproductivity proxy, despite of the low-resolution and scattering of our $\delta^{30}Si$ records. Although most of factors controlling oceanic $\delta^{30}Si$ are difficult to be constrained, this inverse relation might be explained by changes in $\delta^{30}Si$ of mafic/felsic rock weathering ratio, inferred from paleogeographic distribution of Mesozoic volcanic rocks. We will also discuss $\delta^{30}Si$ variations within chert beds.

Keywords: silica cycle, silicon isotopes, radiolaria

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Geology and paleontology of the Tetori Group distributed in the Shokawa area, Gifu prefecture

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The Tetori Group, consisting of the Jurassic to Cretaceous terrigeneous and shallow-sea sedimentary rocks, is widely distributed in Fukui, Gifu, and Toyama prefectures, central Japan. The group in the Shokawa area, Gifu prefecture, are investigated geologically and paleontologically in this study. On the basis of lithology, the Tetori Group outcropping along the Matsuyamadani valley in the Shokawa area is divided into the Akahoke, Mitarai, and Otaniyama formations in ascending order. The Akahoke Formation is mainly made up of sandstone, black shale, and alternations of sandstone and mudstone. The Mitarai Formation, overlying the Akahoke Formation comformably, comprises black mudstone. The Otaniyama Formation, which overlies the Mitarai Formation in alignment, mainly comprises medium sandstone and includes mudstone and alternations of sandstone and mudstone. Sedimentary facies analysis reveals that the Akahoke Formation is considered to have been formed between an outer shelf and shorefaces, the Mitarai Formation on an outer shelf to inner shelf, and the Otaniyama Formation in a shallower sea than inner shelf. Ammonites occurred from the Mitarai Formation indicate that the depositional age of this formation is Berriasian, early Cretaceous.

Keywords: Cretaceous, Shokawa, Tetori Group

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Marine Os isotopic evidence for multiple submarine volcanic activities during Aptian, mid-Cretaceous

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The mid-Cretaceous is marked by repeated Oceanic Anoxic Events (OAEs) that are characterized by episodic burials of organic-rich sediments in various oceanographic settings. In the Aptian, several black shale horizons (e.g., Selli (OAE1a), Noir, and Fallot levels) have been reported from the Tethys, Atlantic, and Pacific sedimentary records. Since these black shale horizons are accompanied by the perturbations of the carbon cycle and biotic crises of marine organisms, the understanding of their triggers and influence on the marine ecosystem is important for the comprehension of the mid-Cretaceous marine environment. Radiometric ages of a major part of the Ontong Java Plateau (124.9-119.6 Ma) roughly correspond to the sedimentary ages of these black shale layers (124.55 to 117.84 Ma). However, large chronological uncertainties of radiometric ages of Ontong Java Plateau and sedimentary sequences have prevented the direct correlations of these events.

Marine Os isotope ratio ($^{187}Os/^{188}Os$) reflects the balance between the unradiogenic Os input from hydrothermal activities and radiogenic Os input from continental materials. The relatively short residence time (10-100 kyr) of Os makes it possible to constrain the precise duration of massive release of unradiogenic Os through hydrothermal activities using past marine $^{187}Os/^{188}Os$ ratios. Previous studies have revealed extremely unradiogenic marine $^{187}Os/^{188}Os$ values at the Selli level, suggesting active hydrothermal activity possibly at the Ontong Java Plateau during OAE1a. However, the Aptian Os isotopic record is limited to only OAE1a and no Os isotopic studies have focused on the aftermath of OAE1a. This study aims to reconstruct the continuous Os isotopic record during Aptian using pelagic Tethyan sediments deposited in the Umbria-Marche Basin to constrain the duration of massive volcanic activities related to the Ontong Java Plateau and its relationship with the Early Aptian black shale horizons (Selli, Noir, and Fallot levels).

Our new Os isotopic data reveal negative Os isotope excursions at the Noir and Fallot levels. These Os isotopic excursions can be explained by a massive input of unradiogenic Os isotopic through hydrothermal activities associated with submarine volcanism. Combining the Os isotopic record around the Selli level, which was reported in previous studies, there are four major submarine volcanic signals during the Early to mid-Aptian. Three of these volcanic pulses correspond to the deposition of black shales (e.g., Selli, Noir, and Fallot levels), which suggests the strong linkages between submarine volcanism and deposition of organic-rich sediments. The most probable candidate for these volcanic signals is submarine volcanic activities at the Ontong Java Plateau.

Keywords: Cretaceous Oceanic Anoxic Event, Osium isotope, large igneous provinces

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Cu- or Ag-enriched grains in the K-Pg boundary clays: New evidence for acid rain immediately after the meteorite impact

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Cretaceous-Paleogene (K-Pg) boundary clays are enriched in both chalcophile elements as well as siderophile elements [1]. As the elemental ratios of siderophile elements in these clays are very similar to chondritic values, the enrichment of siderophile elements results from the incorporation of meteorite condensates. As the ratios of chalcophile and siderophile elements (such as Zn/Ir, As/Ir, and Sb/Ir) are one to two orders of magnitude higher than those in chondrites, chalcophile elements in these clays include components not related to meteorite condensate [2]. The chemical compositions of such components should thus reflect the processes that might have enhanced the concentrations of chalcophile elements in seawater. Moreover, as these clays may consist of materials from various origins, it is important to distinguish materials related to meteorite impact from those deposited before and after this event in order to clarify environmental perturbations induced by the meteorite impact. In this study, we used synchrotron X-ray fluorescence (SXRF) microscopy to distinguish materials from various origins in the K-Pg boundary clays from Stevns Klint, Denmark.

The concentrations of major and trace elements in the Stevns Klint K-Pg boundary clays varied, even in samples collected from neighboring outcrops. Cross plots of elemental concentrations suggested the mixing of three components (a, b, c) with different chemical compositions. Component a was enriched in chalcophile elements and iron; this may be related to pyrite. Component b was depleted in chalcophile elements and enriched in calcium; this may be related to calcite, judging from its Ca concentration (~40 wt%). Component c was particularly enriched in Cu, Ag, and Pb. Components a and c included iridium (obviously supplied by the K-Pg meteorite impact), suggesting that these components were related to immediately subsequent events after the meteorite impact. Cu and Ag levels in these components were adequate to allow SXRF-microscopy to obtain their micro-distributions.

This SXRF analysis indicated two phases incorporating Cu: pyrite with Cu as a trace element and discreate Cu-enriched grains. These potentially correspond to the two chalcophile-containing components (a and c, respectively). The Cu-enriched grains did not contain measurable Ag, although Ag was present in discrete Ag-enriched grains. Although both Cu- and Ag-enriched grains existed as discrete grains, there was a positive correlation between the Cu and Ag concentrations in the K-Pg boundary clays, suggesting that a common process was involved in supplying these elements to sediments. Both Ag and Cu can be transported by organic matter from seawater to the seafloor. Cu is scavenged by complexation with organic matter in seawater, whereas strong organic Ag complexes have not been observed in seawater. Ag scavenging probably occurs as a result of Ag_2S precipitation within oxygen-depleted microenvironments inside organic particulates [3]. The ability of organic matter to accumulate both Cu and Ag in the oceans by different mechanisms may have led to discrete grains of Ag and Cu in the K-Pg boundary clays with a strong correlation between their concentrations. Cu, Ag, and Pb concentrated in component c generally exist in acid soluble sulfides such as sphalerite and galena. Therefore, the chalcophile elements in component c may have been supplied to seawater by intense acid rain after the K-Pg impact.

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Keywords: meteorite impact, impact heating, acid rain, chalcophile elements

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[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS01] Tsunami deposit

convener:Daisuke Ishimura(Department of Geography, Tokyo Metropolitan University), Takashi Chiba(Faculty of Bioresource Sciences, Akita Prefectural University), Masaki Yamada(Department of Geology, Faculty of Science, Shinshu University), Takashi Ishizawa(International Research Institute of Disaster Science, Tohoku University)

The 2011 off the Pacific coast of Tohoku Earthquake and tsunami have an influence on the development of tsunami deposit research. After the tsunami, a lot of findings have been reported on various research fields. However, it is still uncertain how to use the tsunami deposit in the estimation of tsunami size and source and the risk assessment. In this session, we welcome researches from all aspect of sedimentary records of modern and paleo tsunamis both onshore and offshore, and numerical and experimental modeling studies for risk assessment. In addition, we also welcome other event deposits, such as flooding and storm surge, that they are considered to be important for discrimination of tsunami deposit.

[MIS01-01] Evaluation for transport processes of paleo-tsunami by organic geochemical analyses of peat sediments in eastern Hokkaido, Japan

*Hiroyasu Asahi[1], Ken Sawada[2], Satoshi Furota[3] (1.Graduate School of Science, Hokkaido University, 2.Department of Earth and Planetary Science, Facility of Science, Hokkaido University, 3.National Institute of Advanced Industrial Science and Technology)

[MIS01-02] **Paleotsunami record in Hachinohe, Aomori Prefecture, northern Japan.**

*Erick Velasco R.[1], Kazuhisa Goto[2], Daisuke Sugawara[3], Yuichi Nishimura[4], Takahiro Shinohara[1], Takashi Chiba[5] (1.Earth Science Department, Graduate Faculty of Science, Tohoku University, 2.Department of Earth and Planetary Science, Graduate School of Science, the University of Tokyo, 3.Museum of Natural and Environmental History, Shizuoka, 4.Institute of Seismology and Volcanology, Graduate School of Science, Hokkaido University, 5.Faculty of Bioresource Sciences, Akita Prefecture University.)

[MIS01-03] Geological features of tsunami deposits associated with the 1983 Nihonkai-chubu earthquake in pine-based windbreak forests of Noshiro City and Happo Town in Akita Prefecture, Japan

*Takashi Chiba[1], Yuichi Nishimura[2] (1.Faculty of Bioresource Sciences, Akita Prefectural University, 2.Institute of Seismology and Volcanology, Faculty of Science, Hokkaido University)

[MIS01-04] Identification of tsunami, storm, and river flood deposits besed on the multi-proxy evidence on the coastal lowland of Odaka District, Minamisoma City, Fukushima Prefecture, Northeast Japan

*Shiori Uchiyama[1], Junichi Machida[1], Koichi Hoyanagi[1] (1.Shinshu University)

[MIS01-05] Literature review and numerical modeling for updating physical identification criteria of tsunami and storm deposit

★Invited Papers

*Masashi Watanabe[1], Kazuhisa Goto[2], Fumihiko Imamura[3] (1.Chuo University, 2.The University of Tokyo, 3.Tohoku University)

Discussion

Evaluation for transport processes of paleo-tsunami by organic geochemical analyses of peat sediments in eastern Hokkaido, Japan

*Hiroyasu Asahi[1], Ken Sawada[2], Satoshi Furota[3]

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Tsunami deposit is mainly characterized by mixture of marine sand and sedimentary structures formed by huge tsunami flow. In many cases, however, sedimentological information recorded as the structure of tsunami deposit was erased by erosion and disturbance during the post-depositional processes. In the present study, we performed organic geochemical analyses using biomarker and kerogen of the peat sediment cores from the Akkeshi and Kiritappu areas, eastern Hokkaido, Japan to evaluate the sedimentological and geochemical features of the paleo-tsunami deposits.

We analyzed the peat sediment cores collected from the Akkeshi Town and Kiritappu wetland of Hamanaka Town, eastern Hokkaido, Japan, during August 2016. These sediment cores mainly comprise the peats, intercalated with some sand layers (at most several 10 cm thick), which are presumed to be the layers deposited by the paleo-tsunami.

In kerogen analysis, terrestrial plant fragments are mainly observed in all sand layers, indicating the redeposition of peat-derived matter by tsunami. However, the inner organic lining of foraminifera and the marine dinocyst could be identified in the tsunami layers. These reults can be direct evidences of paleo-tsunami.

In steroid biomarkers, stanols could be detected in all samples of the Akkeshi and Kiritappu cores. The stanol conversion reaction from biosterol is thought to occur by microbial reduction in the sediment–water interface and anoxic water column of marine and lacustrine environments. Therefore, the stanol/sterol ratio can be used as redox indicator. We found that the C27 stanol/sterol (cholestanol/cholesterol) ratios are clearly higher than those of C29 in the sand layers of both Akkeshi and Kiritappu cores. The higher C27 stanol/sterol ratios suggest the contribution of marine compounds deposited under more reduced condition in the tsunami layer. However, some sand layers do not show this trend, and they can be considered event deposits of other origin.

Ring-A degraded triterpenoids (*Des*-A triterpenoids) are formed by microbial degradation under anoxic environments after deposition, and have been indicated to be abundant in flood sediments (Furota et al., 2014). In the Kiritappu core, the relative abundances of *des*-A triterpenoids remarkably increased in the sand layers in low C27 stanol/sterol ratios, although these are almost constant throughout the core. From these results, these sand layers may be interpreted as flood deposits, not tsunami deposits. However, the abundances of *des*-A triterpenoids show different trends for Akkeshi than Kiritappu cores. Thus, it is suggested that organic geochemical methods provide much information to event sediments and this methods are useful for identification of the paleo-tsunami sediments.

Keywords: Paleo-tsunami, biomarker, Hokkaido

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Paleotsunami record in Hachinohe, Aomori Prefecture, northern Japan.

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Along the 120 km of the coast of the Shimokita Peninsula, only two previous studies have recorded sand deposits related to paleotsunami events. Seismic activity and historical events on the Kuril and Japan trenches and its flexion showed the presence of seismic asperities and its capacity to generate damaging earthquakes and ensuing tsunamis. However, the information is still limited to develop an adequate hazard assessment. Hence, finding new evidence is vital to unveil tsunamigenic behavior in the neighboring subduction area. Here we present the results derived from the geophysical, sedimentological, paleontological, geochemical, and mineralogical analyses of coastal sedimentary records at Hachinohe City. On a transect of ~500m, we conducted a total of thirteen GPR lines and extracted thirteen core samples. Sedimentary features, authigenic minerals and paleontological evidence revealed that there are seven sandy event deposits related to marine origin out of a total of ten sand events recorded. Sedimentary features, and diatom analysis suggest the sedimentary environment consisted of a marsh complex formed by sequential ponds. Numerical modeling of storm and tsunami surges shows the limited inundation and transportation capacity of storm surges of our study site on the 5m-uplifted marine terrace. The numerical calculation allowed us not only to improve the survey site selection criteria but also to rule out storms as a possible genetic source. Based on 14C dating, we estimated a recurrence interval of 310 to 435 years (1 σ) from 5500 yr. BP to 2500 yr. BP. Based on a pure chronostratigraphic correlation, this interval is shorter than the calculated from the sedimentation ages calibrated by Takada et al. 2016 in Harashinai, northern Sanriku Coast, near our survey site, that suggests an interval of 530 to 956 years (1 σ) for the same time frame. Such geological record and recurrence interval reaffirm the importance of Hachinohe as a paleotsunami record site since it has recorded more events than the adjacent study site, evidence that could be related to the activity of both trenches.

Keywords: Paleotsunami deposits, Hachinohe, tsunami recurrence, X-Ray Tomography, Numerical modeling, ITRAX

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Geological features of tsunami deposits associated with the 1983 Nihonkai-chubu earthquake in pine-based windbreak forests of Noshiro City and Happo Town in Akita Prefecture, Japan

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On 26 May 1983, Nihonkai-chubu earthquake occurred off the west coast of Noshiro City in Akita Prefecture, Japan. The tsunami associated with the earthquake caused widespread damage to the north-eastern coastal areas of the Sea of Japan, including Akita Prefecture, depositing sand and mud from the tsunami. These deposits were immediately reported in the 1990s; however, no reports on these deposits have been found since then. In contrast, we conducted geological surveys from December 2019 to January 2020 on soil thinning observed in the pine-based windbreak forests planted along the coastal area of Noshiro City and Happo Town in the period from 1948 to 1970. Thus, sand layers showing inland thinning were found in the soil at a depth of less than 10 cm at both locations. As this sand layer contains fossil brackish marine diatoms, it is highly probable that it was brought from the seaside; the continuity distribution was confirmed from the coast to about 300 m inland only within the windbreak forest. According to historical records, it was considered that this sand layer was a result of the 1983 tsunami because the area was not reachable by means other than the tsunami of the Nihonkai-chubu Earthquake. Since there exist few reports of tsunami sediments with specific ages in Japan, they are an important historical record of past disasters and are geologically significant; the samples can be used to study the magnitudes and inundation processes of tsunamis. It has been noted that tsunami deposits lose their sedimentary structures and constituents with time and changes in weather conditions. In this work, we conducted geological surveys along the coastal areas of Noshiro City and Happo Town to determine the distribution of deposits caused by the tsunami due to the 1983 Nihonkai-chubu earthquake. In this presentation, we will report basic geological features such as the planar distribution of the tsunami deposits as well as changes in their thickness, grain size distributions, and fossil diatom assemblages.

Keywords: The 1983 Nihonkai-chubu earthquake, Tsunami deposit, Diatom

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Identification of tsunami, storm, and river flood deposits besed on the multi-proxy evidence on the coastal lowland of Odaka District, Minamisoma City, Fukushima Prefecture, Northeast Japan

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Study of tsunami deposits is significant for mitigation of tsunami hazard, because it helps to assess the scale and periodicity of future tsunamis. However, the unequivocal identification criteria of tsunami deposits have not established yet. Therefore, comprehensive determination criteria based on several evidences are required.

The study area, Idagawa lowland (formerly Idagawa estuary) is located on the coast of the Pacific Ocean, Odaka District, Minamisoma City, Fukushima Prefecture, northeast Japan. Small estuary was formed due to the transgression into the incised valley after the Last Glacial Maximum. The Idagawa estuary was reclaimed in 1929 and it has been used for a rice growing area until the occurrence of 2011 off the Pacific coast of Tohoku Earthquake and tsunami. Even before the 2011 Earthquake, it has been pointed out that the study area has tended to subside during Holocene epoch (Niwa et al., 2017, *Quaternary International*), and has been inundated by several tsunamis (Sawai et al, 2015, *Geophysical Research Letters*). Also, the lowland has poor drainage and has been flooded several times by the river (Fukushima Prefecture, 2004). From these historical records, both tsunami and flood deposits were possibly preserved in the study area.

We took two Holocene drilling cores at seaside and landside of the lowland to study of the event deposits. The two cores are composed of Pliocene basement rocks, backshore sand, tidal flat sand and mud, central basin mud, salt marsh mud with intercalated event sand beds, and artificial fill and paddy soil. Fourteen event sand units are preserved in the salt marsh deposits. The origin of each sand unit was distinguished based on the multi-proxy evidence, radiometric ^{14}C dating, grain size, diatom fossil and geochemical (TS, TOC and $\delta^{13}C_{org}$) analyses, comparison with present tsunami deposits formed by the 2011 Tsunami and with historical tsunami records in Fukushima and Miyagi prefectures.

Most of event sand units thin and fine towards landside, and represented laminations and grading structures. They yield shell fragments, and marine diatom fossils increased in the overlaying mud and/or in the event sand units. Also, the value of $\delta^{13}C_{org}$ demonstrated increasing trend above the event units. These features are similar to 2011 Tsunami deposits, and indicating that they are possible tsunami deposits. While, some sand units represent different features. The sand units thin towards seaside, and yield fresh river diatoms increased above the units. Also, the value of $\delta^{13}C_{org}$ demonstrated decreasing trend in overlain mud. It indicates that they are possible river flood deposits.

We compared the possible tsunami units and historical tsunami records in surrounding areas. Some sand units were corresponded to paleo-tsunami events, such as AD 869 Jogan Tohoku tsunami. In the other hand, a thin sand unit above the possible tsunami sand unit was not corresponded to any historical tsunami records. It can be considered as storm deposits. Nevertheless, there is no historical storm records reported from the study area. It is interpreted that storm surge would not inundate in normal condition because the lowland is protected by beach ridges. However, when large tsunami once occurs, tsunami

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events break the beach ridges. As a consequence, storm surge can easily inundate and form sandy deposits.

We excluded the possible storm and river flood deposits, and considered the occurrence intervals of tsunami in this study area. The occurrence intervals of tsunami were calculated to be approximately 700 years, and it consistent with the invasion period of tsunamis reported from Fukushima and southern Miyagi prefectures.

Keywords: Holocene, Environmental changes, Event deposits, Estuary

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Literature review and numerical modeling for updating physical identification criteria of tsunami and storm deposit

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Once tsunami or storm deposits can be identified, (1) inundation area of tsunami or storm wave/surge in the prehistoric age, and (2) recurrence interval of tsunami or storm can be estimated. However, the both sedimentological characteristics are very similar because the both type of deposits are formed by coastal waves from the sea (e.g., Bourgeois et al., 2006). For appropriate risk assessment at coastal region, tsunami and storm deposits are needed to be reasonably identified.

The studies for identifying tsunami and storm deposit has been conducted mainly based on geological approach. However, field examination is insufficient to clarify the relationship between distribution trend of deposit and topography or input wave condition. To reveal the relationship, the examination using numerical calculation based on ideal topography condition is valid as in Cheng and Weiss, (2013). The objective of this study is to update identification criteria of tsunami and storm deposit based on our numerical modeling and literature review.

We firstly conducted the simulation of sand sediment transport by tsunami and storm waves on ideal topography condition to reveal general distribution trend of onshore sandy tsunami and storm deposit and the parameters that contribute to the distribution characteristic of the both deposits. As a result, we revealed the parameters which mostly contribute to the distribution of sandy tsunami and storm deposits and inundation limits of tsunami or storm wave. The parameters which mostly contribute to inundation distance of storm wave were land slope and initial water level rise. In contrast, the parameters which mostly contribute to inundation distance of tsunami were land slope and input wave condition. The parameters which mostly contribute to distribution distance of sandy storm deposit was land slope and initial water level rise. While, the parameters that mostly contribute to distribution distance of tsunami deposit were topography condition and input wave condition. Indeed, some studies identified sandy tsunami deposit based on the fact that the distribution limit of sandy tsunami deposit is small compared to sandy storm deposits. For using the same method to identify sandy tsunami deposit, knowing what factors affect to the inundation of tsunami and storm wave or distribution of sandy deposit would be very effective. As a result of our simulation, we also revealed that volume of storm deposit become very small compared to tsunami deposit when a size of storm surge was strong or there is source of sand sediments near the coastline. Thus, confirming deposit volume over land is effective for discriminating tsunami deposit from storm deposit.

We secondary conducted literature review according to identification of onshore sandy tsunami and storm deposits, then the identification criteria of sandy tsunami and storm deposits was updated with the result of our numerical simulation on ideal topography condition. Using the updated criteria proposed in this study, identification of tsunami and storm deposits can reasonably be conducted, although further development of numerical models are also required. Once the tsunami or storm deposits are appropriately identified, size or recurrence interval of extreme waves can be examined, which will be useful for future risk assessment at coastal area in the world.

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Keywords: tsunami deposit, storm deposit, sediment transport simulation

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[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS01] Tsunami deposit

convener:Daisuke Ishimura(Department of Geography, Tokyo Metropolitan University), Takashi Chiba(Faculty of Bioresource Sciences, Akita Prefectural University), Masaki Yamada(Department of Geology, Faculty of Science, Shinshu University), Takashi Ishizawa(International Research Institute of Disaster Science, Tohoku University)

The 2011 off the Pacific coast of Tohoku Earthquake and tsunami have an influence on the development of tsunami deposit research. After the tsunami, a lot of findings have been reported on various research fields. However, it is still uncertain how to use the tsunami deposit in the estimation of tsunami size and source and the risk assessment. In this session, we welcome researches from all aspect of sedimentary records of modern and paleo tsunamis both onshore and offshore, and numerical and experimental modeling studies for risk assessment. In addition, we also welcome other event deposits, such as flooding and storm surge, that they are considered to be important for discrimination of tsunami deposit.

[MIS01-06] Relationship between the distribution of crevasse-splay deposits and the inundation distance of the October 2019 flooding of the Chikuma River, central Japan

*Masaki Yamada[1], Hajime Naruse[2], Yuhei Matsuda[1], Tetsuya Shinozaki[3], Tetsuya Tokiwa[1] (1.Faculty of Science, Shinshu University, 2.Faculty of Science, Kyoto University, 3.Center for Research in Isotopes and Environmental Dynamics, University of Tsukuba)

[MIS01-07] Numerical method for constraining maximum local size of paleotsunamis using storm boulder deposits

*Kenta Minamidate[1], Kazuhisa Goto[2], Hironobu Kan[3] (1.Department of Earth Science, Tohoku University, 2.Department of Earth and Planetary Science, The University of Tokyo, 3.Graduate School of Integrated Sciences for Global Society, Kyushu University)

[MIS01-08] Preservation and weathering of tsunami deposits formed during the eruption of Anak Krakatau volcano, Indonesia, on December 22, 2018

*Yuichi Nishimura[1], Purna Sulastya Putra[2], Septriono Hari Nugroho[2], Eko Yulianto[2], Takashi Chiba[3] (1.Graduate School of Science, Hokkaido University, 2.Research Center for Geotechnology, Indonesian Institute of Sciences (LIPI), 3.Faculty of Bioresource Sciences, Akita Prefectural University)

[MIS01-09] **Reconstruction of Hydraulic Conditions from Tsunami Deposits: Inverse Modeling using Deep-Learning Neural Network**

*Rimali Mitra[1], Hajime Naruse[1], Tomoya Abe[2] (1.Kyoto University, Graduate School of Science, 2.Research Institute of Geology and Geoinformation, Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan)

[MIS01-10] Tsunami source estimation from tsunami deposit and numerical simulation
★Invited Papers

*Kenji Satake[1], Satoshi Kusumoto[2] (1.Earthquake Research Institute, University of Tokyo, 2.JAMSTEC)

Discussion

Relationship between the distribution of crevasse-splay deposits and the inundation distance of the October 2019 flooding of the Chikuma River, central Japan

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On October 13, 2019, the disastrous flooding of the Chikuma River was caused by concentrated heavy rainfall in central Japan. The 30-m-wide levee revetment was breached over a length of 70 m in Hoyasu, Nagano City, located on the left bank of the river. As a result, the 6-km-wide lowland was inundated up to 2.2 km from the breached levee. This study aims to reveal the relationship between the distribution of sandy and muddy crevasse-splay sediments and the inundation distance of the flooding by field surveys immediately after the flooding event. The inundation area by this flooding is relatively larger among flooding events that have occurred in Japan in recent years and is equal to those caused by recent tsunamis. Clarifying the relationship between the inundation distance and the distribution of crevasse splay and tsunami deposits should be useful in identifying deposits of past events in geologic strata.
We set up three river-perpendicular 1.4–2.2-km-long transects and investigated crevasse-splay deposits at about 100 m intervals together with the current direction and water depth along each transect. The measured elevation is lowering until 1.2 km from the levee and is getting higher from that point onwards. The crevasse-splay deposits were composed of a lower sand layer and overlying mud layer near the breached levee, but they were massive muddy sediments at the area distant from the levee. The thickness of the sand layer shows a thinning trend toward the foot of mountains, while the thickness of the mud layer varies in association with the topography rather than the distance from the levee. Along the 2.2-km-long transect from the breached levee, the sand layer extended to 0.8 km from the levee, whereas the mud layer was distributed until 1.6 km from the levee. The distribution of sand layer is affected by the distance from the breached levee, but not by water depth, indicating that the deposition of sandy sediments during a river flooding is affected by current velocity probably correlated with a distance from the breached levee. There were no sediments near the limit of the flooded area, between 1.7 and 2.2 km from the levee. This is probably because the stagnant floodwater took a relatively short time to recede at around the inundation limit since the elevation is higher than the area where the thick muddy sediments were observed.
The maximum limit of the sand and mud layers along three transects extended to 0–36% and 73–84% of the inundation distance, respectively. The maximum limit of the recent sandy tsunami deposits, in contrast, extended to over 90% of the inundation distance where the inundation distance is less than 2.5 km (Abe et al. 2012, Sedimentary Geology). The difference between the distribution of a sand layer by crevasse splay and tsunami is probably attributable to the difference in their hydraulic behaviors. It is considered that the crevasse-splay flow is too weak to transport sand grains to the area distant from the breached levee.

Keywords: Flood deposit, Crevasse splay

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Numerical method for constraining maximum local size of paleotsunamis using storm boulder deposits

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The history and sizes of paleotsunami events that hit the Ryukyu Islands, Japan have not been clarified well because observational and historical records are scarce and discussion on the seismology at the Ryukyu trench is still ongoing. Ryukyu Islands are surrounded by reef. There are numerous storm wave boulders on the reef flat of each island. While, there are tsunami boulders only on the coast and inland of the southern Ryukyu Islands (e.g., Ishigaki Island). On the other hand, in the central Ryukyu Islands (e.g., Kudaka Island and Okinawa Island), the boulders are found only on the reef flat, but not inland or on the coast. These facts suggest that a large tsunami hit the southern Ryukyu Islands, but may not have hit the central islands. However, possibility of occurrence of minor tsunamis cannot be excluded and question is remained as to whether a huge tsunami has occurred and, if yes, how large tsunamis would be at the central Ryukyu Trench. In order to estimate the largest tsunami that may have occurred in the past around the central Ryukyu Trench, we performed calculations for tsunami and boulder movement with constrains that the coastal boulder distribution on the reef of Kudaka Island are not significantly modified. Our calculation results show that, if large tsunami caused by an near-field subduction earthquake (e.g., Mw>8) occurs, a tsunami became too large and the boulder distribution in Kudaka Island would be significantly modified. Our preliminary results do not exclude the possibility of occurrence of a earthquake with Mw<8 with minor tsunami that did not change the current boulder distribution in Kudaka Island. Further comprehensive modeling would provide useful information to constrain the maximum earthquake magnitude in this region.

Keywords: Ryukyu trench, tsunami, coastal boulder deposit

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Preservation and weathering of tsunami deposits formed during the eruption of Anak Krakatau volcano, Indonesia, on December 22, 2018

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On December 22, 2018, the eruption of Anak Krakatau volcano, Indonesia caused a tsunami up to about 15 m in Banten Province, Java. Following the tsunami, abundant coral boulders were carried up and deposited on the coast of the area, and sandy tsunami deposits were also formed. The Indonesian Institute of Sciences (LIPI) conducted a survey of tsunami traces one week after the tsunami occurred, and recorded the features of the fresh tsunami deposits left on the surface. We visited the affected area around one year after the tsunami, from December 2019 to February 2020 to examine the early stage of weathering and preservation of the tsunami deposits on the tropical coral coast. Thickness and grain size characteristics of the tsunami deposits mainly composed of coral fragments were well preserved after one year. There are places where a silt layer, which is considered to be reworked, was formed at the top of the sediment and new soil was being formed on it. The reason that deposits are well preserved in this area is that vegetation recovers quickly. For microfossils such as foraminifera and diatoms, their preservation potential was studied while examining soil properties. We also conducted a survey in the Ujung Kulon National Park area. This is the first survey of tsunami and tsunami deposits in this park. Since there are no settlements or roads in the park and access to tourists is restricted, the formation and preservation process of tsunami deposits in the natural environment can be confirmed. The 2018 tsunami deposits were already covered with soil in the forest and were well preserved as patchy very fine sand near the run-up limit of more than 500 m inland from the coast. It was also found that coral tsunami boulders, which may be tsunami deposits of the Krakatau volcano in 1883, have been left inland at the run-up limit of the 2018 tsunami. This work was supported by Japan Science and Technology Agency (JST) as part of SICORP.

Keywords: Anak Krakatau volcano, tsunami deposit, preservation of deposit, tsunami boulder, the Ujung Kulon National Park

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Reconstruction of Hydraulic Conditions from Tsunami Deposits: Inverse Modeling using Deep-Learning Neural Network

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Tsunami deposits provide clues for estimating the magnitude and hydraulic conditions of paleo-tsunamis, which can serve as a tool for evaluating tsunami hazard and mitigation strategies. In this study, a numerical approach towards inverse modelling of tsunami deposit has been taken. The present model uses Deep learning Neural Network (DNN) to understand quantitative hydraulic conditions of tsunamis from the tsunami deposits using non-uniform, unsteady transport of suspended sediments during turbulent mixing. This 1D inverse model incorporates a forward model which employs iterative random flow conditions as boundary conditions (e.g. maximum flow depth, flow velocity, concentration, etc.) to produce artificial training data sets which represent depositional characteristics, such as, thickness and grain-size distribution. The machine learning of DNN includes several hyperparameters which are used for an optimizer (Stochastic Gradient Descent) and activation function (Rectified Linear Unit). Subsequently, DNN was trained to find relationships between simulation results and initial conditions using the artificial output datasets of forward model. The uncertainties in the model were calculated using Jackknife method. Finally, the inverse model was applied to natural field data sets from 2011 Tohoku-Oki Tsunami deposits around the Sendai plain and Odaka in Joban coastal plain, exhibiting that the method can reconstruct hydraulic conditions of paleo-tsunamis. The proposed inverse model in tandem with other forward models such as Delft3D are expected to simulate unsteady 2D hydrodynamics and sediment transport. Thus, in future studies, it is expected that this model could be used to successfully reconstruct the flow conditions of modern and older tsunamis with the uncertainty analysis.

Keywords: Tsunami Deposit, Inverse Model, 2011 Tohoku-Oki Tsunami, Deep Learning Neural Network

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Tsunami source estimation from tsunami deposit and numerical simulation

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Attempts to estimate a tsunami source from comparison of tsunami deposit distribution and simulated inundation area have been done for the 17th century giant earthquake along Kuril trench (Satake et al., 2008, EPS) or the 869 Jogan earthquake (Sawai et al., 2012, GRL). The 2011 Tohoku earthquake revealed that the tsunami inundation area extended farther inland than the distribution of sandy tsunami deposits. Numerical simulation of the 2011 tsunami indicated that flow depths and velocities were approximately 1m and 0.6m/s, respectively, at the most inland sand deposit sites on the Ishinomaki and Sendai plains. These values were used to re-estimate the size of the 869 Jogan earthquake, and the revised estimates show a larger size of the 869 earthquake (Namegaya and Satake, 2014, GRL). For a uniform-slip model, the fault length is at least 200 km, slip amount is at least 12 m, and Mw is at least 8.6. For the 2011-type variable-slip fault models, the fault length is at least 300 km and Mw is 8.8 or larger.

Recently, attempts have been made to estimate flow depths and velocities from the distribution of tsunami deposits as an inverse problem (e.g., Naruse and Abe, 2017, JGR). The tsunami source also controls the number of waves, duration and dominant period, as well as amplitude and velocity. For example, far-field tsunamis have long-lasting characteristics (Satake et al, Earth-Science Reviews, in press). Here we review studies using a sediment transport model developed by Takahashi (2012, J. Sed. Soc. Japan).

In this model, conservation of sediment mass in the bed load layer and the suspended load layer, as well as the exchange rate between these layers, are calculated, based on the bottom shear stress computed from ordinary tsunami numerical simulations. The total erosion and deposition of sediment thus computed are compared with the observation. While the original model was developed for single grain size, Gusman et al. (2018, Marine Geology) extended the model to multiple sand grain sizes from 0.063 to 5.657mm based on the hydraulic experiments, and compared the results with grain size distribution of the 2011 tsunami deposit in Numanohama coast on Sanriku coast. Further, they demonstrated that the observed thickness and grain size distribution are controlled by the amplitude and period of incoming wave, and indicated the possibility to study the tsunami source model from deposit.

Kusumoto (2018, Ph.D. thesis) applied one-dimensional sediment transport modeling to the 2011 Tohoku tsunami deposits at Idagawa lowland (Fukushima prefecture), Sendai plain, and Numanohama marsh, and compared the results with the observations. The slip amount and distribution of the 2011 Tohoku earthquake model (Satake et al., 2013, BSSA) were modified in ten different source models. These models produce different distribution and thickness of deposit. He also showed that the coastal forest has significant effects for tsunami deposit distribution. Comparison with the 869 Jogan deposit indicates that the 869 Jogan earthquake had the magnitude and fault length slightly smaller than the 2011 Tohoku earthquake.

Keywords: tsunami, tsunami source, tsunami deposit

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[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS02] Environmental, socio-economic and climatic changes in Northern Eurasia

convener:Pavel Groisman(NC State University Research Scholar at NOAA National Centers for Environmental Information, Asheville, North Carolina, USA), Shamil Maksyutov(National Institute for Environmental Studies), Evgeny P Gordov(Institute of Monitoring of Climatic and Ecological Systems SB RAS), Akiyo Yatagai(Hirosaki University)

We invite presentations on the biogeochemical cycles, the surface energy budget and water cycle, and climate and ecosystem interactions in Northern Eurasia (land-cover/land-use change, atmospheric aerosols, soil, and permafrost changes that affect and are being affected by climate and ecosystem change), human dimension, and tools to address the Northern Eurasia studies.

In environmental studies, our Session foci are on the permafrost changes in Siberia, Asian Mountains, and the Arctic coastal regions and on the carbon cycle of Northern Eurasia.

In the regional water cycle studies, our Session foci are on the changing distribution of precipitation intensity, frequency, form (solid versus liquid) and on the pattern and seasonal cycle changes of runoff.

In the human dimension studies, our Session foci are on assessments of impact of the ongoing environmental changes in Northern Eurasia on the human well-being and on mitigation strategies development in response to harmful consequences of these changes.

The particular foci of this Session will be the studies of changes that impacts regional sustainable development in Eurasian Arctic and the Drylands of Northern Eurasia.

We invite also early career scientists associated with (or interested in) the Northern Eurasia Earth Science Partnership Initiative and its continuation, Northern Eurasia Future Initiative (http://nefi-neespi.org/NEFI-WhitePaper.pdf).

[MIS02-01] Change in metals speciation in waters of Arctic lakes (1975-2018): climate, anthropogenic loads, geochemical feature

★Invited Papers

*Marina I Dinu[1] (1.Russian, Vernadsky Institute of geochemistry and analytical chemistry)

[MIS02-02] Revised methane emission estimate for West Siberia based on Landsat mapping of wetland types

*Shamil Maksyutov[1], Irina E Terentieva[2], Alexander F Sabrekov[2], Ilya Filippov[3], Mikhail V Glagolev[4,5] (1.National Institute for Environmental Studies, Tsukuba, Japan, 2.Institute of Ecology and Evolution, RAS, Moscow, Russia, 3.Yugra State University, Khanty-Mansyisk, Russia, 4.Institute of Forest Science, RAS, Uspenskoe, Russia, 5.M.V. Lomonosov Moscow State University, Moscow, Russia)

[MIS02-03] A climatological study on freezing rain, freezing drizzle, and freezing fog in northeastern China

Yang Bai[1], *Tetsuya Hiyama[2], Hatsuki Fujinami[2] (1.Graduate School of Environmental Studies, Nagoya University, 2.Institute for Space-Earth Environmental Research, Nagoya University)

[MIS02-04] Economic Assessment of Permafrost Degradation Effects on Road Infrastructure Sustainability under Climate Change in the Russian Arctic

*Dmitry Olegovich Eliseev[1], Boris Nikolaevich Porfiriev[2], Dmitry Andreevich Streletskiy[3] (1.Russian New University (RosNOU), Moscow, Russia; Sochi scientific research center, Russian Academy of Sciences, Sochi, Russia, 2.Institute of Economic Forecasting, Russian Academy of Sciences, Moscow, Russia, 3.George Washington University, Washington, United States; Earth Cryosphere Institute, Tyumen' Scientific Center, Siberian Branch, Russian Academy of Sciences, Tyumen', Russia)

[MIS02-05] Informal use of linear road infrastructure of the extraction of natural resources in Eastern Siberia.

*Viktor Bogdanov[1] (1.Institute of geography V.B. Sochava Siberian Branch of the Russian Academy of Sciences)

[MIS02-06] **Characterization of contemporary fire regimes in Russian boreal forest under impact of climate change and anthropogenic alterations: Thematic study of the Sakha Republic (Yakutia)**

*Kiunnei Kirillina[1], Wanglin Yan[1] (1.Graduate School of Media and Governance, Keio University SFC)

Change in metals speciation in waters of Arctic lakes (1975-2018): climate, anthropogenic loads, geochemical feature

*Marina I Dinu[1]

1. Russian, Vernadsky Institute of geochemistry and analytical chemistry

Speciation of metals in natural waters is an important information about the level of toxicity of a natural object. According to numerous published data, the most dangerous form of migration of heavy metals (except mercury) is an ionic form.

However, the study of metals distribution forms in each water object is a task that requires a huge physical-chemical work.

Understanding the patterns of element distributions in surface water and the reasons for the increase in their concentrations at the regional and global level is one of the most urgent problems facing the environment. Enrichment of surface water by metals is the result of both natural processes and human activities. The anthropogenic impact in the discharge of trace elements in the environment has increased dramatically over the last century, which is associated with the ever-increasing volumes of extracted metals and their dispersal in the environment.

The aim of our research was to investigate the distribution of the metals speciation in water lakes on the Kola Peninsula under different anthropogenic load.

Samples of lakes near industrial sites were selected near the mining processing complex in Kovdor, from Lake Monche (Lovozero) near the copper-nickel manufacture. Natural waters characterized by high alkalinity and pH about 7. The iron ions at such pH values are more form hydrox- compounds and sorption aggregation compared with aluminum ions. Under conditions of high load anthropogenic, chromium ions characterized by sufficient complexing capacity, which may be due to an increase in the concentration of the metal is several times as compared with lakes without direct sources. Manganese in such conditions has a high capacity to form suspensions. The complexation of heavy metals (Cd, Pb, Cu, Zn) is modified as follows: as well as for lakes without a direct source of pollution, zinc is complexed by more than 50%, copper also forms complexes with organic matter actively due to a significant increase in concentration. Depending on the type of copper coming from the wastewater, copper may form sorption unit and the low-molecular inorganic compound.

Speciation of nickel in natural waters with a direct source of pollution range from units to sorption complexes with organic matter as was found. A significant increase in metal concentration shifts the equilibrium in the system towards formation of high-molecular compounds. An interesting feature of the distribution of elements on the forms such natural waters is increasing the complexation with organic matter for the elements of the lanthanide series. Lanthanide elements is associated elements of many rocks of the Kola Peninsula, which explains the increase in their concentration in the areas near the plant. The affinity of these elements to an organic substance as follows: Fe>Al>Zn>Ni>Cu>Pb>La>Ce>Co.

High content of technogenic elements –Ni, Cu - create conditions for competition for organic ligand and the other formation of charge. Zeta potential change occurs dynamically and not smoothly.

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Middle waters (25 samples between the polluted area and the background) are characterized by 2 maxima of zeta potential. The color of the solution does not change. Turbidity and pH vary widely.
Trends 1990-2014-2018 for small lakes

Non-labile forms of nickel and cobalt are changing dynamically from 1990 to the present and this fact directly depends on episodes of maximum pollution and turbidity. The proportion of the soluble part of the iron and aluminum compounds is also reduced.

Trends 1990-2014-2018 for Imandra lake
The change in the labile forms of nickel, cobalt, and copper also fluctuates and is associated with competitive processes in Lake Imandra in certain years. It was in this lake that the highest labile cadmium contents were found in the middle of the study period.

Keywords: spetiation, metals, Arctic Lake

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Revised methane emission estimate for West Siberia based on Landsat mapping of wetland types

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Quantifying boreal wetland extent and wetland methane emissions is important for estimating the amplitude of methane emission feedback to climate change and the relative contribution of natural and anthropogenic emissions at the national scale. Fine-scale heterogeneity of wetland landscapes and methane emission rates poses a serious challenge for producing regional-scale estimates of greenhouse gas fluxes based on point observations and wetland maps. In order to reduce emission uncertainties at the regional scale, we mapped wetlands and water bodies in the West Siberian lowland (WSL) using a supervised classification of Landsat imagery. Mapping was guided by training data composed of high-resolution images and field data collected at 41 test areas visited for observations of methane emissions with a static chamber method. The classification scheme suited for methane emission inventory included 7 wetland ecosystem types distinguishable on high resolution (1-2 m) images constituting 9 different wetland complexes distinguishable at the Landsat resolution. To support the use of 30 m Landsat images, fractional coverage of wetland ecosystems within each wetland complex type was estimated using high-resolution images. The total area of the WSL wetlands and water bodies was estimated to be 70.78 Mha. Various oligotrophic environments are dominant among wetland ecosystems, while different fens cover only 14% of the taiga area. In WSL, taiga contributes 85% to regional methane flux and tundra only 8%. Elevated environments as forested bogs and ridges emit at the lowest rates. They account for only 2% of the regional total emissions occupying almost 40% of the wetland area. Applying the new map resulted in total methane emissions of 4.6 TgCH4/yr which is higher than the earlier estimate based on paper maps, due to larger area fraction of mesotrophic open wetlands found in the middle taiga zone. The revision resulted from the changes in fractional coverages of methane emitting ecosystems due to the fill area coverage of the WSL with Landsat-based mapping.

Keywords: wetland mapping, Landsat, methane emissions, West Siberia

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A climatological study on freezing rain, freezing drizzle, and freezing fog in northeastern China

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Freezing phenomena, which derive icy ground surface over a wide area, frequently occur in cold (winter) season. Freezing phenomena, more specifically freezing precipitation, are classified into freezing rain, freezing drizzle, and freezing fog. In 2008, huge freezing rain occurred in southeastern China from early January to early February, which caused enormous economic losses and casualties. In the winter of 2010, a huge freezing rain attacked northeastern China. As a result, many airports and highways were forced to closed. Since freezing phenomena have a great influence on human activities, it is very important to explore under which weather conditions freezing phenomena will appear from a climatological point of view. Previous studies have focused on freezing rain, and explored the generation processes of freezing rain while freezing drizzle and freezing fog were not concerned. In addition, previous studies mainly focused only on the mechanism of the extreme events. None of climatological researches has been conducted based on multiple cases including freezing drizzle and freezing fog.
In this study, we investigated almost all of the freezing phenomena events which occurred at four airports of the major cities in northeastern China (Harbin, Changchun, Shenyang, and Dalian), and we analyzed atmospheric circulation pattern when freezing phenomena appeared. The aim of this study is to demonstrate the climatological features of freezing phenomena in northeastern China. The aviation meteorological reports at the above four airports is used for this study and the study period is from the 2005 to 2018 (14 years). And, the ERA-Interim atmospheric reanalysis data is also used for the analysis of large-sale atmospheric condition. The civil aviation meteorological weather reports were recorded every 30 or 60 minutes. We used meteorological data such as wind direction, wind speed, air temperature, and dew point temperature. We defined a freezing phenomenon which continued for more than three hours as one event.
We found one freezing rain and one freezing drizzle event in 14 years. On the other hand, 238 events of freezing fog in total were extracted. We found the melting process was the main reason of the freezing rain process in Shenyang airport. This was the same process as in the large-scale freezing rain event in southeastern China. In the case of the freezing drizzle event at Dalian, we found the cold air intrusion into the humid atmosphere just after a rainfall event. The sudden cold air intrusion in association with the high pressure may play a key role for the formation of freezing drizzle. Thus, it was considered that freezing drizzle could appear in case that Dalian was covered by a high-pressure system just after passing a low-pressure system.
Most of the freezing fogs were detected from nighttime to the next morning. This might be related to the surface radiative cooling. On the day of the appearance in freezing fogs, high-pressure anomalies were found around northern Japan relative to the climatological mean (for 14 years from 2005 to 2018). This made northerly winds weaker near the surface in northeastern China than those in the climatological mean of winter. Interestingly, in case of the appearance of freezing fogs in midday, stronger high-pressure anomalies were detected around Japan.

Keywords: freezing rain, freezing drizzle, freezing fog

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Economic Assessment of Permafrost Degradation Effects on Road Infrastructure Sustainability under Climate Change in the Russian Arctic

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Russian regions containing permafrost play an important role in the Russian economy, containing vast reserves of natural resources and hosting large-scale infrastructure to facilitate these resources' exploitation. Rapidly changing climatic conditions are a major concern for the future economic development of these regions. This study examines the extent to which the transport infrastructure are affected by permafrost in Russia. Three model scenarios of changes in road infrastructure sustainability under permafrost thawing and degradation due to global climate change in nine Russian Arctic regions are considered. Until the current mid-century, economic assessment of the aftermath of climate change in these regions was physicogeographically based on six model climate assessments of cryogenic conditions, reflecting the most negative (scenario RCP8.5) option of the IPCC global climate change forecasts, which best fits the conditions of the Russian Arctic. The data of Russia's Transport Strategy until 2035, updated by the authors, serve as the basis for predicting road infrastructure development. An inertial (conservative) scenario of road infrastructure development in 2020–2050 shows that capital costs to maintain road infrastructure sustainability and reduce damage risks under permafrost thawing and degradation will average at least 250 m US dollars a year and will exceed 350 m. and 470 m. respectively, under the moderate and modernization scenarios. The maximum indicators will be relevant for the Republic of Sakha (Yakutia), Magadan oblast, and the Chukotka Autonomous Okrug. The implementation of the modernization scenario will require revision of the existing standards, technologies, and entire economy of the road infrastructure and capital construction favoring the development of innovative standards and construction technologies, as well as the improvement of the proposed methodology and methods of cost estimation for these purposes.

Keywords: climate change, permafrost degradation, road infrastructure, risks, development scenarios, russian arctic

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Informal use of linear road infrastructure of the extraction of natural resources in Eastern Siberia.

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A study on the use of linear road infrastructure as an informal road network has not been sufficiently studied. It is especially relevant in areas of intensive extraction of various natural resources.

The objectives of our study: to calculate the change in transport accessibility in connection with the construction of a new linear road infrastructure, to identify the positive and negative aspects of its use for informal transportation purposes, make an inventory, classification, and creation of a road network database including both formal and informal roads. We consider informal roads as roads outside of the existing network of public roads built, maintained and used by various organizations and individuals based on private, special goals and or informal rules.

The study area is located in the northern part of the Irkutsk region within the boundaries of the Ust-Kut and Katanga regions. It is characterized by difficult natural conditions: adverse winter temperatures, discontinuous permafrost, bogging, etc. The area had very low transport accessibility, but with the extractive industrial development the linear road infrastructure is growing rapidly.

Methods

For the project purposes, we used existing topographic materials, oil and gas field technological road maps, and remote sensing data. The calculation of the transport accessibility of this territory was made by the method of isochrons - lines of equal time spent on overcoming the space concerning the given points, using open GIS "GRASS GIS". To study the influence of roads on natural landscapes, we conducted several in-situ observations.

Results

The study area is a community of the Evenk indigenous population, which is mainly engaged in hunting and fishing. In the last 10 years, intensive logging, exploration and production of oil and gas has been carried out in the area. Accordingly, a linear road infrastructure is being built to service fields and transportation of resources.

There is a pronounced sequence in the construction of linear infrastructure.

The study area has significant forest and oil and gas resources, the company operators have long-term plans for their development. As new oil and gas fields are built and deforestation felled to the north, previously constructed technological roads become transit roads with relatively intense year-round traffic.

At the same time, there are no year-round public roads; the municipality organizes only winter roads that partially pass through abandoned geological profiles and forest roads.

We calculated transport accessibility using the linear road infrastructure of extractive companies. The

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time spent on a way from the studied settlements to the transportation hubs of the region decreased to 50% in the winter period, while the transport assimilation of the entire studied territory significantly improved.

At the same time, there are other positive and negative effects of improving the transport development of the territory: the municipality's costs for maintaining winter roads are reduced, as well as the cost of delivering goods, hunters have the opportunity to get to new lands, while poaching by non-local people also increases. Field studies in key areas of Tokma and Khanda revealed landscape disturbances, replacement of the original forests with secondary birch forests, the development of thermal caste in swampy valley areas, soil heaving due to disturbance of soil cover and vegetation, and as a consequence of the development of high roads. The development of erosion processes on the slopes is intensifying.

Therefore, the studies of informal road network development have significant importance for studies of social and environmental impact of the extractive industrial development.

Keywords: road infrastructure, transport accessibility, indigenous population

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Characterization of contemporary fire regimes in Russian boreal forest under impact of climate change and anthropogenic alterations: Thematic study of the Sakha Republic (Yakutia)

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Characterization of contemporary fire regimes is still a challenging scientific task, especially in the light of climate warming and increasing human alteration to forests. This research is the first study to characterize the contemporary fire regimes in the Sakha Republic of Russia. Due to dry climate, high regional lightning activity along with increasing anthropogenic pressure on forests and forested lands, the Republic is characterized by one of the highest forests burning in the country. At the same time, since 1960s, there was detected strong warming trend, especially in the transition spring season, which affected the duration of the fire season and overall fire intensity. The problem of forest fires in the region is escalated by the fact that in the Sakha Republic still does not exist digital, spatially explicit fire database, so our first task was to develop own fire database using combination of the regional fire statistics and satellite fire estimates based on NOAA AVHRR and MODIS products in order to construct the reliable data for fire regime characterization and further use by scientists and other stakeholders.

We carried out fire activity analysis for two institutional levels. First was the regional level (the Sakha Republic) and the second forestry district level. Analysis on forestry district level was performed with the aim to capture the regional changes in the fire regime and establish whether existing significant increasing trends in the main fire variables such as fire frequency and burned area. The main focus was on the burned area as more critical one in the terms of losses.

We developed a new approach for fire regime characterization based on common statistical analysis techniques, which can be applied to any region. The study period, 1996-2018, had not been chosen at random, since 1996 the Sakha Republic underwent rapid industrialization, which we are proposing impacted the fire activity and exist satellite fire estimates.

Changes in the fire regime of the Republic were analyzed with the aim to examine the historical and recent dynamics of main fire features such as number of fires and burned area. During the study period both number of fires and burned area showed increasing trends. The same increasing trends were found at local (forestry district) level. The spatial distribution of fires across the Republic shows that the highest fire activity was observed in Central and Western forestry districts affected by both climate warming and economic industrialization accompanied by involvement of more forested lands into industrial activities and large agroindustry.

The main original part of our research was the investigation of changes in the temporal evolution of fire regimes. This analysis was performed using the Rodionov regime shift detection method. We could identify not only the character of fire trends, but also the exact time when they were occurred. It helped us to identify the causes of the increase of fire activity. The other original part of our research was the fire seasonality analysis. Using combination of regional fire statistics and satellite fire estimates we found that the fire season in the recent decades (from 2009) was started from April and continues through October. As result, were increased both duration of the fire season and total burned area extent. In the most recent

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fire seasons (2017 and 2018), the total burned area was increased more than twice. To capture the impact of climate warming on fires was done the comprehensive analysis of the fire weather during extreme fire seasons.

As a final result, were prepared projections of future fire weather based on the ensemble of climate models. They are showing a high possibility of the temperature increase and intensification of drought conditions on the whole territory of the Republic which can make future fire seasons even more severe. The results of projections of fire weather were used to estimate future burned area extent based on regression modeling.

Keywords: boreal forest, forest fires, fire regimes, fire seasonality and causes, climate change, climate change and forest fires

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[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS02] Environmental, socio-economic and climatic changes in Northern Eurasia

convener:Pavel Groisman(NC State University Research Scholar at NOAA National Centers for Environmental Information, Asheville, North Carolina, USA), Shamil Maksyutov(National Institute for Environmental Studies), Evgeny P Gordov(Institute of Monitoring of Climatic and Ecological Systems SB RAS), Akiyo Yatagai(Hirosaki University)

We invite presentations on the biogeochemical cycles, the surface energy budget and water cycle, and climate and ecosystem interactions in Northern Eurasia (land-cover/land-use change, atmospheric aerosols, soil, and permafrost changes that affect and are being affected by climate and ecosystem change), human dimension, and tools to address the Northern Eurasia studies.

In environmental studies, our Session foci are on the permafrost changes in Siberia, Asian Mountains, and the Arctic coastal regions and on the carbon cycle of Northern Eurasia.

In the regional water cycle studies, our Session foci are on the changing distribution of precipitation intensity, frequency, form (solid versus liquid) and on the pattern and seasonal cycle changes of runoff.

In the human dimension studies, our Session foci are on assessments of impact of the ongoing environmental changes in Northern Eurasia on the human well-being and on mitigation strategies development in response to harmful consequences of these changes.

The particular foci of this Session will be the studies of changes that impacts regional sustainable development in Eurasian Arctic and the Drylands of Northern Eurasia.

We invite also early career scientists associated with (or interested in) the Northern Eurasia Earth Science Partnership Initiative and its continuation, Northern Eurasia Future Initiative (http://nefi-neespi.org/NEFI-WhitePaper.pdf).

[MIS02-07] Analysis of CMIP6 Multi-model Climate Change Smulations and Projections Over Northern Eurasia

★Invited Papers

*Qingyun Duan[1], Xuewei Fan[2], Chenwei Shen[2], Chiyuan Miao[2] (1.Hohai University, 2.Beijing Normal University)

[MIS02-08] Evaluation of a snow scheme in Integrated Land Simulator

*Tomoko Nitta[1], Kei Yoshimura[1] (1.Institute of Industrial Science, the University of Tokyo)

[MIS02-09] Closing water budgets of the three great Siberian River Basins

*Pavel Shabanov[1], Ambroise Dufour[1], Olga Zolina[2], Sergey Gulev[1], Martin Wegmann[3] (1.Shirshov Institute of Oceanology, Russian Academy of Sciences, 2.Institut des Géosciences de l'Environnement, Université Grenoble Alpes, 3.World Meteorological Organisation, Geneva)

[MIS02-10] Evaluation of orographical precipitation over Central Asia and its super-ensemble and downscaling simulations to evaluate precipitation change under the warming environment

*Akiyo Yatagai[1], Saki Yanagisawa[1], Kumar Vinay[2], Ayano Senda[1], Minami Masuda[1] (1.Hirosaki University, 2.Texas A&M University)

[MIS02-11] ENVIRONMENT CHANGES IN THE EURASIAN ARCTIC

*Pavel Groisman[1,2,3], Sergey Gulev[2], Ambroise Dufour[2], Ge Peng[1], Dmitry Streletskiy[4], Nina Speranskaya[5], Nadezhda Tchebakova[6] (1.North Carolina Institute for Climate Studies, North Carolina State University, USA, 2.Institute of Oceanology, Russian Academy of Sciences, Russia, 3.Hydrology Science and Services Corporation, USA, 4.George Washington University, USA, 5.State Hydrologic Institute, Russia, 6.Forest Institute of the Siberian Branch of the Russian Academy of Sciences, Russia)

[MIS02-12] How much variation in land surface phenology can seasonal climate oscillations explain at pasture scale in Kyrgyzstan?

*Monika Anna Tomaszewska[1], Geoffrey M. Henebry[1,2] (1.Center for Global Change and Earth Observations, Michigan State University, East Lansing, MI 48823, USA, 2.Department of Geography, Environment, and

Spatial Sciences, Michigan State University, East Lansing, MI, 48824, USA)

Analysis of CMIP6 Multi-model Climate Change Smulations and Projections Over Northern Eurasia

*Qingyun Duan[1], Xuewei Fan[2], Chenwei Shen[2], Chiyuan Miao[2]

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Northern Eurasia has observed an above average increase in surface air temperature over the last century compared to other parts of the world and is the region most sensitive to climate changes as increased temperature has a huge impact on its water and energy cycles and on its ecosystem. This presentation summarizes an analysis of the climate simulations over the period 1901–2014 and climate change projections over the period 2015-2100 under four different Shared Socioeconomic Pathways (SSPs) from 16 global climate models (GCMs) participating in the sixth phase of the Coupled Model Intercomparison Project (CMIP6). Simulations and projections of surface air temperature and precipitation over the study regions were intercompared and were compared to multi-model consensus simulations and projections obtained by Bayesian Modeling Averaging (BMA) method. The results show significant differences among results of individual GCMs and BMA multi-model consensus results are the most reliable when compared to observations in terms of spatial averages and seasonal averages. BMA method is also useful in providing uncertainty information about the projections of future climate changes. Overall, CMIP6 results show an increasing trend in average air temperature over Eurasia.

Keywords: CMIP6, Multi-model consensus simulations and projections, Climate Change over Northern Eurasia

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Evaluation of a snow scheme in Integrated Land Simulator

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Accurate representation of land processes is crucial for many purposes, such as climate simulation, weather and flood prediction, and water resources assessment. To realize high-accuracy land simulations with rapid model development cycles, we have been developing a new land simulation framework, Integrated Land Simulator (ILS). ILS consists of multiple land components and an independent I/O component. They are executed based on an MPMD (Multiple Program-Multiple Data) approach using a general-purpose coupler Jcup. Currently, ILS includes a physical land surface model, Minimal Advanced Treatments of Surface Interaction and Runoff (MATSIRO), a next-generation river model, CaMa-Flood, and an independent I/O component. MIROC5 version of MATSIRO was rewritten in the modern structure. Using the reference site dataset prepared in ESM-SnowMIP project, we evaluated a snow scheme in ILS. The result shows that the reproducibility varies by sites but there are some systematic biases such as cold biases in soil temperature in winter. Future directions of the model improvement will be discussed in the presentation.

Keywords: land model, snow scheme

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Closing water budgets of the three great Siberian River Basins

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The basins of the three great Siberian rivers –Ob, Yenisei, Lena –have come under scrutiny as symptomatic of the effects of Arctic amplification on regional water cycles. As the air moistens, Zhang et al. (2013) report more vapour convergence and greater discharges into the Arctic Ocean. The thawing permafrost is also extremely relevant. However, the warming signal can display counterintuitive patterns (Wegmann et al., 2018) and the consequences on moisture fluxes are not straightforward (Dufour et al., 2016).

This study draws on several reanalyses including ERA-5 (Hersbach et al., 2019). The discharge data before 1999 comes from the Global Runoff Data Centre (GRDC, 2014) and from the Arctic Great River Observatory (Shiklomanov et al., 2018) hitherto. We also consider an intermediate product : river discharge from the Global Flood Awareness System at 0.1° resolution (GloFAS v2.1). This is the output of the HTESSEL land model and LISFLOOD river routing model, run at 0.1° resolution.

We replicate the significant moisture convergence trend found in Zhang et al., 2013 for the extended 1948-2018 period. However, the trend breaks down for the shorter 1979-2018 time windows and in other reanalyses except MERRA-2 over 1980-2018. The discharge observations summed over the mouths of all three rivers are significantly increasing in the long run but not during the satellite era. The initial findings appear sensitive to the starting and ending points of the study period. We believe part of the explanation is to be found in warm Arctic - cold Siberia pattern (Wegmann et al., 2018). The weak increasing trend in convergence and discharge is not driven by a straightforward global warming trend. Rather, it is the consequence of atmospheric variability which is inherently more noisy than thermodynamical signals.

Nearly all reanalyses exhibit significant negative net precipitation trend over the satellite era with the exception of NCEP NCAR R1 and MERRA-2. Further analysis indicates that these trends are due to a decrease in precipitation rather than an increase in evaporation. The decrease in precipitation occurred mainly in summer and is absent in the Global Precipitation Climatology Project. The conflicting trends between convergence and net precipitation indicate a severe unbalance of moisture budgets over Siberia. The GloFAS product also displays a decreasing net precipitation trend - a consequence of the HTESSEL land model being forced by reanalysis precipitation fields.

Over the Siberian river basins, there are weak long-term increasing trends of moisture convergence and river discharge. The reanalyses show perplexing negative precipitation trends in contradiction with the increasing/constant moisture transport. The causes of either tendencies are likely atmospheric variability and strong analysis increments.

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GloFAS v2.1, 2019-11-05, DOI: 10.24381/cds.a4fdd6b9

Keywords: water cycle, moisture transfer, reanalysis data

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Evaluation of orographical precipitation over Central Asia and its super-ensemble and downscaling simulations to evaluate precipitation change under the warming environment

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Following JpGU 2019 presentation, here we apply the multimodel superensemble (MMSE) technique to monthly precipitation of Central Asia(CA, 50E-85E/35N-60N). We focus on our results in spring. As reference datasets, we used GPCC monthly precipitation as well as APHRODITE precipitation. First we apply MMSE to CMIP5 “historical” precipitation according to each monthly precipitation. We use data for 1980 –1990 (11 years) and all registered 20 climate models from CMIP5 archive. We used 10 years data for “training” to decide weighting parameters according to APHRODITE, then we “simulate” the rest of 1 year with the parameters. Then we compared the “simulated” value with APHRODITE data of the year. We repeated this process for 11 times, so that every year’s data is forecasted by MMSE.

Comparison of each model precipitation pattern to observations, the correlation coefficients (CC) between MMSE results are higher than that of each models for all years. We also made SUP with top 6 models that show high CC between time series of CA mean precipitation and that of each model. Namely, we select the models that simulate interannual variation of total precipitation to the CA area, because it was reflected how each model simulate the dynamical structure by the observed force. In JpGU2019, we evaluate these CC over whole CA, however, now we focused on Tianshan/Pamir area (65-80E, 37-45N) to calculate horizontal pattern of monthly precipitation and temporal changes in areal mean precipitation.

Results show that highest correlation has been made by the airs with using APHRODITE for training than that of GPCC. However, the top 6 models for showing interannual variability showed minus correlation to the precipitation of validation years. Before applying the parameters to future forecasts, we need to evaluate the interannual variability of the precipitation change with a long-term dataset with APHRODITE type orographic precipitation.

Keywords: Precipitation, Central Asia, superensemble forecast

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ENVIRONMENT CHANGES IN THE EURASIAN ARCTIC

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Environment changes in the Eurasian Arctic are among the largest during the past century. Surface air temperature increases are most pronounced in spring and winter. In the winter season we observe the largest interannual temperature variability and in spring the warming is accompanied by a regional-wide increase in Convective Available Potential Energy (CAPE) in the atmosphere (see attached Figure). In other seasons, there is a steady temperature increase by 1 to 2˚C per century. The cold season temperature increases play a relatively low direct role in the Arctic environmental changes. However, in the cold season, the Arctic temperatures controls the temperature difference between the tropics and the high latitudes. This difference has already significantly declined and impacted the strength of the westerlies and the heat transport from the North Atlantic Ocean into the continental extratropics. This decline, among others, results in higher winter variability over Northern Eurasia, including the strengthening of the winter blocking events. More and more frequently in the last winters, we observe destructions in the circumpolar atmospheric vortex that generally prevents the cold Arctic air masses to enter the lower latitudes. This may affect the entire cold season weather over the Northern Extratropics as we used to know. Average annual and summer rates of warming are 1.6˚C and 1.2˚C per 100 years respectively. During the last 60 years these rates have nearly doubled. The summer temperatures in the Eurasian Arctic began their rise only about 30 years ago and since 2005 their values in each year remained among the highest in the instrumental record. This summer warming plays a critical role in environmental changes in the Arctic. It controls the vegetation season onset and ecological zone shifts, the demolition of the multi-annual sea ice, and the permafrost thawing. The last factor impacts the well-being of man-made infrastructure in the Arctic. Vegetation season onset and ecological zone shifts have been observed across the entire Northern Eurasia. In warming and drying climates during the 21 century simulated by 2.6 and RCP 8.5 scenarios of the 20 GCMs ensemble of CMIP5, the northern zono-biomes (tundra, forest-tundra, northern woodlands) neighboring the Arctic were predicted to decrease and shift northwards while forest-steppe, steppe, and drylands were predicted to extend over Eurasia. In the end of each warm season in the Arctic, the extent of the Arctic sea ice is steadily declining at about 13.5% per decade since the time of establishment of the circumpolar satellite sea ice monitoring in 1979. Furthermore, the structure of the sea ice is changing leaving a lesser amount of multi-annual ice and making the sea ice cap thinner. For the Arctic as whole, melt onset and ice opening are getting earlier at a rate of over 5 days per decade, making it more transparent to the solar radiation and upward heat fluxes from the ocean. The permafrost warming rates in Northern Eurasia are among the highest documented globally. Permafrost degradation negatively affects well-being on communities upon it and has severe economic consequences. Recent study estimated that under RCP 8.5 scenario more than 50% of all residential housing and 20% of critical infrastructure will be severely affected by permafrost degradation by mid-21 century. The cost of mitigation due to permafrost degradation is likely to exceed 100 billion USD.

Keywords: Eurasian Arctic, regional climatic change, impact on infrastructure due to environment changes, environmental changes

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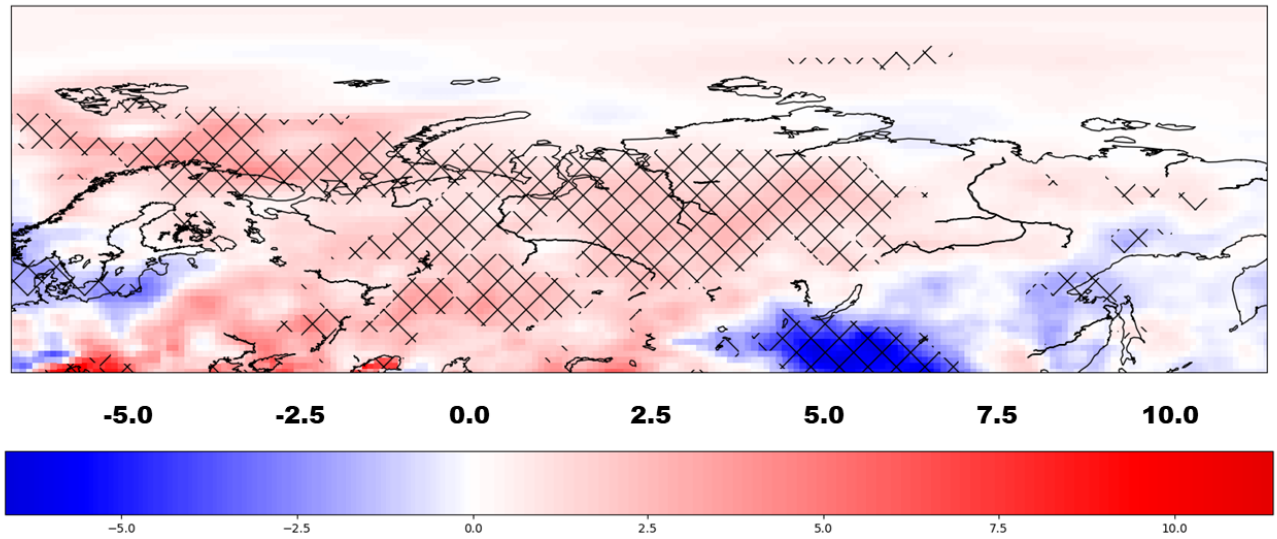
Spring (MAM) Convective Available Potential Energy Trends (1979-2018)



◈ ERA interim reanalyses; CAPE trends (J kg^{-1} $decade^{-1}$); regions with statistically significant at the 0.05 level CAPE trends are hatched.

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How much variation in land surface phenology can seasonal climate oscillations explain at pasture scale in Kyrgyzstan?

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Interactions of the atmosphere with the oceans play an essential role in shaping climate and its variability. Naturally-occurring dynamical modes result in teleconnections—correlated weather patterns between remote locations—that can account for a substantial amount of large-scale climatic variability, and can play significant roles in determining seasonal weather anomalies. In developing economies, where the rural resource base relies on favorable weather, such anomalies may be very deleterious. For example, in montane Central Asia, where the regional economy is grounded in agropastoralism and the climate is cool and dry due to elevation, precipitation received outside the growing season may determine the difference between success and failure in annual production.

We sought to assess whether the impacts of teleconnections are detectable and significant in early season dynamics of highland pastures across five rayons in Kyrgyzstan from 2001 through 2017. Specifically, we focused on the explanatory and predictive power of five seasonal (winter, spring, and summer) climatic oscillations on land surface phenology (LSP) based on fine spatial resolution data. We included two sets of environmental variables already shown to influence LSP in these highland pastures: two snow cover seasonality metrics derived from the MODIS snow cover product—the last date of snow (LDoS) and the number of snow covered dates (SCD)—and three terrain characteristics derived from the NASA SRTM Digital Elevation Model—elevation, slope, and the TRASP index, a linearization of aspect.

We characterized early season vegetation growth using two phenometrics derived from the LSP model that links the normalized difference vegetation index (NDVI) derived from Landsat data at 30 m with accumulated growing degree-days (AGDD) derived from MODIS land surface temperature data at 1 km: (1) the maximum modeled NDVI or Peak Height (PH); and (2) the quantity of AGDD required to reach the PH or Thermal Time to Peak (TTP).

We used Spearman’s rank correlation to assess the strength and significance of geographic differentiation of the phenometrics’ linkages to environmental variables. PH showed significant but weak correlations with TTP (positive in western rayons but negative in eastern rayons), and moderate positive relationships with LDoS and SCD appearing only in one northeastern rayon. Of the 15 seasonal indices we evaluated, only two showed significant (positive or negative) correlation with PH. In contrast, TTP showed consistently significant strong negative relationships with LDoS, SCD, and elevation, but very weak significant positive correlations with three winter modes and only in western rayons.

Second, we used Partial Least Squares regression to investigate how much of additional variation in LSP metrics can be explained by seasonal oscillation indices. PLS modelling showed that thermal time accumulation could be explained mostly by elevation and snow cover metrics, explaining 55–70 % of the observed variation in TTP. Only three oscillation indices (two summer and one spring) had a significant relationship with TTP, but contribution of each to the model’s predictive power was negligible. PLS models were able to explain no more than 29% of PH variability. Similarly, just two oscillation indices (one spring and one summer) were significantly linked to PH, but their predictive contribution was minimal. Influences of climate oscillations were too weak to provide effective seasonal prediction of LSP at fine spatial resolution. Rather, the effects of climatic oscillations on highland pastures phenology were overshadowed by terrain features (primarily elevation) and the timing of snow cover seasonality.

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Whether seasonal climate oscillation indices may provide some useful information about growing season conditions remains a provocative question, particularly given the multiple environmental challenges facing agropastoralism as a sustainable livelihood in montane Central Asia.

Keywords: Land-atmosphere interactions, Snow seasonality, Montane Central Asia, MODIS, Landsat, Phenology modeling

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[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS03] Structure and deformation in the overlying plate due to subduction and related feedbacks

convener:Hiroshi Sato(Earthquake Prediction Research Center, Earthquake Research Institute, The University of Tokyo), David A Okaya(University of Southern California), Eh Tan(Institute of Earth Sciences, Academia Sinica), Masahiro Ishikawa(Graduate School of Environment and Information Sciences Yokohama National University)

Subduction over time modifies the overriding plate by fractionation, accretion, and tectonic deformation. This can lead to processes such as tectonic shortening (orogeny), regional uplift, weakening by back-arc spreading and volcanism, basin formation, and/or destabilization of the lithosphere. In turn, the composition, strength, and morphology of the overlying plate, which may be the product of a long geological history and have significant along-strike variations, can affect current large-scale subduction dynamics such as slab dip, and ultimately broad-scale plate kinematics in two and three dimensions. Examples of geological settings that bear witness to these processes are found along the Pacific Rim, including Japanese arcs, Taiwan, Hikurangi, northwestern North America, and Tethys margin, including Himalaya and the Mediterranean mobile belt. We seek contributions from all geoscience disciplines that document the structure and tectonic evolution of overlying plate deformation and their feedbacks onto subduction processes. We welcome studies on topics such as: geologic and tectonic geomorphological deformation of the overlying plate and its relation to the subduction; geodetic deformation of the overlying plate; active and passive imaging of the overlying plate and crustal structure; rheological features obtained by laboratory and earthquake seismology; basin development and mountain building processes; numerical geodynamical modeling of overlying plate deformation; and backarc opening proceses. Comparisons of the Nankai and Japan Trench subduction systems to other global subduction zones are of particular interest. This session is supported by ILP (International Lithosphere Program).

[MIS03-01] **Crustal structure of the Nankai subduction zone revealed by two decades of onshore-offshore and ocean-bottom seismometer data**

*Dan Bassett[1], Adrien Arnulf[2], Shuichi Kodaira[3], Ayako Nakanishi[3], Alistair Harding[4] (1.GNS Science, 2.University of Texas at Austin, 3.JAMSTEC, 4.Scripps Institution of Oceanography)

[MIS03-02] Lower lomit of seismogenic zone beneath Japan based on hyopocenter catalog determined with 3D seismic velocity structure

*Makoto MATSUBARA[1], Tomoko Elizabeth Yano[1], Hiroshi Sato[2] (1.National Research Institute for Earth Science and Disaster Resilience, 2.Earthquake Research Institute, the University of Tokyo)

[MIS03-03] Thermal structure of the Honshu arc deduced from high P-T ultrasonic experiments and seismic tomography

*Masahiro Ishikawa[1], Shigeki Sugita[1], Satoshi Fukunaga[2] (1.Graduate School of Environment and Information Sciences, Yokohama National University, 2.College of Engineering Science, Yokohama National University)

[MIS03-04] Back-arc spreading induced by weakening in the overriding plate and mantle wedge

*Eh Tan[1], Chi-Chin Lee[2] (1.Institute of Earth Sciences, Academia Sinica, 2.Department of Geosciences, National Taiwan University)

[MIS03-05] Origin of seismogenic source faults in the backarc of Honshu, Japan.

*Hiroshi Sato[1], Tatsuya Ishiyama[1], Tetsuo No[2], Makoto MATSUBARA[3], Shuichi Kodaira[2] (1.Earthquake Research Institute, The University of Tokyo, 2.Japan Agency for Marine-Earth Science and Technology, 3.National Research Institute for Earth Science and Disaster Resilience)

[MIS03-06] Stress loading on crustal source faults due to megathrust coupling: the Nankai Trough and the Kuril trench

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(1.Earthquake Research Institute, University of Tokyo, 2.Purdue University, 3.The University of Texas at Austin)

Crustal structure of the Nankai subduction zone revealed by two decades of onshore-offshore and ocean-bottom seismometer data

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Subduction zones produce the largest and most hazardous earthquakes on Earth. Regional constraints on the structure and geometry of both the subducting and overthrusting plates, and of conditions at the plate interface, can improve knowledge of physical controls on fault slip behavior. It is, however, challenging to obtain a detailed synoptic view of subduction zones from seismic methods over areas comparable to those of the largest ruptures (10^5 km^3). Earthquake tomography studies provide 3-D images, but at low resolution (~30-50 km). Individual marine seismic experiments yeild higher resolution, but are often limited to 2-D profiles and shallower depths.

Our work seeks to bridge this imaging gap for the Nankai subduction zone by making use of the largest onshore-offshore and ocean-bottom seismometers (OBSs) dataset ever recorded: air gun sources from multiple offshore experiments passively recorded onshore by dense permanent networks of borehole seismometers, augmented by 3-D OBS experiments offshore and carefully selected Earthquake events from existing catalogs onshore. This dataset has accumulated over two-decades and includes over 45+ million source-receiver pairs with coverage of the entire Nankai subduction zone.

In this presentation, I will describe refined 3-D constraints on the geological architecture of the Nankai subduction zone and relationships with along-strike variations in geodetic locking, large earthquake occurrence and the distribution of slow earthquake phenomena at depth.

Keywords: Subduction, Nankai, Earthquakes, Crustal structure

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Lower lomit of seismogenic zone beneath Japan based on hyopocenter catalog determined with 3D seismic velocity structure

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1. Introduction

Japanese Islands are under compressional stress owing to the subduction of the Pacific plate from the east. There are many active faults in and around the Japanese Islands. The lower limit of the seismogenic zone (D90) is important to estimate the maximum size of the earthquake with the active faults. We relocate hypocenters with three-dimensional (3D) seismic velocity structure (Matsubara et al., 2019) and estimate the lower limit of seismogenic zone for the crustal events beneath Japanese Islands.

2. Data and Method

We relocated 561,611 events from October 2000 to December 2017 within 129.2-146.3E, 30-46N, and 0-100 km depth with 3D seismic velocity structure (Matsubara et al., 2019). We selected events with depths of 0-25 km to be considered as those related to the active faults. We investigated the index D90 as the lower limits of the seismogenic layer defined as the depth above which 90 % of the whole crustal events occurred from the surface. The size of area in which we count earthquake is +/-0.1 degree in case of focusing the active faults and 0.25 degree in case of focusing the area.

3. Result

The shallow seismicity is low in the Hokkaido. D90 is shallow as 7-10 km at the central Hokkaido along the volcanic front. D90 beneath the southern Hokkaido is extremely deep as 20-25 km. D90 is extremely shallow around 7-10 km along the volcanic front however those along the coast of Sea of Japan and Pacific Ocean are deep as 16-20 km beneath the northeastern Japanese island arc. D90 is shallow as 9-12 km around Iwaki region activated after the Tohoku-oki Earthquake on March 11, 2011.

D90 beneath the central and Kinki region are approximately 15 km except the shallow 7-12 km D90 regions such as the volcanic chain, the Izu Peninsula, and the southern side of the Median Tectonic Line (MTL). D90 beneath the Kanto Mountains and Kiso and Akaishi Mountains are deeper than 20 km.

D90 on the side of the Sea of Japan beneath the Chugoku region are shallow however, the southern side are extremely deep. D90 on the southern side of the MTL is also shallow as 10 km beneath the Shikoku region.

D90 beneath the Kyushu region is 12-16 km except the volcanoes. D90 in the southeastern part on the PAC coastal region of Kyushu is 16-20 km shallower than the upper boundary of the PHS plate.

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4. Discussion

Our result is roughly consistent with the results by Olmuralieva et al. (2012). Shallow D90 region is consistent with the high heat flow region (Matsumoto, 2007) such as volcanic zones and deep D90 region is consistent with the low heat flow such as southern Hokkaido, coastal region of the northeastern Japan, the Kanto region, southern Chugoku region, and southeastern Kyushu region. These are also consistent with the result by Olmuralieva et al. (2012).

Deep D90 regions are consistent with shallow Moho regions such as southeastern Hokkaido, eastern side of the Hidaka Mountains, coastal regions of northeastern Japan, northwestern Kanto region, southern Kii peninsula, and Seto Inland Sea region (Matsubara et al., 2017). The Sea of Japan coastal region of northeastern Japan and northwestern Kanto region are consistent with the failed rift formed at the Sea of Japan opening. Shallow D90 regions are consistent with deep Moho regions such as volcanic front beneath Hokkaido and northeastern Japan, and central mountainous region. eneath the mountainous region in the central Japan except the volcanoes is consistent with the deep Moho region.

5. Conclusion

We calculate the D90 as the lower limit of the crustal seismogenic zone beneath the Japanese Islands. The D90 beneath Japanese Islands is almost 12-16 km except the active volcanic zone and mountainous zone. D90 beneath the active volcanoes is shallower than 10 km, however, that beneath the mountaineous zone is deeper than 20 km. Deep D90 regions correspond to the high heat flow regions and shallow ones correspond to low heat flow regions.

Keywords: Seismogenic zone, Lower limit, Hypocenter catalog

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Thermal structure of the Honshu arc deduced from high P-T ultrasonic experiments and seismic tomography

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Quantifying the thermal structure of the overlying plate is essential for understanding the nature of deformation of the island arc. In order to interpret seismic tomography into thermal structure, it is important to accurately measure the temperature dependence of elastic wave velocity of lower crustal/upper mantle rocks and minerals. In this study, simultaneous measurements of ultrasonic compressional wave velocities (Vp), shear wave velocities (Vs), Vp/Vs ratio and their temperature dependence were conducted on natural xenolith samples collected from the Honshu arc and sintered polycrystalline mineral samples at high temperature and high pressure conditions representative of the lower crust and uppermost mantle of the island arc. The experimental results for each sample have shown a distinct negative temperature dependence of P and S wave velocities. The Vp/Vs ratio, on the other hand, depends heavily on mineral compositions of rocks, not temperature. By extracting regions that are presumed to have the same lithology from the Vp/Vs tomography, Vp perturbations or Vs perturbations of the extracted regions can be interpreted as thermal perturbations. In this study, Vp or Vs in an arbitrary Vp/Vs range were extracted using the three-dimensional seismic tomography of Matsubara et al. (2019), and the thermal structure was estimated from the extracted velocity structure by comparing experimentally determined temperature dependence of Vp or Vs of the samples with Vp perturbations or Vs perturbations in the lower crust and uppermost mantle. An example of the estimated thermal feature is described below. To clarify the temperature perturbation of the lower crust of the NE Honshu arc in the east-west direction, P-wave velocities and S-wave velocities in the range of Vp/Vs = 1.75 to 1.77 were extracted from the seismic tomography of 20km depth. At latitude of 39.75-40˚N, the lower crust of the Ou Backbone Range is estimated to be the hottest, because the extracted velocities of the P and S waves indicate the lowest velocities below the Ou Backbone Range. P-wave velocity and S-wave velocity increase toward Kitakami Lowland (141 ˚E) and Hachirogata (140 ˚E), and the feature suggest that the temperature of the lower crust decreases from the Ou Backbone Range to the east and west sides. The feature is common in the NE Honshu arc, but there are some differences and exceptions in the north-south direction. The detailed thermal structures and estimated temperatures will be discussed in our presentation.

Keywords: seismic velocity, thermal structure, crustal structure

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Back-arc spreading induced by weakening in the overriding plate and mantle wedge

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Back-arc spreading occurs in the overriding plate of the subduction system. As the subducting plate descends into the mantle, water is released into the mantel wedge by the dehydration of hydrous minerals. Partial melting occurs in the mantle wedge owing to the hydrous condition. The presence of melt reduces the viscosity in the wedge and the yield stress in the lithosphere above. We parameterized the partial melting, melt migration, and strength weakening processes with 2D numerical geodynamic models. We found that mild weakening due to melt is sufficient to induce back-arc spreading. If the weakening is more vigorous, it is possible to generate multi-staged back-arc spreading, similar to the spreading in the Mariana Basin.

Keywords: geodynamics, back-arc spreading

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Origin of seismogenic source faults in the backarc of Honshu, Japan.

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To evaluate the tsunami and seismic hazards along the sea of Japan coast draw a public concern, especially after the devastative tsunami hazards after the M9 2011 Tohoku-oki earthquake. Last decade, seismic surveys have been performed by JAMSTEC and ERI, Univ. Tokyo for mapping the source faults. Seismic velocity structure obtained by earthquake tomography provides the fundamental lithospheric structure beneath Honshu. Those data clearly demonstrate that the present source faults were formed mainly during the period of the rifting and backarc spreading.

Stretched continental crust is located in southern and eastern part of the sea of Japan and backarc of Northern Honshu associated with the saloon door type of opening of the Sea of Japan. The boundary of the two blocks is northern part of the Itoigawa Tectonic line and Kanto tectonic line. The SW Honshu forms a continuous block and arc-parallel trending normal faults and rift basins have been developed associated with the clockwise rotation. The opening of sea of Japan terminated by the collision of Izu-Bonin arc and backarc (young Shikou basin). Due to the northward motion of Philippine Sea plate and high-friction along the subduction zone, a fold-and-thrust belt (Shinji fold belt) has been developed in the stretched continental crust in the backarc at 15-6 Ma. After begging of subduction along the Nankai trough, shortening deformation was terminated. Thus the arc-parallel normal faults reactivated as reverse faults and some of them behave as strike-slip fault under the present stress regime. Eastern part of the SW Honshu block deformed by the collision of Izu-Bonin arc. Due to the horizontal bending in the north of Median Tectonic line, NS-trending normal faults were developed in the zone of Kinki triangle, where presently marked by the concentration of reverse faults.

Northern Honshu is characterized by widely exposed stretched continental crust and distribution of small-scale rifts. Backarc rift basins, such as Northern Fossa-Magna, Niigata, Akita-Yamagata basins, are marked by thick post rift sediments (> 2 km) and floored basalt, high Vp in the lower crust beneath a narrow rift. Commonly an edge of narrow rift is bounded by outward-dipping fault. The origin of the fault is a boundary between continental crust and mafic intrusions. Corresponding to amount of rotation, the southern part of northern Honshu shows wider distribution of rifted structure, such as Kinuagwa river valley, northwestern part of the Kanto plain. Large differential movement of the NE and SW Honshu block, suggested by paleomagnetism, produce thin crust demonstrated by earthquake tomography. Common style of stretched continental crust is marked by half grabens. After the compression since the Pliocene, reactivation of normal fault as reverse fault produced uplifted zones. However, in the rift basin bounded by outward-dipping edge faults, the basin fill strongly deformed and produced fold-and-thrust belts. The size of present length of source faults is strongly controlled by tectonics during the formation of the sea of Japan. The arc parallel rift is displaced by transcurrent faults defining the size of earthquakes. The occurrence of devastative earthquakes along the eastern part of Sea of Japan is correlated with the amount of stretching. Due to the rheology of continental and oceanic crust, shortening deformation is concentrated in the continental crust and especially failed rift zone in the continental crust.

Keywords: Seismogenic source fault, backarc rifing, Formation of the Sea of Japan, Honshu

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Stress loading on crustal source faults due to megathrust coupling: the Nankai Trough and the Kuril trench

*Akinori Hashima[1], Hiroshi Sato[1], Tatsuya Ishiyama[1], Andrew M. Freed[2], Thorsten W. Becker[3]

1. Earthquake Research Institute, University of Tokyo, 2. Purdue University, 3. The University of Texas at Austin

As observed in the seismicity change due to the 2011 Tohoku-oki earthquake, Japan, stress loading in the plate interior is controlled by the interplate process, particularly, megathrust coupling. Thus, the probability of crustal earthquake occurrence can change on decadal scales. Relatively short-term change of this kind is not yet incorporated in the long-term seismic risk assessment based on longer time-scale records from paleoseismology.

This study proposes a deterministic approach to calculate stress loading rates in the plate interior due to the interplate process and examine the consistency with the occurrence of the crustal earthquakes. We use geodetic data from the dense observation network in the Japanese islands to constrain the model. We apply this approach to the Nankai trough and the Kuril trench.

We construct 3-D finite element model including the Japanese islands. This model consists of the Eurasia, Pacific and Philippine Sea plates. The plate boundaries are determined by the previous studies based on distribution of the interplate earthquakes. The plate boundary shallower than depth of 80 km is divided into ~700 subfaults to generate Green’s functions. The model includes viscoelastic property in the asthenosphere to treat the long-term process. As the source fault geometry, we revised the geometry model by Headquaters for the Earthquake Research Promotion and added the source faults under the Sea of Japan based on the recent geophysical surveys.

Using our model, we invert geodetic data to obtain the slip-deficit rates (locking rates) on the plate boundary. Then, we compute Coulomb stress rates on the crustal source faults due to the locking. We obtained positive Coulomb stress rates on the source faults of the 2016 Mw7.0 Kumamoto and the other ~M7 earthquakes due to the Nankai trough locking. As for the Kuril trench, we also obtained positive Coulomb stress rates for the 2018 Mw6.7 Iburi (Hokkaido) earthquake. These results imply that crustal earthquakes occur to release the stress loaded by the megathrust coulpling.

Keywords: Stress loading, Nankai trough, Kuril trench, Source fault, Finite element method, Crustal deformation

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[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS03] Structure and deformation in the overlying plate due to subduction and related feedbacks

convener:Hiroshi Sato(Earthquake Prediction Research Center, Earthquake Research Institute, The University of Tokyo), David A Okaya(University of Southern California), Eh Tan(Institute of Earth Sciences, Academia Sinica), Masahiro Ishikawa(Graduate School of Environment and Information Sciences Yokohama National University)

Subduction over time modifies the overriding plate by fractionation, accretion, and tectonic deformation. This can lead to processes such as tectonic shortening (orogeny), regional uplift, weakening by back-arc spreading and volcanism, basin formation, and/or destabilization of the lithosphere. In turn, the composition, strength, and morphology of the overlying plate, which may be the product of a long geological history and have significant along-strike variations, can affect current large-scale subduction dynamics such as slab dip, and ultimately broad-scale plate kinematics in two and three dimensions. Examples of geological settings that bear witness to these processes are found along the Pacific Rim, including Japanese arcs, Taiwan, Hikurangi, northwestern North America, and Tethys margin, including Himalaya and the Mediterranean mobile belt. We seek contributions from all geoscience disciplines that document the structure and tectonic evolution of overlying plate deformation and their feedbacks onto subduction processes. We welcome studies on topics such as: geologic and tectonic geomorphological deformation of the overlying plate and its relation to the subduction; geodetic deformation of the overlying plate; active and passive imaging of the overlying plate and crustal structure; rheological features obtained by laboratory and earthquake seismology; basin development and mountain building processes; numerical geodynamical modeling of overlying plate deformation; and backarc opening proceses. Comparisons of the Nankai and Japan Trench subduction systems to other global subduction zones are of particular interest. This session is supported by ILP (International Lithosphere Program).

[MIS03-07] Collapse of fore-arc crust: Cretaceous Japan case

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[MIS03-08] First stage to reveal the structure of the Fujikawa-kako Fault Zone by the integrated seismic experiments across the northwestern region of the Izu collision zone, central Japan

*Tanio Ito[1], Ken'ichi Kano[2], Toshiki Watanabe[3], Shintaro Abe[1], Hiroshi Sato[4], Takaya Iwasaki[4], Tatsuya Ishiyama[4], Makoto MATSUBARA[5], Akira Fujiwara[6], Susumu Abe[7], Motonori Higashinaka[7] (1.Association for the Development of Earthquake Prediction, 2.Shizuoka University, 3.Nagoya University, 4.University of Tokyo, 5.NIED, 6.Geosys, 7.JGI, Inc.)

[MIS03-09] The shape of Philippine sea plate and the subsurface structure near Mt. Fuji

*Yasushi Harada[1], Hinako Nomachi[1], Kenya Yamanaka[1] (1.School of Marine Science and Technology, Tokai University)

[MIS03-10] Quaternary back-arc strain localization of Northeast Japan accommodated by fault-related folding

*Tatsuya Ishiyama[1], Hiroshi Sato[1], Naoko Kato[1], Shin Koshiya[2] (1.Earthquake Research Institute, University of Tokyo, 2.Department of Civil and Environmental Engineering, Faculty of Science and Engineering, Iwate University)

[MIS03-12] Tectonostratigraphic evolution of the North Pyrenean Fold and Thrust Belt and the Aquitaine foreland basin: constraint along a SSW-NNE cross-section (West Comminges – Mirande basins).

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Collapse of fore-arc crust: Cretaceous Japan case

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For reconstructing geometry of the fore-arc basin developed along the Cretaceous-Paleogene arc-trench system in Japan, provenance analysis has been carried out by U-Pb dating of detrital zircons, particularly for the “Cretaceous-Paleogene” fore-arc sandstones/conglomerates discontinuously traced from western Kyushu to southern Tohoku district. These new age data clarified that terrigenous clastic rocks share the same secular change in age spectra, and suggest the followings. 1) Monotonous sedimentary basin developed in the fore-arc together with relevant provenacne for over 1,300 km along the arc. 2) This spatial dimension of the Cretaceous-Paleogene fore-arc basin in the Japan segment in East Asia requires that its width probably has reached up to 100 km across the arc with respect to modern analogues. 3) The current wodth of 15-20 km was driven by significant removal of fore-arc crust on the order of several tens of kilometer. 4) As to the large-scale crust disappearnce, the low-angle Median Tectonic Line (MTL) in SW initiated probably in the Oligocene, and triggered fore-arc crust shortening to juxtapose the Ryoke (arc granitoid) belt with early Paleogene cover (fore-arc) sediments and the structurally underlying Sanbagawa (blueschist) belt. 5) This crustal shortening was restricted in a domain between central Kushu and northern Kanto, where the initial rifting of the Japan Sea affected.

Keywords: fore-arc , provenance, Japan, Cretaceous, arc crust, Median Tectonic Line

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First stage to reveal the structure of the Fujikawa-kako Fault Zone by the integrated seismic experiments across the northwestern region of the Izu collision zone, central Japan

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The Fujikawa-kako Fault Zone (FKFZ) is one of the most alarming active fault zones in Japan, because it is composed of the northwestern border of the Izu collision zone and its vertical slip rates are thought to reach up to 7 m / 1000 year (MEXT, 1998, 2010). However, thick pyroclastic materials and lavas from Mt. Fuji obscure surface structures, and inevitably make it difficult to examine the subsurface ones. As these difficulties are serious for evaluation of the activities of the FKFZ, we carried out the following integrated seismic reflection experiments in order to reveal deep to shallow structure of FKFZ, especially the relationship between the deeper part of FKFZ and the upper surface of the Philippine Sea Plate (PHS) as well.

FIST (from FKFZ to the Itoigawa-Shizuoka Tectonic Line :36km in length) was done using 4 vibrators (17 tons) and 2 dynamite shots (100 kg) in 2012. Main targets were deep structures. Quasi-3 D high resolution (Hoshiyama Hills: 6 lines and 16 km in total length) was done using 2 vibrarors (6.8 tons) in 2015. Main targets were shallow structures of the Omiya and the Iriyamase faults along the eastern margin of the Hoshiyama Hills.

The results are summarized as follows based on seismic profiles obtained from the experiments:
The N-trending area of FKFZ is filled by the early to middle Pleistocene Ihara group (P wave <3.6 km / s) and overlying pyroclastic and lavas from the Mt. Fuji. The total vertical displacement of FKFZ is estimated to be 2000 m. Supposed that the base of the Ihara group is 1.5 Ma, the average vertical displacement rate is about 1.3 m/1000 years. The Shibakawa fault, westernmost of FKFZ, contributes mainly to the total vertical displacement. Its deep structure is not clear in the profile. The Omiya fault is generated from the upper surface of the PHS as a 30-degree-dipping reverse fault at several km in depth considering the recent results of the seismic profiling across the Suruga Bay. The Omiya fault reaches the tip point about 500 m in depth forming a kind of a wedge thrust structure above the tip point. Within the hanging wall of the wedge thrust, a fault-bent fold occurs forming a steep limb along the northeastern margin of the Hoshiyama Hills. The limb was formerly misunderstood as a normal fault. On the contrary, within the wedge, complicate chevron folds are developed suggesting horizontal shortening along subhorizonntal detachments in the Hoshiyama Hills. The Iriyamase fault may be a high-angle tear fault related to the Omiya fault. The precise structure and of the surface trace of the Iriyamase fault is unclear.

Although these results present new scope to us, we still remain in the first stage of revealing the structure of FKFS. In the next step we try to challenge to establish the subsurface stratigraphy with age-scale by scientific drillings in and around the Hoshiyama Hills. After then we will be able to interpret the profiles more precisely, reconstruct the history of FKFZ, and evaluate the activities of FKFZ.

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Keywords: Fujikawa-kako fault zone, Izu collision zone, integrated seismic experiment, Omiya fault, Iriyamase fault, Shibakawa fault

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The shape of Philippine sea plate and the subsurface structure near Mt. Fuji

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A shape of plate is essential information for understanding not only locations, mechanisms, magnetudes and occurrence cycles of earthquakes, but also positions of volcanic fronts. Ishida,1992 and Hirose et al., 2008 produced models of Philippine sea plate, but even Hirose et al., 2008 plate shape does not neccesary fit to recent seismic velocity structure by Matsubara et al., 2017. Takahashi (2019, JpGU) explained the possible cause of the size and the position of Mt. Fuji using the shape of Hirose et al., 2008, but there are some misfits to subsurface seismic structure near Mt. Fuji. In this study, we utilize not only the 6 by 6 min grid of seismic velocity structure by Matsubara et al., 2017 but also 3 by 3 min grid of the same model, we constructed a shape model of Philippine sea plate beneath Mt. Fuji.
The convex shape of the plate beneath the Mt. Fuji has more curvature than that of Hirose et al., 2008, thus more influence from the Pacific plate on the Philippine sea plate than before is interpreted.

Keywords: shape of Philippine sea plate, seismic structure beneath Mt. Fuji

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Quaternary back-arc strain localization of Northeast Japan accommodated by fault-related folding

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Styles and mechanisms of permanent deformation of Northeast (NE) Japan has been widely discussed based on crustal structures, topography, seismicity, and other geophysical dataset and analyses in millennial timescale. To clarify its structural evolution, mountain building processes and possible mechanisms, here we show across-arc distribution of Quaternary deformation of NE Japan estimated by structural analysis on deformed middle to late Pleistocene fluvial and marine terraces combined with structural datasets mainly based on seismic reflection profiles and Plio-Pleistocene stratigraphy. Overall topographic characters of the NE Japan are mainly subdivided into three domains, including (a) back-arc sedimentary basins, (b) Ou Backbone Ranges, and (c) coastal mountain ranges facing the Pacific Ocean. Whereas the Backbone Ranges comprises the most prominent and highest topographic domains among them, our structural analyses clearly indicate that larger permanent strains have been accommodated by N to NNE trending active fault-related folds above blind thrusts beneath back-arc sedimentary basins, rather than those on either or both flanks of the Backbone Ranges with much slower fault slip rates. This view on strain localization is consistent with structural analyses on compiled Neogene outcrop data. Structural growth of most seismically active, offshore structures in back-arc are partly manifested by remnants of uplifted and/or folded marine and fluvial terraces. Interestingly, back-arc sedimentary basins located along the Sea of Japan coast simultaneously experienced rapid subsidence during Quaternary, so that near surface signals of structural growth of active structures are mostly concealed beneath alluvial plains. Such back-arc strain localization in NE Japan can be interpreted as combinations of localized post-rift positive inversion of normal faults within most prominent and mechanically and thermally weakest Miocene back-arc failed rifts within the overriding plate, and fast subsidence prompted by densification of the lower crust near rift axis intruded by substantial mafic rocks. Back-arc strain localization characterize structural evolution and mountain building processes in NE Japan and is considered as a primary response of the overriding plate to subduction which should be taken into account in understanding geodynamic processes of this subduction margin.

Keywords: Active fault , Northeast Japan, Fault-related fold, Quaternary deformation

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Tectonostratigraphic evolution of the North Pyrenean Fold and Thrust Belt and the Aquitaine foreland basin: constraint along a SSW-NNE cross-section (West Comminges –Mirande basins).

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The Pyrenees are the result of the convergence of the Iberian and the European plates. They are subdivided into two fold-and-thrust belts (north and south) separated by an axial zone. The orogenic load led to the formation of two flexural basins: the Ebro pro-foreland basin in the southern Pyrenees and the Aquitaine retro-foreland basin on the northern side. This study is part of the ANR PYRAMID project which aimed at having a better understanding of the evolution of a retro-wedge (fold belt and flexural basin). To do so, a study of the subsidence history, the stratigraphic and structural features of the Aquitaine basin has been carried out along a 129 km long SSW-NNE cross-section. It extends from the North Pyrenean Zone to the "Mole of Montauban", in the Aquitaine platform. Subsurface data (2D seismic profiles and wells) have been used to constraint the chrono-and lithostratigraphy, which helped to realize the subsidence analysis and construct a balanced cross-section.

This study revealed that the North Pyrenean retro-wedge evolved in two main tectonic regimes. A first extensional regime since Triassic times allowing the deposition of an important thickness of evaporites. These extensional phenomena continued until the Albo-Cenomanian times, which constitute the major phase of extension. During this period, there was the formation of the black flysch basin in the North-Pyrenean Zone. This basin contained volcanic deposits (tuffs) and breccias which show an important extensional phase. The compressional regime occurred during Late Cretaceous times marking the onset of the foreland basin. The sedimentation observed in the Aquitaine retro-foreland basin goes from Late Cretaceous times (Campano-Masstrichtian) until the Miocene times and records the growth phase of the mountain belt. The depocenters are characterized by a variation in thickness and a migration towards the north. The thrust front sealed by Miocene deposits is the result of the inversion of the Albo-Cenomanian depocenter border. The Keuper Group is made up of evaporites representing a decollement level and is strongly involved in the deformation. The study of the subsidence history of the basin reveals three main phases:
Coniacian to Maastrichtian (89–66 Ma): high subsidence rate corresponding to the onset of flexural subsidence related to the beginning of the Pyrenean orogenesis, accompanied by post-rift thermal subsidence; Beginning of Paleocene (66–59 Ma): very low or no subsidence rate, implying tectonic quiescence; From Thanetian to Oligocene-Miocene times (59–5 Ma): increasing subsidence rate corresponding to the resumption of orogenic flexural subsidence until Miocene. It is the generalization of the compressional regime.
The subsidence curves show an overall decrease and a slight migration of subsidence from south to north.

Keywords: North Pyrenean retro-wedge, Aquitaine retro-foreland basin, Basin inversion, Subsidence migration

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[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS04] An asteroid impact in SE Asia at 0.8 Ma and its effect on the environment and biota

convener:Ryuji Tada(Department of Earth and Planetary Science, Graduate School of Science, The Univeristy of Tokyo), Paul A Carling(University of Southampton), Wickanet Songtham(Nakhon Ratchasima Rajabhat University, Thailand), Kerry Sieh(Nanyang Technological University)

The impact of a small celestial body in Indochina Peninsula at 0.79 Ma, known as Australasia Tektite event (AATE), has been known for more than half a century due to the wide-spread distribution of tektite. Yet, the source crater of the tektite is not yet found inspite of the probable large size (>30 km in diameter) of crater, its relatively young age, and intensive search by many researchers. However, the situation is changing rapidly during the last several years and the area for the location of the crater is gradually narrowed down. Also, the evidence of environmental perturbation and possible relation with local extinction and migration of hominid and animals has been suggested recently.
In addition, because its timing is close to the Matsuyama/Brunhes paleomagnetic reversal event and in the middle of glacial lowstand during MIS 20, precise age of AATE and its relation with glacio-eustatic sea level changes should have a significant implication to Quaternary chronostratigraphy.
For these reasons, we propose a special interdisciplinary session on the location, mode, magnitude, and exact timing of the AATE impact and its possible effect on the environment and biota
The topic should be of major interest to geologists, sedimentologists, planetary scientists, paleontologists, paleoclimatologists, anthropologists, and so on, especially to those working in SE Asia. Thus adequate topic for JpGU-AGU joint meeting.

Introduction

[MIS04-01] Converging lines of evidence for burial of the Australasian impact crater within the Bolaven volcanic field, Southern Laos

★Invited Papers

Kerry Sieh[1], *Jason S Herrin[1], Dayana Angel Schonwalder[1], Vanpheng Sihavong[2], Brian Jicha[3], Brad Singer[3], Weerachat Wewegwin[4], Paramesh Banerjee[1], Tawachai Chualaowanich[4], Punya Charusiri[5] (1.Earth Observatory of Singapore, Nanyang Technological University, Singapore, 2.Department of Geology and Mines, Ministry of Energy and Mines, Vientiane, Lao People's Democratic Republic, 3.Department of Geoscience, University of Wisconsin–Madison, Madison, Wisconsin, USA, 4.Department of Mineral Resources, Ministry of Natural Resources and Environment, Ratchatewi, Bangkok, Thailand, 5.Department of Geology, Chulalongkorn University, Khet Pathumwan, Bangkok, Thailand)

[MIS04-02] A terrestrial mafic component in Australasian tektites and associated strata; Geochemical record of the Bolaven impact.

*Jason S Herrin[1], Dayana Schonwalder[1], Kerry Sieh[1], James D. P. Moore[1], Tawatchi Chualaowanich[2], Brian Jicha[3], Brad Singer[3], Vanpheng Sihavong[4], Weerachat Wiwegwin[5], Punya Charusiri[5] (1.Earth Observatory of Singapore, Nanyang Technological University, 639798 Singapore, 2.Department of Mineral Resources, Ministry of Natural Resources and Environment, Ratchatewi, 10400 Bangkok, Thailand, 3.Department of Geoscience, University of Wisconsin–Madison, Madison, WI 53706, 4.Department of Geology and Mines, Ministry of Energy and Mines, Vientiane, Lao People's Democratic Republic, 5.Department of Geology, Chulalongkorn University, Khet Pathumwan, 10330 Bangkok, Thailand)

[MIS04-03] Identification of Ejecta Deposit formed by Australasian Tektite Event based on Discovery of Shocked Quartz and *in situ* Tektite Fragments in North Eastern Thailand

*Toshihiro Tada[1], Ryuji Tada[1,2,3], Paul Carling[4], Wickanet Songtham[5], Praphas Chansom[5], Toshihiro Kogure[1], Yu Chang[1], Eiichi Tajika[1] (1.Department of Earth and Planetary Science, The University of Tokyo , 2.Planetary Exploration Research Center, Chiba Institute of Technology, 3.Research Center for Earth System Science, Yunnan University, 4.Geography and Environmental Science, University of Southampton, 5.Northeastern Research Institute of Petrified Wood & Mineral Resources, Nakhon Ratchasima Rajabhat University)

[MIS04-04] **Regionally-extensive ejecta layer of the Australian tektite strewn-field: the MIS 20 large meteorite impact in Indochina**

*Paul A Carling[1,2], Toshihiro Tada[3], Ryuji Tada[3,4], Wickanet Songtham[5], Alan Cresswell[6], David Sanderson[6], Naomi Porat[7], Jaroon Duangkrayom[5], Luba Meshkova[2], Ian Croudace[2], Stephen Darby[2], Xuanmei Fan[1] (1.Chengdu University of Technology, 2.University of Southampton, 3.Chiba Institute of Technology, 4.Yunnan University, 5.Nakhon Ratchasima Rajabhat University, 6.Scottish Universities Environmental Research Centre, 7.Geological Survey of Israel)

[MIS04-05] Did Javan *Homo erectus* suffer a damage from an asteroid impact event?

★Invited Papers

*Masayuki Hyodo[1] (1.Research Center for Inland Seas, Kobe University)

Converging lines of evidence for burial of the Australasian impact crater within the Bolaven volcanic field, Southern Laos

Kerry Sieh[1], *Jason S Herrin[1], Dayana Angel Schonwalder[1], Vanpheng Sihavong[2], Brian Jicha[3], Brad Singer[3], Weerachat Wewegwin[4], Paramesh Banerjee[1], Tawachai Chualaowanich[4], Punya Charusiri[5]

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Physical and chemical characteristics of the Australasian tektites suggest that they originated within the Thai-Lao Khorat Plateau, and more specifically within the 100,000 km^2 inner strewnfield of Muong Nong-type tektites. The lack of an obvious crater and very low rates of erosion in this region imply that the crater must lay buried. Several converging lines of evidence imply that indeed the 0.8-Ma impact crater is buried beneath the 350-m thick summit flows of the 5,000-km^2 Bolaven volcanic field in southern Laos. Chemical compositions of the tektites indicate the presence of a weathered basaltic component that had accumulated mostly during the few million years before the impact. Accordingly, ^{40}Ar-^{39}Ar dates from distal lava flows can be traced uphill to weathered pre-impact basalts now buried beneath younger flows of the summit impact region. Also as predicted by the hypothesis, all ^{40}Ar-^{39}Ar dates from exposed flows at and near the impact region post-date the impact. Moreover, a gravity anomaly there may reflect the presence of a buried ~15 km wide elliptical crater with low-density fill. We interpret a thick deposit of crudely layered, bouldery sandstone and mudstone breccia in two outcrops 10–20 km from the center of the impact crater to be part of the proximal ejecta blanket. Fractured quartz grains within these boulder clasts lend support to this interpretation of an impact origin of these peculiar deposits. A pebbly, cobbly layer that extends and thins for more than 100 km from the impact site, almost everywhere containing angular muong nong tektites, comprises the more distal part of the ejecta blanket. Commonly, atop this layer is a massive, meters-thick coarse-silty to fine-sandy layer that we interpret to be partially or largely comprised of fallout of fine debris driven and convected into the atmosphere during and immediately following the impact. In this talk, we will present available physical and geochronologic evidence for the Bolaven impact as the source for the Australasian tektite strewnfield. In an accompanying contribution, we will present correlative geochemical evidence.

Keywords: Australasian, tektite, Bolaven, impact, Laos

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A terrestrial mafic component in Australasian tektites and associated strata; Geochemical record of the Bolaven impact.

*Jason S Herrin[1], Dayana Schonwalder[1], Kerry Sieh[1], James D. P. Moore[1], Tawatchi Chualaowanich[2], Brian Jicha[3], Brad Singer[3], Vanpheng Sihavong[4], Weerachat Wiwegwin[5], Punya Charusiri[5]

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Whilst compositions of Australasian tektites are consistent with a predominantly sandstone target lithology, chemical evidence suggests that a minor basaltic component is also ubiquitous in Australasian tektites. A mafic or ultramafic component within the Australasian target rocks has long been hypothesized [1,2] based on sporadic enrichment in Ni, Co, and Cr in some tektites [2-4]. Attempts to interpret this as chemical contribution from the impactor [3,4] are frustrated by a lack of concomitant enrichment of highly siderophile elements which would seem to preclude inheritance of siderophiles from common asteroid types [2,5]. The occurrence of Cr,Fe,Ni-oxide dendrites on microtektite surfaces [4] demonstrates that these elements can also be locally concentrated by high-temperature processes in the impact plume, offering a likely explanation for anomalous Ni, Cr, and Co concentrations in some tektites amplified above what can be explained by direct mixing with terrestrial mafics. We performed a principal component analysis on major-element compositions of 241 tektites from various locations around the strewnfield and found that >90% of the observed chemical variation can be attributed to mixing of Mesozoic sequences of the Khorat Plateau with Bolaven basalts, with more distal tektites tending toward higher proportions of basalt. Variations in the Sr-isotopic composition of the tektites shows mixing of a low-Sr, high-$^{87/86}$Sr end member with a high-Sr, less-radiogenic component [6], which is also consistent with an admixture of bedrock and basalt from the Bolaven. More basalt-like Sr is observed in more distal tektites, Australites in particular. Characteristically high ^{10}Be in Australasian tektites could be derived from a tropical volcanic target wherein layered basalt flows weather rapidly to clay-rich saprolite, a process well-suited for absorption and retention of meteoric ^{10}Be. As with the other chemical trends described, characteristics inherited from target basalt, in this case high ^{10}Be, are more expressed with increasing distance from Indochina [7]. The finite half-life of ^{10}Be ($t_{½}$=1.39My) would necessitate that a significant fraction of the basaltic target saprolitized within a few million years of the impact, implying an active or recently active volcanic field. In summary, the majority of geochemical variation in Australasian tektites can be ascribed to mixing of sandstone/mudstone bedrock with a recently weathered basalt. The geographic distribution of these chemical trends is consistent with a basalt-over-bedrock target geology with the upper basaltic layers offering greater mass contribution to distal trajectories. Although fragments of basalt are unlikely to survive weathering, we have also observed chemical signals of a basaltic component in immobile trace element systematics (e.g. Zr/Nb, Hf/Ta) of the red pebbly laterite stratigraphic layer intimately associated with muong nong tekites throughout the region. Dissolution and re-precipitation of basaltic and other components of the impact deposit likely contributed to formation of this ferricrete layer. We also explore whether the impact might have resulted in an initial ~3500 km^2 outpouring of basalt at the impact site and influenced the subsequent evolution of the field. [1] Koeberl (1992) GCA 56:1033–1064. [2] Wasson (1991) EPSL 102:95 –109. [3] Goderis et al. (2017) GCA 217:28-50. [4] Folco et al. (2018) GCA 222:550-568. [5] Shirai et al. (2016) LPSC #1847. [6] Blum et al. (1992) GCA 56:483–492. [7] Ma et al.

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(2004) GCA 68:3883–3896.

Keywords: australasian, tektite, Bolaven, Laos, impact, bolide

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Identification of Ejecta Deposit formed by Australasian Tektite Event based on Discovery of Shocked Quartz and *in situ* Tektite Fragments in North Eastern Thailand

*Toshihiro Tada[1], Ryuji Tada[1,2,3], Paul Carling[4], Wickanet Songtham[5], Praphas Chansom[5], Toshihiro Kogure[1], Yu Chang[1], Eiichi Tajika[1]

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The Australasian Tektite Event (AATE), which occurred ca. 0.8 Ma, is the youngest record of a large impact event on the Earth. Although it is estimated that it occurred somewhere within eastern Indochina based on the distribution of tektites, the crater has never been located definitively. Distribution of proximal ejecta deposit will provide useful information to specify the location and magnitude of the impact because the thickness of an ejecta deposit varies with distance from the crater and magnitude of the impact. However, the proximal ejecta deposit of the AATE has never been identified on land in the Indochina Peninsula. Here, We identified the Quaternary depositional sequence at Huai Om in northeastern Thailand as the ejecta deposit based on the discovery and occurrence of shocked quartz with planar deformation features (PDFs) and in-situ occurrence of layered tektite fragments.

The Quaternary depositional sequence at Huai Om can be divided into three lithostratigraphic units 1–3, in ascending order. Unit 1 is composed of decimeter scale silt–sand layers containing rip-up clasts and showing cross-lamination. Unit 2 is a tektite-bearing gravel layer, and the thickness varies from 20 cm to 1 m. Unit 3 is a massive well-sorted sand layer, and the thickness is 3 m.

Shocked quartz grains with PDFs were found throughout units 1–3. PDFs were confirmed by measurement of the orientation of 62 lamellae sets in 49 grains on thin sections using a universal stage microscope and observations using a scanning electron microscope and transmission electron microscope. The abundance of shocked quartz measured on smear slides (percentage of quartz grains with PDFs to the total quartz grains counted) is 8–9 % throughout the units 1–3.

In addition to the presence of the shocked quartz, we found an assemblage of fragments of a layered tektite in the upper part of unit 2. At least 160 tektite fragments were concentrated in a small (~40 cm x 40 cm) area. The tektite fragments vary from 2 mm to 3.5 cm in size, showing very poorly sorting, and have angular shapes. Each of the fragments has a similar chemical composition, which was confirmed by EPMA analysis. These characteristics suggest that these tektite fragments were formed by fragmentation of one large (~30–40 cm sized) layered tektite. To investigate their occurrence in three-dimension, we took a block sample of this layer as including tektite fragments and conduct CT-scan analysis. The CT-scan images revealed that the tektite fragments are buried facing their fracture surfaces each other, and can fit together like a jigsaw puzzle. This occurrence indicates that the fragments were buried immediately after fragmentation and not transported after the burial. Thus, the tektite fragments were formed *in situ* when a large layered tektite landed on the ground after traveling a ballistic trajectory.

Based on the continuous presence of the shocked quartz throughout units 1 to 3 and the occurrence of *in situ* tektite fragments, we identify that units 1 to 3 at Huai Om is the proximal ejecta deposit formed by

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the AATE. Based on lithological and sedimentological evidence, unit 1 is considered as deposited by a flow loaded with fine ejecta grains possibly induced by the lateral wind of vapor expansion, unit 2 is considered as representing ejecta curtain gravels, and unit 3 is considered as representing fallout ejecta.

The result of this study provides criteria to identify the proximal ejecta deposit in the surrounding area, which will be useful to trace the distribution and lateral changes of the ejecta deposit and specify the location, magnitude, and target rocks of the AATE.

Keywords: Australasian Tektite, Shocked quartz , Ejecta deposit

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Regionally-extensive ejecta layer of the Australian tektite strewn-field: the MIS 20 large meteorite impact in Indochina

*Paul A Carling[1,2], Toshihiro Tada[3], Ryuji Tada[3,4], Wickanet Songtham[5], Alan Cresswell[6], David Sanderson[6], Naomi Porat[7], Jaroon Duangkrayom[5], Luba Meshkova[2], Ian Croudace[2], Stephen Darby[2], Xuanmei Fan[1]

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For more than 50 years aspects of the Quaternary sedimentary geology of South-East Asia have proven problematic in terms of interpretation as to the origins and relationships of the surface sediment layers. The MIS 20 large meteorite impact (c. 750 to 800ka BP) occurred within Indochina, as is evident from the well-researched ‘Australian Strewn Tektite Field’ which extends over one tenth of the surface of the Earth. Key questions include; 1) whether the sedimentary impact signature is preserved in the region; and 2), whether stratigraphic indicators and dating methods can discriminate meteorite-impact related associations of strata. The importance of the questions raised relate to the search for the impact site, which has not been located conclusively. Moreover, the sedimentary signatures of meteorite impacts are not well-known and the descriptions in this study should aid the recognition of impact signatures elsewhere in the world. An hypothesis was developed: “Characteristics of the surface sediments across a wide area of Indochina represent the effects of a regionally-extensive meteorite impact”. Over one hundred sedimentary sections were logged across five countries in Indochina. A range of methods was used to define the stratigraphy and sedimentology, including CT and X-ray scanning, geochemistry, magnetic susceptibility and environmental luminescence as well as conventional grainsize analyses. Luminescence dating was used to date key strata. The results of the investigation explain the nature of the stratigraphy and relate it specifically to the MIS 20 meteorite impact. In this manner, the strata and sedimentary signatures of a large cosmic impactor are defined across a broad region, rather than being described at singular and isolated sections. The novelty is the spatial scale of the investigation which nevertheless remains detailed. The significance is that a summary model of impact stratigraphy is presented for the region. Moreover, the model may well be applicable outside of Indochina, wherever other large impactors are suspected to have occurred.

Keywords: Australian strewn field, tektite, meteorite impact, cosmic impact , ejecta, Indochina

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Did Javan *Homo erectus* suffer a damage from an asteroid impact event?

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1. Research Center for Inland Seas, Kobe University

Humans first evolved in Africa, and most of human evolution including the emergence of Homo sapiens occurred on Africa. The first migration out of Africa occurred soon after humans evolved to *Homo erectus* in East Africa, and arrived at Dmanisi, Georgia at about 1.8 Ma. Since then, *Homo erectus* further migrated into Europe (1.2 Ma) and Eastern Asia (1.6 Ma), and arrived in Java (1.3 Ma). The Sangiran Dome, central Java is one of the most important anthropological sites, but a debate on chronology of hominid-bearing beds continued for more than two decades. A recent study combining U-Pb and Fission-track dating methods revealed that the earliest arrival of *Homo erectus* in Sangiran was at about 1.3 Ma or after, and the second migration of more evolved *Homo erectus* into Sangiran occurred at about 0.9 Ma (marine isotope stage 22). Sangiran *Homo erectus* disappeared at 0.79 Ma. The uppermost hominin fossil-bearing layer lies just below the Matuyama-Brunhes polarity transition, almost comparable with a horizon of tektite, an asteroid impact evidence at 0.79 Ma. About 0.5 million years after the impact event, a *Homo erectus* fossil reappeared in Sambungmacan, east Java, probably with keeping morphological features of Sangiran *Homo erectus*. The gap of hominin fossil findings possibly indicates that hominins suffered a great damage from an asteroid impact event, like a significant population decline. *Homo erectus* survived until about 100 ka in Java.

Keywords: Sangiran Dome, Javan Homo erectus, tektite

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[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS05] Cenozoic Evolution of the Asian Monsoon and the Indo-Pacific Paleoclimates

convener:Masanobu Yamamoto(Faculty of Environmental Earth Science, Hokkaido University), Steven C Clemens(Brown University), Hongbo Zheng(Research Center for Earth System Science, Yunnan University), Ryuji Tada(Department of Earth and Planetary Science, Graduate School of Science, The Univeristy of Tokyo)

The Asian monsoon (AM) and the El Nino-Southern Oscillation (ENSO) are dominant atmospheric-ocean phenomena on the Earth and affect the climates of Asia, Oceania and circum-Pacific regions. During the Cenozoic, the climate of these areas changed drastically, but the behaviors of the Asian monsoon and the tropical ocean-atmosphere interactions like the ENSO were not fully understood. From July 2013 to December 2016, IODP conducted a series of expeditions such as 346 (Asian Monsoon), 353 (Indian Monsoon Rainfall), 354 (Bengal Fan), 355 (Arabian Sea Monsoon), 356 (Indonesian Throughflow), 359 (Maldives Monsoon and Sea Level), 361 (Southern African Climate), and 363 (Western Pacific Warm Pool) that are related to the AM and tropical Pacific climate evolution and its interaction with global climate system in NW and tropical Pacific and Indian Ocean regions, and exciting results are coming out. We believe it is timely to start synthesizing the results of these cruises and update and exchange information and ideas to promote our understanding of the AM and tropical Pacific evolution, variability, their controlling factors, and their interaction with global climate system during the Cenozoic. On orbital and millennial timescales, studies on the response of the AM and the ENSO to climate forcing are intensively studied using various archives such as sediments, speleothems, corals, etc., during the last decade. Presentations and discussions on the above topics from various backgrounds (proxy and modeling studies) are highly welcome.

[MIS05-01] The Western Pacific Warm Pool hydrology during the last 1.68 million years

*Masanobu Yamamoto[1], Sohei Kikuchi[1], Yoji Yamamoto[1], Samantha Bova[2], Yair Rosenthal[2] (1.Faculty of Environmental Earth Science, Hokkaido University, 2.Rutgers University)

[MIS05-02] Indonesian Throughflow variability during the Mid Pleistocene Transition (IODP 363 Site U1483)

★Invited Papers

*Kenji Matsuzaki[1], Li Gong[2], Ann Holbourn[2], Wolfgang Kuhnt[2] (1.Atmosphere and Ocean Research Institute, The university of Tokyo, 2.Institute of Geoscience, Christian Albrechts University of Kiel)

[MIS05-04] Influences of East Asian summer and winter monsoons on the millennial-scale color alternation of Japan Sea sediment

★Invited Papers

*Takuya Sagawa[1], Yusuke Narita[2], Takuya Matsuzaki[3], Masafumi MURAYAMA[4], Takashi Hasegawa[1], Akiko Goto[1], Takeshi Nakagawa[5] (1.Institute of Science and Engineering, Kanazawa University, 2.Graduate School of Natural Science and Technology, Kanazawa University, 3.Center for Advanced Marine Core Research, Kochi University, 4.Faculty of Agriculture and Marine Science, Kochi Univeristy, 5.Ritsumeikan University)

[MIS05-05] Variations in sea surface environments recorded by algal biomarkers in the Japan Sea off the western Hokkaido (IODP Site U1422) over the last 700 ky

*Asako Suzuki[1], Ken Sawada[1], Saki Yanou[1], Satoshi Furota[2], Tomohisa Irino[3] (1.Graduate School of Science, Hokkaido University, 2.National Institute of Advanced Industrial Science and Technology, 3.Graduate School of Environment, Hokkaido University)

The Western Pacific Warm Pool hydrology during the last 1.68 million years

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The hydrology of the Western Pacific Warm Pool (WPWP) region is a key element of the earth's climate, which sensitively responds to greenhouse gas concentration, insolation, hemispheric energy balance, Hadley and Walker circulations, interhemispheric monsoons and El Niño-Southern Oscillation. The behaviors of the WPWP hydrology are not fully understood on a glacial-interglacial timescale. In this study, we generated a 1.68 Myr records of sea surface temperature (SST) and precipitation from IODP Site U1486 based on TEX_{86} and the cyclization index of branched GDGTs (CBT). The SST varied 26.5 and 30.5˚C, showing a pattern similar to variations in global ice volume and atmospheric CO_2 concentration. The greenhouse gas effect was a most likely factor determining the SST at Site U1486. Soil organic matter contribution, expressed as the CBT, shows a strong precession cycle. The precipitation maxima in northern New Guinea was anti-phased with the minima of Chinese stalagmite $\delta^{18}O$ on a precession cycle, suggesting a common forcing of hydrology in the WPWP and East Asia.

Keywords: WPWP, ITCZ, Pleistocene

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Indonesian Throughflow variability during the Mid Pleistocene Transition (IODP 363 Site U1483)

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The Indonesian Throughflow (ITF) is crucial in controlling the exchange of heat between the Pacific and Indian Oceans. The heat transported by the ITF is related to the Asian-Australian Monsoon dynamics because the strength of the warm surface flow and cool thermocline is controlled by the seasonal reversal of monsoonal winds (Gordon, 2005). Recent studies showed that changes in sea-level also influence the ITF because most of the seas feeding the ITF are very shallow. The Mid Pleistocene Transition between 1400 and 600 ka represents a major shift in global climate, as it was marked by a change from ~41 to ~100 kyr glacial/interglacial periodicity, resulting in higher amplitude sea-level variations and intensified glacial cooling. Reconstruction of ITF variability during the MPT has the potential to clarify the impact of glacio-eustatic sea-level and temperature changes affected the monsoonal climate and hydrology of Northwestern Australia.

The International Discovery Program (IODP) Expedition 363 retrieved at Site U1483 (13°5.24′S, 121° 48.25′E) drilled in 1733 m water depth on the Scott Plateau, off Northwestern Australia, an extended, continuous hemipelagic sediment succession spanning the past two million years. We analyzed radiolarian assemblages at this site to reconstruct the evolution of sea surface temperature (SST) and primary productivity during the MPT. We also combined radiolarians accumulation rates and elemental ratios of Si/Ti data obtained from X-Ray Fluorescence core scanning to monitor changes in siliceous productivity. Preliminary results suggest a drastic and abrupt decrease in local marine productivity at ~1000 ka. Interestingly this decrease occurred just before the first intense glaciation of the MPT. Thus, it is probable that significant changes related to both sea-level variation and Asian-Australian Monsoon dynamics occurred, which highly influenced the ITF.

Keywords: IODP, Indonesian Throughflow , Asian-Australian Monsoon

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Influences of East Asian summer and winter monsoons on the millennial-scale color alternation of Japan Sea sediment

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Millennial-scale total organic carbon (TOC) content in the Japan Sea sediments is characterized by the Dansgaard-Oeschger (DO) event like variability. The DO-like pattern of TOC is thought to reflect the East Asian summer monsoon induced productivity and stratification change. However, TOC content is also influenced by changes in the oxygen content of the bottom water. Here, we conducted Br measurement of two sediment cores retrieved from close sites with different depth, 400 and 850 m water depths, off the Wakasa Bay in the southern Japan Sea. The deeper sediment core (WB6: 850 m) shows clear dark-light color alternations, and parallel laminations are observed in some dark layers. On the other hand, the shallower sediment core (WB4: 400 m) shows gradual color change and no lamination is observed throughout the core. Since the analyzed Br/Ti shows a strong positive correlation with the marine organic carbon (MOC) contents estimated by TOC and their carbon isotope, we use Br/Ti as a MOC content proxy. The MOC contents of two sediment cores show generally similar variations but details are not similar. The WB6 shows a larger MOC amplitude and higher frequency fluctuation than that of WB4. We infer that the MOC change in the shallower WB4 core mainly reflects primary productivity because no anoxic condition is indicated by sediment structures and that in the deeper WB6 core is influenced by both productivity and oxygen level of the bottom water, which is regulated by ventilation due to winter cooling. Since the MOC fluctuation of WB6 is more similar to the Greenland ice core isotope record than WB4, it is suggested that the MOC variation (alternation of dark and light color) in the deeper Japan Sea sediment is caused by both East Asian summer and winter monsoon variations.

Keywords: Japan Sea, East Asian monsoon

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Variations in sea surface environments recorded by algal biomarkers in the Japan Sea off the western Hokkaido (IODP Site U1422) over the last 700 ky

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The Japan Sea is a marginal sea that is connected to the open ocean through four straits, and the surface is characterized by the Tsushima Warm Current (TWC) and the deep water is occupied with Japan Sea Proper Water. In glacial-interglacial cycles in the Quaternary, the sea surface environment in the Japan Sea has repeatedly changed by sea level fluctuation. It is reported that the land bridge was formed between the continent and Hokkaido, in the northern part of the Japan Sea, during the last glacial maximum (LGM) as a result of sea level fall. Therefore, this area is also important from anthropological and archaeological points of view in the northeastern Asia. However, only a few paleoenvironmental studies have been conducted in this area, which motivate us to establish a high-resolution and long-term reconstruction of paleoceanographic condition using an appropriate sediment archive.

In this study, we analyzed algal biomarkers of a sediment core collected from the northern Japan Sea for the last 700 ky. In particular, we apply the paleothermometer using long-chain alkyl diols, which are thought to be produced by diatoms and *eustigmatopyte* in addition to a proxy for sea surface temperature (SST based on alkenones, which are produced by haptophyte algae). Recently, the long-chain alkyl diols were used as the indices not only for SST, but also for the upwelling intensity and inflows of fresh water, and thus, can provide multiple information for reconstruction of marine environments.

The sediment cores in this study were drilled at Site U1422 in the northern part of the Japan Basin (the Japan Sea off the western coast of Hokkaido) at 43˚45. 99’ N, 138˚49. 99’ E during Integrated Ocean Discovery Program (IODP) Expedition 346. We focused on the duration from the present to the MIS16 (-ca. 700 ka). Lipids were extracted with dichloromethane/methanol, and separated to aliphatic, aromatic and polar fractions. Lipids were identified and quantified by GC/MS and GC/FID.

The SSTs based on alkenones and alkyl diols basically fluctuated along with the glacial-interglacial cycles. The alkenone-based SSTs were found to be much higher than the diol-based SSTs during the MIS 2-3. The differences are likely attributed to ecological differences of these algae including habitant water depth and seasonality of the production, as well as high contribution of distinctive alkenone producers during these.

Diol Indices 1 and 2, which are proxies of upwelling intensity, are overall low levels. These results indicate that consistently strong upwelling system is hardly developed in the northern Japan Sea. However, the

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indices increase in the glacial ages, implying that vertical mixing was promoted as a result of the surface cooling.

Moreover, the C32 1, 15-diol ratio, which is considered as an indicator of riverine water input into marine environment, tended to increase at the transition periods such as the glacial to interglacial periods, and the timings of relatively warm ages in the glacial periods. These results suggest that fresh water arisen by melting of snows and ices accumulated on lands was flowing into the Japan Sea through the rivers at these timings. One pulse coincided with the timing of melt water pulse 1a (MWP 1a), which is known as a global ice-melting event, so this site may have affected by the global climate event.

Keywords: IODP, Algal biomarker, The Japan Sea, The Quaternary, Diol, Alkenone

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[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS05] Cenozoic Evolution of the Asian Monsoon and the Indo-Pacific Paleoclimates

convener:Masanobu Yamamoto(Faculty of Environmental Earth Science, Hokkaido University), Steven C Clemens(Brown University), Hongbo Zheng(Research Center for Earth System Science, Yunnan University), Ryuji Tada(Department of Earth and Planetary Science, Graduate School of Science, The Univeristy of Tokyo)

The Asian monsoon (AM) and the El Nino-Southern Oscillation (ENSO) are dominant atmospheric-ocean phenomena on the Earth and affect the climates of Asia, Oceania and circum-Pacific regions. During the Cenozoic, the climate of these areas changed drastically, but the behaviors of the Asian monsoon and the tropical ocean-atmosphere interactions like the ENSO were not fully understood. From July 2013 to December 2016, IODP conducted a series of expeditions such as 346 (Asian Monsoon), 353 (Indian Monsoon Rainfall), 354 (Bengal Fan), 355 (Arabian Sea Monsoon), 356 (Indonesian Throughflow), 359 (Maldives Monsoon and Sea Level), 361 (Southern African Climate), and 363 (Western Pacific Warm Pool) that are related to the AM and tropical Pacific climate evolution and its interaction with global climate system in NW and tropical Pacific and Indian Ocean regions, and exciting results are coming out. We believe it is timely to start synthesizing the results of these cruises and update and exchange information and ideas to promote our understanding of the AM and tropical Pacific evolution, variability, their controlling factors, and their interaction with global climate system during the Cenozoic. On orbital and millennial timescales, studies on the response of the AM and the ENSO to climate forcing are intensively studied using various archives such as sediments, speleothems, corals, etc., during the last decade. Presentations and discussions on the above topics from various backgrounds (proxy and modeling studies) are highly welcome.

[MIS05-06] Pleistocene Water Isotope Reconstructions from the Indian Monsoon Region

*Steven C Clemens[1], Masanobu Yamamoto[2], Sarah McGrath[1], Kaustubh Thirumalai[3], Yongsong Huang[1], Kerr Katrina [4], Richey Julie [5], Rosenthal Yair[6] (1.Brown University, 2.Hokkaido University, 3.University of Arizona, 4.Open University, 5.USGS, 6.Rutgers University)

[MIS05-07] Depositional environment at IODP Site U1445 in the northeastern Indian Ocean based on the litho- and isotope-stratigraphy

*Tomohisa Irino[1], Masanobu Yamamoto[1], Liviu Giosan[2], Steven Clemens[3] (1.Faculty of Environmental Earth Science, Hokkaido University, 2.Woods Hole Institution of Oceanography, 3.Brown University)

[MIS05-08] Reconstruction of asian dust flux variability since 10 Ma based on grain size specific mineral composition at IODP Site U1425 in the Japan Sea

*Mui Fa Alison Lee[1], Tomohisa Irino[1] (1.Faculty of Environmental Earth Science, Hokkaido University)

[MIS05-09] Changes in Tibetan Plateau latitude as an important factor for understanding East Asian climate since the Eocene: A modeling study

*Ran Zhang[1] (1.Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China)

[MIS05-10] From Desert to Monsoon: Irreversible Climatic Transitionat ~36 Ma in Southeastern Tibetan Plateau

*Hongbo Zheng[1], Qing Yang[1], Shuo Cao[3], Peter Dominic Clift[4], Mengying He[2], Akihiro Kano[5], Ryuji Tada[5], Fred Jourdan[6] (1.Research Center for Earth System Science, Yunnan University, 2.School of Geography Science, Nanjing Normal University, 3.School of Earth Sciences, China University of Geosciences, 4.Department of Geology and Geophysics, Louisiana State University, 5.Department of Earth and Planetary Science, University of Tokyo, 6.Western Australian Argon Isotope Facility, Department of Applied Geology and JdL Centre, Curtin University)

Pleistocene Water Isotope Reconstructions from the Indian Monsoon Region

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We synthesize results of orbital-scale Late Pleistocene water-isotope records from the Indian Monsoon region including previously published and new records of seawater $\delta^{18}O$, speleothem $\delta^{18}O$, and leaf wax δD. These records are widely distributed, spanning the core monsoon zone, the Himalayas, the northeast Indian Margin, and the Andaman Sea.

These three proxy types share large-scale aspects of Indian monsoon circulation (e.g., seasonality and oceanic moisture source), but differ in how the signal is recorded. For example, seawater $\delta^{18}O$ monitors direct rainfall as well as runoff and mixing in the ocean environment. Speleothem $\delta^{18}O$ and leaf wax δD are both influenced by soil processes while speleothem $\delta^{18}O$ may be additionally influenced by karst and cave environmental factors. Employing a multi-proxy approach provides a means of identifying common signals among the proxies and helps to unravel the processes that impact the recorded signals on orbital timescales.

To accomplish this, we examine these proxy time series in the context of spectral structure and phase in order to ascertain the extent to which they do or do not covary with one another and the extent to which they monitor aspects of local rainfall and/or larger-scale moisture source and transport path dynamics. We find common variance among the speleothem $\delta^{18}O$ and leaf wax δD records which differ in significant and systematic ways from the seawater $\delta^{18}O$ records. On the basis of model results, we provisionally interpret the differences in the context of changes in vapor transport path dynamics having an influence on the leaf wax and speleothem records, causing them to lead the seawater isotopic response at orbital time scales.

Keywords: Indian Monsoon , Oxygen isotopes, Pleistocene

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Depositional environment at IODP Site U1445 in the northeastern Indian Ocean based on the litho- and isotope-stratigraphy

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1. Faculty of Environmental Earth Science, Hokkaido University, 2. Woods Hole Institution of Oceanography, 3. Brown University

International Ocean Discovery Program (IODP) Site U1445 is located near the southern end of the Mahanadi basin, on the eastern margin of India, ~94 km from the Indian coastline, and 2502 m water depth in a flat-lying region of the upper continental rise. The summer monsoon is the primary control on present-day suspended sediment discharge from the Mahanadi River. The narrow continental shelf promotes rapid transit of particulates to the continental slope and rise. Therefore, U1445 could provide an ideal sediment archive to reconstruct the past summer monsoon variability using various proxies for vegetation, detrital flux and sea surface salinity. However, this location on the upper rise is not protected from turbidite deposition although the seismic profile around Site U1445 is characterized by parallel, flat-lying reflectors minimally interrupted by small-scale dewatering faults.

Three holes were drilled at U1445 and cores have been spliced down to 284.834 m CCSF-A (composite depth) with appended cores down to 707.278 m CCSF-A. This nearly continuous sediment sequence covers the past 6 million years based on shipboard bio- and magneto-stratigraphy. Sediments are principally composed of hemipelagic clays with a significant biogenic component, as well as occasional thin turbidites. Detailed examination of shipboard stratigraphy revealed that inconsistent datum were recognized at 110 m, 250m, 350-420 m, 630 m, and 650 m CCSF-A, which suggest the reworking of diatom and foraminifers.

In order to establish an orbitally tuned age model for the whole sequence of U1445, we started to measure stable oxygen and carbon isotopes of benthic foraminifers. The oxygen isotope for the top 50 m CCSF-A ranges from 1 to 5.5 permil VPDB and shows spiky profile. Spiky data seems to be always lower by 2.5 permil from the baseline profile with normal oxygen isotope curve down to MIS 7, which suggests the rework of benthic foraminifer tests from upper slope. Carbon isotope does not show a spiky feature. Considering the depth profile of temperature and phosphate in this region, abnormally light oxygen isotope foraminifer tests were formed around 250 m water depth where temperature was 10 ˚C higher than and phosphate (or carbon isotope of DIC) was similar to the water depth of Site U1445.

Therefore, it is necessary to distinguish reworked sediments and to know their thickness for calibration of the age model. Although turbidite layers observed on the core section surface are sometimes very faint, color enhancement of section photographs and examination of compositional changes by XRF scanner data might enable us to identify reworked sediments and measure their thickness.

Keywords: IODP Site U1445, Indian Ocean, Sediment facies, Benthic foraminifer, Isotope stratigraphy

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Reconstruction of asian dust flux variability since 10 Ma based on grain size specific mineral composition at IODP Site U1425 in the Japan Sea

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Terrigenous sediments at Site U1425 in Japan Sea receiving significant amount of mixture dust materials from Taklamakan desert, Gobi deserts and Chinese Loess. Japan Sea is located approximately 4000 km, 2800 km, and 2400 km to the east of Taklimakan Desert, Gobi Deserts, and Chinese Loess Plateau respectively, which are the main areas of dust emission in Asia.

In this research, total 180 samples obtained from IODP Site U1425 Hole D (354m depth) were measured for mineral composition of their silt and clay fractions by using X-ray diffraction analysis. The half height width (FWHM) and chemical index of illite were also examined.

The mineral assemblages indicate that the provenances of silt and clay may be different. The mineral composition of Chinese Loess is generally characterized by higher quartz and plagioclase. Illite is the dominant clay mineral in the Chinese Loess (Sun 2011). This suggests that higher ratios of quartz, plagioclase and illite indicate as same detrital origin as the Chinese Loess.

Quartz, plagioclase (albite), and illite are the main components of Asian desert dust minerals. According to the albite (Ab) /quartz (Q) ratio and illite crystallinity (FWHM), Asian dust within the sediment at Site U1425 can be successfully distinguished from riverine input from the Japan Island arc.

The Gobi dust significantly contributed to the Pleistocene sediments with 52% at 0.57 Ma, while Taklimakan dust was a major contributor to the Pliocene and Miocene sediment with 20-40% at Site U1425 in the Japan Sea. Contribution of riverine input from Japanese Island arc was dominant in late Miocene and decreased to less than 20% after 5 Ma.

The total mass accumulation rate (MAR) of Asian dust at Site U1425 showed a decreasing trend from Miocene to Pliocene and a increasing trend from Pleistocene to Present. The highest MAR is 3.96 g/cm2/kyr at 1.02 Ma and another peaks with 3.63 g/cm2/kyr at 9.7 Ma. The lowest MAR of Asian dust is found in Pliocene with 0.5-1.5 g/cm2/kyr.

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Gobi dust showed the highest MAR during Pleistocene than others source areas after 2 Ma in Pleistocene. The highest MAR of Gobi dust is 2.79 g/cm2/kyr at 1.02 Ma while the lowest value with 0.12 to 1.0 g/cm2/kyr occurred in Pliocene. Taklimakan dust showed the highest MAR in late Miocene of 1.83 g/cm2/kyr at 9.5 Ma and slightly lower MAR in Pleistocene with 1.3 g/cm2/kyr. Riverine input of Japanese Island arc showed the lowest MAR with less than 0.5 g/cm2/kyr at Site U1425 during Pliocene to Pleistocene except for 1.02 Ma. During late Miocene, riverine input shows higher MAR from 0.5 to 2.0 g/cm2/kyr.

Asian dust and fluvial input shows different grains sizes. Grain size of riverine input at Site U1425 is finer than dust, and mostly contained in clay fraction, which is consistent with previous researches in this region. Gobi dust grain size in general is coarser than Taklimakan dust, and fluvial input of Japan Island Arc from Miocene to Pliocene. Silt size fraction dominates in Gobi dust at 4, 6.5, 8.3 and 9.5 Ma which may be related to the global cooling and strengthening of winter monsoon that could bring coarser dust particles. After 3.5 Ma, Gobi dust becomes finer than Taklimakan dust. The reason may be the increasing supply of dust from the northern Chinese Loess Plateau which is a main dust source of fine silt and clay.

Keywords: Aeolian dust , Mass accumulation rate , Flux, illite crystallinity (FWHM), Quartz,plagioclase (albite)and illite

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Changes in Tibetan Plateau latitude as an important factor for understanding East Asian climate since the Eocene: A modeling study

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Previous climate modeling studies suggest that the surface uplift of the Himalaya–Tibetan plateau (TP) is a crucial parameter for the onset and intensification of the East Asian monsoon during the Cenozoic. Most of these studies have only considered the Himalaya–TP in its present location between ~26°N and ~40°N despite numerous recent geophysical studies that reconstruct the Himalaya–TP 10° or more of latitude to the south during the early Paleogene. We have designed a series of climate simulations to explore the sensitivity of East Asian climate to the latitude of the Himalaya–TP. Our simulations suggest that the East Asian climate strongly depends on the latitude of the Himalaya–TP. Surface uplift of a proto-Himalaya–TP in the subtropics intensifies aridity throughout inland Asia north of ~40°N and enhances precipitation over East Asia. In contrast, the rise of a proto-Himalaya–TP in the tropics only slightly intensifies aridity in inland Asia north of ~40°N, and slightly increases precipitation in East Asia. Importantly, this climate sensitivity to the latitudinal position of the Himalaya–TP is non-linear, particularly for precipitation across East Asia.

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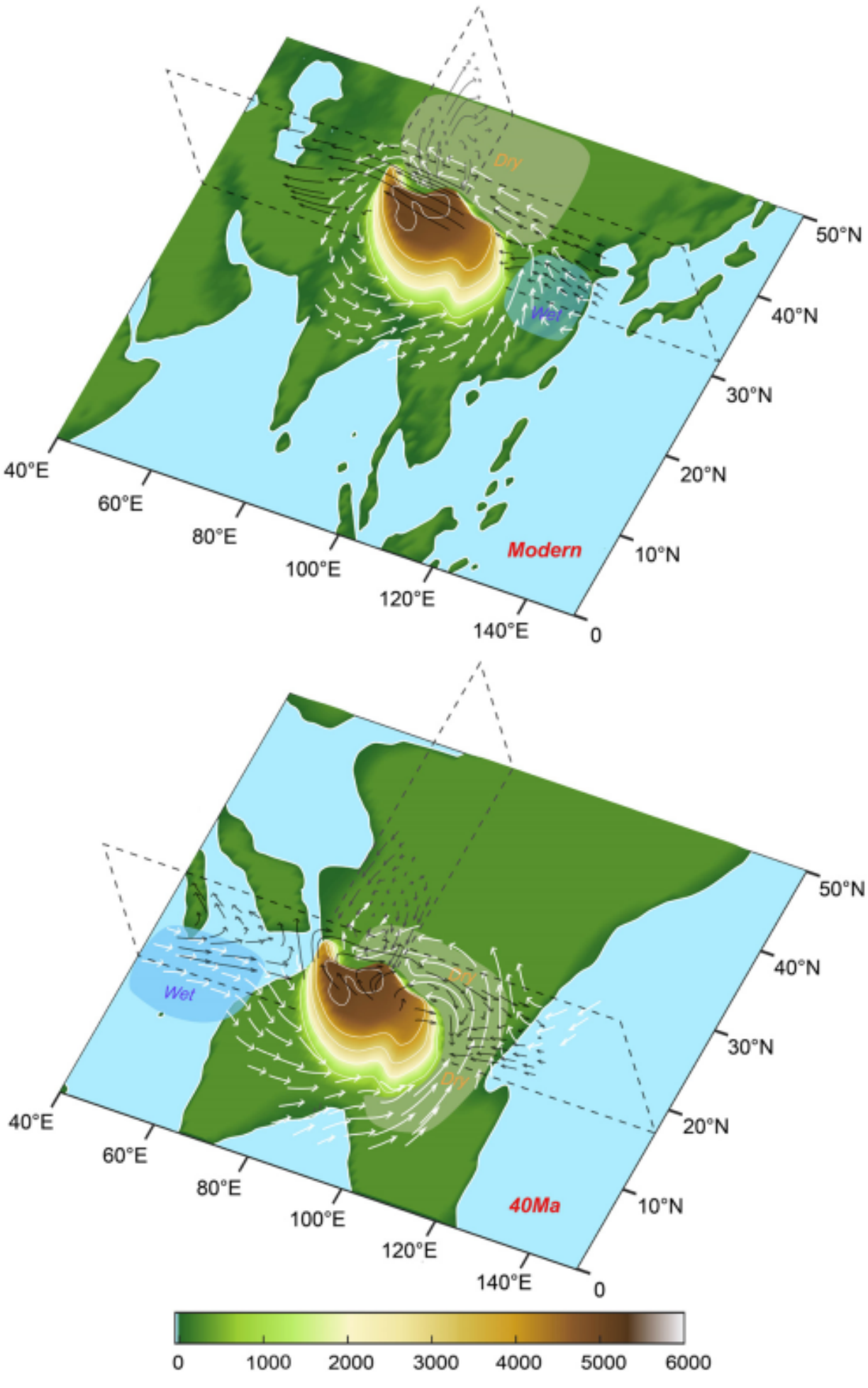

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From Desert to Monsoon: Irreversible Climatic Transition at ~36 Ma in Southeastern Tibetan Plateau

*Hongbo Zheng[1], Qing Yang[1], Shuo Cao[3], Peter Dominic Clift[4], Mengying He[2], Akihiro Kano[5], Ryuji Tada[5], Fred Jourdan[6]

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Although there is increasing evidence for wet, monsoonal conditions in Southeast Asia during the late Eocene it has not been clear when this environment became established. Newly radiometrically dated Eocene sedimentary rocks from the Jianchuan Basin located in the southeast flank of Tibetan Plateau now provide a section whose facies and climatic proxies constrain this evolution. Semi-arid conditions dominated Paleocene to mid Eocene period, culminating with development of desert dunes in late Eocene, which constitutes part of the wide arid zone in East Asia closely associated with the northern Westerly Jet without the blocking of high Tibetan Plateau. From 36 Ma onwards, the basin began to accumulate swamp sediments with coals, together with synchronous braided river deposits, indicating significant increase in precipitation. This remarkable and irreversible transition from dry to wet conditions precedes the E/O boundary at 34 Ma, thus excluding general global cooling as a prime driver. We suggests that uplift of Tibetan Plateau might have reached a threshold level by that time which divided/weakened the Westerly Jet and thus gave way to monsoon rains to intrude into this downwind locality.

Keywords: desert, onset of Asian monsoon, Tibetan Plateau, late Eocene

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[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS06] Dust

convener:Ishizuka Masahide(Kagawa University), Yasunori Kurosaki(Arid Land Research Center, Tottori University), Thomas Sekiyama(Meteorological Research Institute), Kana Nagashima(Japan Agency for Marine-Earth Science and Technology, Research and Development Center for Global Change)

Mineral dust is generated from the ground surface by strong winds, and it transports long distance over the earth. In the process, cloud formation and absorption and scattering of solar radiation cause weather and climate changes. Also, when deposited in the ocean, feeding nutrients to phytoplankton, promoting photosynthesis, and when deposited on snow and ice causes albedo change. This is known as the yellow dust (Asian dust) phenomenon in Asia region including Japan. In order to understand this, integration in a wide range of academic areas is necessary.
 In the emission process, the amount of dust changes greatly depending on the surface conditions in dryland area, and in order to know the effect, it is necessary to deal with broad areas such as soil, topography, vegetation, precipitation, desertification and soil deterioration. In the transport process, we deal with areas such as weather, atmospheric aerosol, radiation. In the deposition process, we deal with areas such as ocean, snow ice, health to people and livestock. Drying and changes in vegetation also have social scientific aspects such as national policies, management of livestock, and population increase. In addition, dust and sand dunes are common phenomena not only in the Earth but also in other planets such as Mars and Saturn. In this way, it is impossible to understand the dust phenomenon only from one field, it is important for researchers in many areas to discuss and share information through this session, and advance exchange of researchers.

Introduction

[MIS06-01] Assessing health risks of exposure to Asian dust among healthy individuals
★Invited Papers

*Kazunari Onishi[1], Masanori Nojima[2], Tsuyoshi Thomas Sekiyama[3], Masato Shinoda[4], Youichi Kurozawa[5], Yasunori Kurosaki[6] (1.Graduate School of Public Health, Support Unit for Conducting Clinically Essential Studies, St.Lukes International University, 2.Center for Translational Research, The Institute of Medical Science Hospital, The University of Tokyo, 3.Meteorological Research Institute, 4.Graduate School of Environmental Studies, Nagoya University, 5.Division of Health Administration and Promotion, Department of Social Medicine, Faculty of Medicine, Tottori University, 6.Arid Land Research Center, Tottori University)

[MIS06-02] Implications of overestimates in mineral dust emissions from Australia on labile iron concentrations in aerosols

*Akinori Ito[1], Morgane M. G. Perron[2], Bernadette C. Proemse[2], Michal Strzelec[2], Melanie Gault-Ringold[2], Philip W. Boyd[2], Andrew R. Bowie[2] (1.Japan Agency for Marine-Earth Science and Technology, 2.University of Tasmania)

[MIS06-03] **Low dust generation from active sand dunes**

*Itzhak Katra[1], Nitzan Swet[1], Jasper Kok[2], Raleigh Martin[2], Yue Huang[2], Hezi Yizhaq[1] (1.Ben-Gurion University, 2.University of California, Los Angeles)

[MIS06-04] What are the main land-surface processes affecting saltation activities in a dust hotspot of the Mongolian desert steppe?

*Kaman Kong[1], Banzragch Nandintsetseg[1,2], Masato Shinoda[1], Masahide Ishizuka[3], Yasunori Kurosaki[4] (1.Graduate School of Environmental Studies, Nagoya University, 2.School of Arts and Sciences, National University of Mongolia, 3.Faculty of Engineering and Design, Kagawa University, 4.Arid Land Research Center, Tottori University)

[MIS06-05] Effects of various vegetation factors on sand saltation from the viewpoint of roughness

*Akito Kono[1], Toshiya Okuro[1] (1.Graduate School of Agricultural and Life Sciences, The University of Tokyo)

Assessing health risks of exposure to Asian dust among healthy individuals

*Kazunari Onishi[1], Masanori Nojima[2], Tsuyoshi Thomas Sekiyama[3], Masato Shinoda[4], Youichi Kurozawa[5], Yasunori Kurosaki[6]

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Background/Aim: Asian dust carried by winds to Japan was on the rise since the year 2000, but has now become irregular due to large-scale climate change. It has been suggested that Asian dust affects the eyes, nose, and respiratory system; however, similar symptoms have also been reported in people exposed to pollen and particulate matter (PM2.5), not derived from Asian dust. Although it is unknown how the components of Asian dust affect health, we suggest that windborne Asian dust may affect the skin (Onishi et al 2012). To investigate this hypothesis, we conducted a long-term survey using web questionnaires, regarding subjective symptoms among the residents of Yonago City, which is at the front lines of windborne Asian dust. We calculated the odds ratio of the development of symptoms on a day with Asian dust, as compared to a day without Asian dust.
Methods: We administered diary-style web questionnaires to 104 volunteers who lived in Yonago City between 2013 and 2015. The subjects answered questions regarding symptoms related to the nose, throat, eyes, respiratory system, skin, body temperature, occurrence of headaches, and stress levels, as well as about the occurrence of common cold and influenza. The results were evaluated using a 6-level subjective symptom score (29 variables in total). We used the Japan Meteorological Agency’ s method of determining the occurrence of Asian dust on each day. Data on climate (temperature, humidity, and atmospheric pressure) were used as covariates. The data were analyzed using t-test, as well as linear and logistic mixed models, and subjected to a multifaceted investigation, including covariate adjustment.
Results: Statistically significant differences were observed in 23 of the 29 variables, between participants' symptoms on the days with Asian dust and the days without Asian dust. The difference in scores for skin tenderness on the days with Asian dust compared to the days without Asian dust was 0.11 (95% CI: 0.06-0.15, $p < 0.001$), suggesting that it is associated with Asian dust. Moreover, the odds ratio for the development of skin tenderness on the days with Asian dust compared to the days non-AD day was 2.39 (95% CI: 1.30-4.39, $p = 0.005$) with adjustment for daily weather conditions. A strong correlation was also observed for symptoms in the eyes, nose, and throat.
Conclusions: The effect of Asian dust on the eyes, nose, respiratory organs, and skin was confirmed by the data collected over 3 years. We also confirmed that the participants developed symptoms related to the skin, which are considered a characteristic of exposure to Asian dust. In the future, we plan to study symptoms related to the skin using Light Detection and Ranging (LIDAR) as an indicator of Asian dust, and investigate the synergistic effects of pollen, other air pollutants, heavy metals, and microorganisms with Asian dust.

Keywords: Asian dust, Health risk assessment, Allergic symptoms

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Implications of overestimates in mineral dust emissions from Australia on labile iron concentrations in aerosols

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Mineral dust is the major source of external micro-nutrients such as iron (Fe) to the open ocean. However, large uncertainties in model estimates of dust emissions and aerosol-bearing Fe solubility (i.e., the ratio of labile Fe (L_{Fe}) to total Fe (T_{Fe})) in the Southern Hemisphere (SH) hampered accurate estimates of atmospheric delivery of bioavailable Fe to the Southern Ocean. This study applied an inverse modeling technique to a global aerosol chemistry transport model (IMPACT) in order to optimize predictions of mineral aerosol Fe concentrations based on recent observational data over Australian coastal regions (110ºE–160ºE and 10ºS–41ºS).

The atmospheric model considered the deposition of both lithogenic and pyrogenic Fe-containing aerosols and their chemical transformation due to reactions with gaseous species. Sensitivity simulations are carried out before (*a priori*) and after (*a posteriori*) model optimizations.

The optimal (*a posteriori*) model successfully estimated T_{Fe} concentrations in aerosols sampled over the 70ºE–150 ºE and 10ºS–70ºS oceanic sector of the SH. As a consequence, the *a posteriori* model reproduced enhanced Fe solubility associated with better agreement of L_{Fe} concentrations with the field measurements. The *a posteriori* model estimates suggested that bushfires contributed a large fraction of L_{Fe} concentrations in aerosols, although substantial contribution from missing sources (e.g., coal mining activities, volcanic eruption, and secondary formation) was still inferred. These findings may have important implications for the projection of future micronutrient supply to the oceans as increasing frequency and intensity of open biomass burning are projected in the SH.

Keywords: Mineral dust, Bushfires in Australia, climate change

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Low dust generation from active sand dunes

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Several studies have indicated that mineral dust is generated from regions covered by sand, proposing that sand dunes might be important sources of dust emission. Aeolian abrasion was proposed as the dominant mechanism for that dust generation. However, the hypothesis of dust emission from active sands under natural aeolian (by wind) conditions was not tested. This study integrates targeted wind tunnel experiments and field observations with mathematical modeling to explore aeolian dust emission from sands. The results from the wind tunnel experiments indicate no dust emission under shear velocities below the saltation threshold. The initial content of dust-sized particles (>63 μm) in the sand was found to impact the measured atmospheric PM10 concentration. The experiments identify clay coating removal as the dominant mechanism of dust emission over time in typical active sand dunes (<2% dust content) with the inclusion of re-emission of the existing dust-sized particles (<63 μm). This was supported by the field measurements conducted in the Oceano sand dunes (California). Despite the common assumption, aeolian abrasion have a minor role in PM10 dust generation from active sands, demonstrating very low dust generation over time. The overall dust emission from sand dunes to the atmosphere is at the low end of the range produced by other dust-soil sources. The new quantitative information obtained can be implemented as more realistic parametrization of dust loading from sand areas to the atmosphere to reduce the existing uncertainties in dust and climate models.

Keywords: Aeolian processes, Dust source, Atmospheric PM10, Wind tunnel, Dust emission

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What are the main land-surface processes affecting saltation activities in a dust hotspot of the Mongolian desert steppe?

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Wind erosion is a global phenomenon that occurs in arid and semi-arid regions worldwide, including the Mongolian desert steppe. In recent decades, dust outbreaks increased in the Mongolian desert steppe posing a serious threat to local ecosystem and animal/human health in both dust source and downwind regions. Dust outbreaks are impacted by wind speed (erosivity factor) as well as by land surface conditions (erodibility factor), such as vegetation cover, freeze-thaw process, soil moisture, soil crust, and snow cover, because they affect threshold wind speed for wind emission. However, in the Mongolian desert steppe, these physical relationships between surface conditions and dust outbreaks have not fully been investigated due to constraint of field observation. In this study, we integrated field observations and process-based ecosystem model DAYCENT to explore the effects of land-surface processes on dust outbreaks and to understand the relative contributions of erosivity and erodibility for wind erosion at Tsogt-Ovoo on the Mongolian desert steppe during 2012–2017. The ecosystem model gave reasonably good simulations of the vegetation, and soil moisture and temperature dynamics. Observational results show that dust outbreaks were mainly caused by westerly and northerly strong winds (>10 m/s) for late February to August. That period can be divided into primary (late February –early May) and secondary sub-periods (late May –August). Based on multiple regression analysis, we found that the threshold wind speed did not correlate with soil moisture, but decreased with increasing soil temperature in the primary sub-period (r=-0.65, p<0.01) and increased with increasing vegetation components of standing dead (dead-leaf hypothesis) and live grasses in the secondary sub-period (r=0.87, p<0.05). These variations of threshold wind speed possibly related to the snow cover and freeze-thaw processes in the primary sub-period, and dead and live grasses in the secondary sub-period, respectively. Our novel model of threshold wind speed explained that more frequent and higher saltation flux in 2012 and 2015 resulted from a combination of frequent strong winds and a lower threshold wind speed for dust emission, which was related to higher soil temperature and smaller vegetation components. In addition, other conditions (e.g. soil physical crust formation and soil particle size distribution) likely affected dust occurrences, particular during transitional period in May.

Keywords: Asian dust, Dead-leaf hypothesis, Ecosystem model, Freeze-thaw process, Saltation, Threshold wind speed

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Effects of various vegetation factors on sand saltation from the viewpoint of roughness

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Vegetation factors such as coverage, height, spatial arrangement and species composition have a combined effect on sand saltation. Several studies reported about vegetation mitigating wind erosion with high coverage. The impact of vegetation coverage has already been incorporated into the aerosol model of Japan Meteorological Agency in the form of the Leaf Area Index. On the other hand, there is not enough research on community height, species composition, and spatial arrangement. Vegetation also suppresses sand saltation by declining the wind speed near the ground surface. It is well known that the vertical wind profile is affected by the community height and the shape of the structures (species composition), however there are few studies on sand saltation considering these factors. In addition, it is pointed out that the vegetation coverage only represents the average coverage of the site, and that the spatial arrangement of plants cannot be considered. It has been proposed that sand saltation causes dust emission with saltation bombardment. Elucidating relationship between sand saltation and vegetation is important to estimate dust emission. Therefore, this study was performed to clarify the effectiveness of several vegetation factors on sand saltation. Sand saltation is important to estimate dust emission.

Our study site is Tsogt-Ovoo sum, Mongolia, which is arid area in Northeast Asia and known as a dust source. In this area, there is a gradient in vegetation from the hilly area to the lowland. We selected two type shrub land (dominated with *Salsola passerine*, *Anabasis brevifolia* and *Nitraria sibirica*) and almost bare land for observation site. Vegetation survey, saltation and meteorological observation were conducted. 9 quadrats were placed at each site and we recorded species composition, coverage and community height. In 4 sites dominated with *N. sibirica*, spatial arrangement and height of every shrubs were recorded. As saltation observation, piezoelectric particle counters (ud-101) was used to count saltation particle numbers and we introduced 3 instruments for each site to identify variance of saltation number in microscale. We also determined wind profile with portable weather meters (Kestrel weather meter 5500). Roughness, zero-plane displacement and friction velocity were calculated from wind profile with maximum correlation method, and threshold friction velocity was estimated with a method of Owen (1964).

Saltation flux were decreased with increasing of coverage. However, threshold friction velocity was not explained with coverage or community height. Roughness length explained threshold friction velocity well. Although it is a well-known fact that vegetation effects on roughness length, it is suggested that each vegetation factor is not enough to explain roughness and also saltation occurrence by itself. In a heterogenous site dominated with *N. sibirica*, 3 instruments showed deferent trends slightly in spite of similar trends in other homogenous sites. Further studies that consider effect of spatial arrangement and its interaction to other factors are needed in order to clarify combined effects of vegetation to sand saltation.

Keywords: Saltation, Threshold friction velocity, Ecosystem functioning, Vegetation cover, Roughness, Distribution of vegetation

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[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS07] Aqua planetology

convener:Yasuhito Sekine(Earth-Life Science Insitute, Tokyo Institute of Technology), Hidenori Genda(Earth-Life Science Institute, Tokyo Institute of Technology), Keisuke Fukushi(Institute of Nature & Environmental Technology, Kanazawa University), Tomohiro Usui(Japan Aerospace Exploration Agency)

This proposed session covers a wide range of topics related to chemical reactions and dynamics involving water on planetary bodies; for instance, water-rock-organics interactions within planetesimals, distribution of water in the early Solar system, hydrological and biogeochemical processes on Earth and terrestrial planets, geochemical cycles, redox-pH gradients, and habitability on early Mars and icy moons, and theory to understand how to build habitable aquaplanets.

[MIS07-01] The Mystery of Unexpected Seasonal Rise in Oxygen on Mars

★Invited Papers

*Sushil K Atreya[1], Melissa G Trainer[2], Paul R Mahaffy[2], Michael H Wong[1] (1.University of Michigan Ann Arbor, 2.NASA-GSFC)

[MIS07-02] Water vapor vertical profiles on Mars: Results from the first full Mars Year of TGO/NOMAD science operations

*Shohei Aoki[1,2], Ann Carine Vandaele[1], Frank Daerden [1], Geronimo Luis Villanueva[3], Giuliano Liuzzi [3], Ian Thomas [1], Justin Erwin [1], Loïc Trompet [1], Lori Neary [1], Robert Todd Clancy[4], Michael Doyle Smith[3], Séverine Robert [1], Arianna Piccialli [1], Sébastien Viscardy [1], Bojan Ristic [1], Miguel Angel Lopez Valverde [5], Manish Patel [6], Giancarlo Bellucci [7], Jose Juan Lopez Moreno [5] (1.Royal Belgian Institute for Space Aeronomy, 2.Université de Liège, 3.NASA Goddard Space Flight Center, 4.Space Science Institute, 5.Instituto de Astrofísica de Andalucía, 6.Open University, 7.Istituto di Astrofisica e Planetologia)

[MIS07-03] Explanation for the increase in high altitude water on Mars observed by NOMAD during the 2018 global dust storm

*Lori Neary[1], Frank Daerden[1], Shohei Aoki[1], James Whiteway[2], Robert Todd Clancy[3], Michael Smith[4], Sébastien Viscardy[1], Justin Tyler Erwin[1], Ian Thomas[1], Geronimo Villanueva[4], Giuliano Liuzzi[4], Matteo Crismani[5], Michael Wolff[3], Stephen Lewis[6], James Holmes[6], Manish Patel[6], Marco Giuranna[7], Cedric Depiesse[1], Arianna Piccialli[1], Séverine Robert[1], Loic Trompet[1], Yannick Willame[1], Bojan Ristic[1], Ann Carine Vandaele[1] (1.Royal Belgian Institute for Space Aeronomy, Brussels, BE, 2.Centre for Research in Earth and Space Science, York University, Toronto, ON, CA, 3.Space Science Institute, Boulder, CO, USA, 4.NASA Goddard Space Flight Center, Greenbelt, MD, USA, 5.NPP/USRA, NASA Goddard Space Flight Center, Planetary Systems Laboratory, Code 693, Greenbelt, MD, USA, 6.School of Physical Sciences, The Open University, Milton Keynes, UK, 7.Instituto di Astrofisica e Planetologia Spaziali, Instituto Nazionale di Astrofisica, Rome, IT)

[MIS07-04] Stability of atmospheric redox states of early Mars inferred from time response of the regulation of H and O losses

*Shungo Koyama[1], Naoki Terada[1], Hiromu Nakagawa[1], Takeshi Kuroda[1] (1.Tohoku university)

[MIS07-05] In-situ detection of early Noachian nitrogen-bearing organics from Martian carbonates

*Mizuho Koike[1], Ryoichi Nakada[2], Kajitani Iori[1,3], Tomohiro Usui[1,4], Yusuke Tamenori[5], Haruna Sugahara[1], Atsuko Kobayashi[4,6] (1.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency , 2.Kochi Institute for Core Sample Research, Japan Agency for Marine-Earth Science and Technology, 3.Department of Earth and Planetary Science, The University of Tokyo, 4.Earth-Life Science Institute, Tokyo Institute of Technology, 5.Research and Utilization Division, Japan Synchrotron Radiation Research Institute, 6.Division of Geological and Planetary Sciences, California Institute of Technology)

[MIS07-06] Liquid Groundwater on Mars Across Time & Implications for Subsurface Habitability
★Invited Papers

*Vlada Stamenkovic[1], Ana-Catalina Plesa[2], Doris Breuer[2], Jack Mustard[3], Jesse Tarnas[3] (1.Jet Propulsion Laboratory, 2.DLR Berlin, 3.Brown University)

The Mystery of Unexpected Seasonal Rise in Oxygen on Mars

*Sushil K Atreya[1], Melissa G Trainer[2], Paul R Mahaffy[2], Michael H Wong[1]

1. University of Michigan Ann Arbor, 2. NASA-GSFC

Measurements over three Mars years have repeatedly confirmed that the relative abundance of oxygen gas in the atmosphere of Mars increases beginning in the spring and continuing through the summer [1]. This startling discovery was unexpected, considering all photochemical models had predicted that oxygen is a long-lived species in the Martian atmosphere [2,3]. The quadrupole mass spectrometer of the Sample Analysis at Mars (SAM) instrument suite on Curiosity Rover at Gale Crater made the measurements. Previous observations could monitor the gas for no more than a few sols. We suggest that the spring-summer excess in oxygen results from a complex interplay of mechanisms between the subsurface and the atmosphere of Mars. Three potential reservoirs of oxygen in the subsurface are perchlorates [4,5], hydrogen peroxide [6,7,8], and brines [9]. Subsurface ice or water is important for their production and loss [10,11]. Seasonal increase in spring-summer is detected also for methane [12], suggesting a common mechanism for the release of oxygen and methane. Both oxygen and methane are potential biomarkers; hence their behavior is key to understanding the habitability of Mars. We stress biological explanations for the observed seasonal pattern in these gases can only be supported after all abiotic processes are ruled out. References: [1]M.G. Trainer et al. (2019) JGR, doi:10.1029/2019JE006175. [2]S.K. Atreya, Z.G. Gu (1994) JGR, 99(E6), 13133. [3]V. Krasnopolsky (2010) Icarus 207, 638. [4]D. Ming et al. (2014) Science doi:10.1126/science.1245267. [5]D. Glavin et al. (2015) JGR 120, doi:10.1002/2014JE004737. [6]Atreya et al. (2006) Astrobiology 6 (no. 3), 439. [7]Encrenaz et al. (2019) AA 627, doi:10.1051/0004-6361/201935300. [8]S.K. Atreya et al. (2019) 9th International Conference on Mars, Abstract #6067. [9]V. Stamenkovic et al. (2018) NGS, doi.org/10.1038/s41561-018-0243-0. [10]Y.S. Kim et al. (2013) J. Am. Chem. Soc. 135, 4910. [11]E.H. Wilson et al. JGR 121, 1472. [12]C.R. Webster et al. Science 360, 1093.

Keywords: Mars, Earth, Aqua, Oxygen, Methane, Habitability

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Water vapor vertical profiles on Mars: Results from the first full Mars Year of TGO/NOMAD science operations

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Nadir and Occultation for Mars Discovery (NOMAD) onboard ExoMars Trace Gas Orbiter (TGO) started the science measurements on 21 April, 2018. We present results on the retrievals of water vapor vertical profiles in the Martian atmosphere from the first Mars year measurements of the TGO/NOMAD.

NOMAD is a spectrometer operating in the spectral ranges between 0.2 and 4.3 μm onboard ExoMars TGO. NOMAD has 3 spectral channels: a solar occultation channel (SO –Solar Occultation; 2.3–4.3 μm), a second infrared channel capable of nadir, solar occultation, and limb sounding (LNO –Limb Nadir and solar Occultation; 2.3–3.8 μm), and an ultraviolet/visible channel (UVIS –Ultraviolet and Visible Spectrometer, 200–650 nm). The infrared channels (SO and LNO) have high spectral resolution (λ /dλ ~10,000–20,000) provided by an echelle grating used in combination with an Acousto Optic Tunable Filter (AOTF) which selects diffraction orders. The concept of the infrared channels are derived from the Solar Occultation in the IR (SOIR) instrument onboard Venus Express (VEx). The sampling rate for the solar occultation measurement is 1 second, which provides better vertical sampling step (~1 km) with higher resolution (~2 km) from the surface to 200 km. Thanks to the instantaneous change of the observing diffraction orders achieved by the AOTF, the SO channel is able to measure five or six different diffraction orders per second in solar occultation mode. In this study, we analyze the solar occultation measurements at diffraction order 134 (3011-3035 cm^{-1}) and 168 (3775-3805 cm^{-1}) acquired by the SO channel in order to investigate H_2O vertical profiles.
Knowledge of the water vapor vertical profile is important to understand water cycle and its escape process. Solar occultation measurements by two new spectrometers onboard TGO - NOMAD and Atmospheric Chemistry Suite (ACS) - allows us to daily monitor the water vapor vertical profiles through the whole a Martian Year and obtain a latitudinal map for every ~20˚ of Ls. In 2018, for the first time after 2007, a global dust storm occurred on Mars. It lasted for more than two months (from June to August). Moreover, following the global dust storm, a regional dust storm occurred in January 2019. TGO began its science operations on 21 April 2018. The NOMAD and ACS observations therefore fully cover the period before/during/after the global and regional dust storms and offer a unique opportunity to study the trace gases distributions during the dust storms. We have analyzed those datasets and found a significant increase of water vapor abundances in the middle atmosphere (40-100 km) during the global dust storm from June to mid-September 2018 and the regional dust storm in January 2019. In particular, water vapor reaches very high altitude, at least 100 km, during the global dust storm (Aoki et al., 2019, Journal of Geophysical Research, Volume124, Issue12, Pages 3482-3497, doi:10.1029/2019JE006109). A GCM simulation explained that dust storm related increases of atmospheric temperatures suppress the hygropause, hence reducing ice cloud formation and so allowing water vapor to extend into the middle atmosphere (Neary et al., 2019, Geophysical Research Letters, accepted, doi: 10.1029/2019GL084354). This study presents the results with the extended datasets. In the presentation, we will discuss the H_2O vertical profiles retrieved from the first full Mars year measurements of the TGO/NOMAD.

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Explanation for the increase in high altitude water on Mars observed by NOMAD during the 2018 global dust storm

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Using the GEM-Mars three-dimensional general circulation model (GCM) (Neary and Daerden, 2018), we examine the mechanism responsible for the enhancement of water vapour in the upper atmosphere as measured by the Nadir and Occultation for MArs Discovery (NOMAD) instrument on board ExoMars Trace Gas Orbiter (TGO) during the 2018 global dust storm on Mars (Aoki et al., 2019).

GCM experiments with different prescribed vertical profiles of dust show that when more dust is present higher in the atmosphere, the temperature increases and the amount of water ascending over the tropics is not limited by saturation until reaching heights of 70-100 km. The warmer temperatures allow more water to ascend to the mesosphere. The simulation of enhanced high-altitude water abundances is very sensitive to the vertical distribution of the dust prescribed in the model (Neary et al., 2019).

The GEM-Mars model includes gas-phase photochemistry, and these simulations show how the increased water vapour over the 40-100 km altitude range results in the production of high-altitude atomic hydrogen which can be linked to atmospheric escape. The figure below shows the ratio of results from two simulations, GDS0008 (with a dust vertical profile corrected to be similar to observations) and nonGDS (no correction to dust profile) for water vapor and hydrogen volume mixing ratios in the equatorial region (between 30N/S) for the period between L_s = 160-280. At the onset of the global dust storm, the water vapor profile responds with a large increase by more than a factor of 150 at a height of around 70 km. At this altitude, the photolysis of water vapor is strong, and atomic hydrogen is produced. After several sols, an increase in hydrogen is seen.

Keywords: Mars, Global circulation modelling, water vapor, water ice clouds, atmospheric escape

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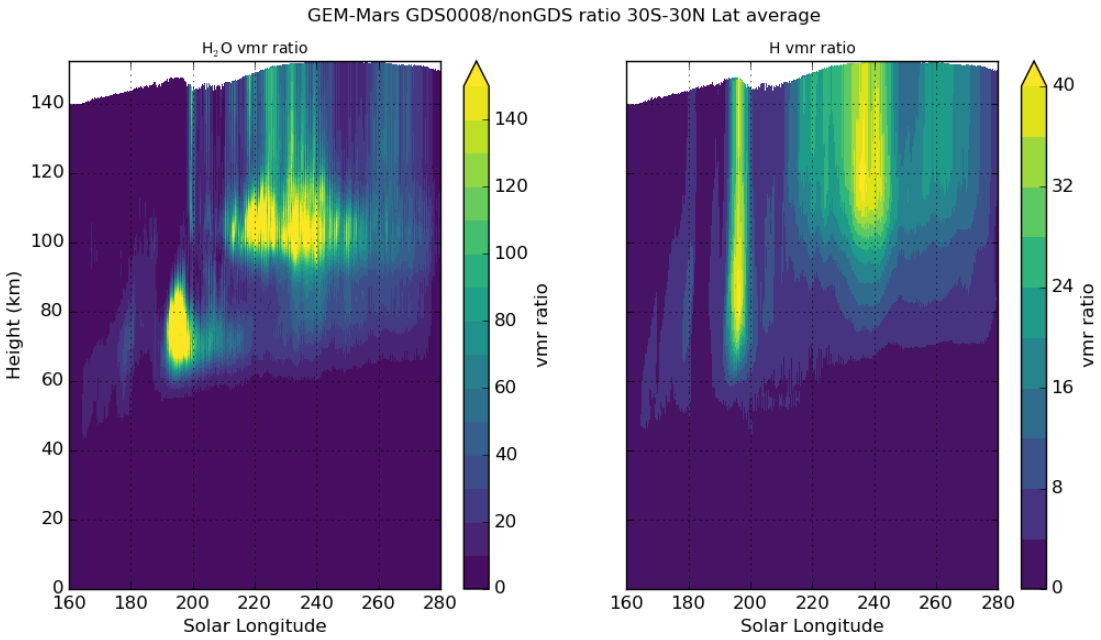

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Stability of atmospheric redox states of early Mars inferred from time response of the regulation of H and O losses

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Atmospheric losses including escapes to space and depositions to the surface play an essential role in the evolution of the Martian surface environment. Especially, a ratio of total losses of hydrogen and oxygen from the atmosphere is crucial to determine its atmospheric redox state. In the condition that H and O losses originate from H_2O, an atmospheric redox state remains the same if the ratio is 2:1, otherwise it is driven into oxidizing or reducing. It was shown by McElroy. (1972) that Jeans escape flux of H and H_2 and nonthermal escape flux of O were regulated to be in the ratio of 2:1 in a converged model of present-day Mars, which is called “self-regulation”. Whether or not the self-regulation works in real atmospheres depends on its timescales, but time responses of the self-regulation are not well understood in different atmospheric conditions.

Here we study time responses of the self-regulation in different atmospheric conditions and discuss the stability of atmospheric redox states. We use a 1D time-dependent photochemical model for various atmospheric conditions and parameters, such as atmospheric CO_2 pressure, surface temperature and O escape rate.

We find that the self-regulation timescale is essentially controlled by the net redox balance (pO_x [mbar] = $2pO_2 - pCO - pH_2$) in a converged state. The timescale gets longer as $|pO_x|$ increases, which suggests that redox-neutral atmospheres have the shortest timescale. We also find that the self-regulation can be classified into two regimes. First regime is the same as the one explained by Liu and Donahue. (1976), which tends to work in oxidizing atmospheres ($pO_x > 0$) including present-day Mars in a way that H escape changes to reach the regulated state following a change in H_2 transportation from the lower to upper atmosphere. Second one is likely to work in thicker and reducing atmospheres ($pO_x < 0$) over a relatively long timescale. The regulation occurs dominantly by changes in CO abundance in the lower atmosphere. These results imply that thicker atmospheres in early Mars are less redox-stable than present-day Mars. Our model calculations also indicate that CO-dominated atmosphere of about 100 mbar might be possible around 3 Ga. We finally discuss the redox stability of H_2-rich CO_2 atmosphere of early Mars.

Keywords: Mars, Photochemistry model, Atmospheric escape, Habitability, Water loss process

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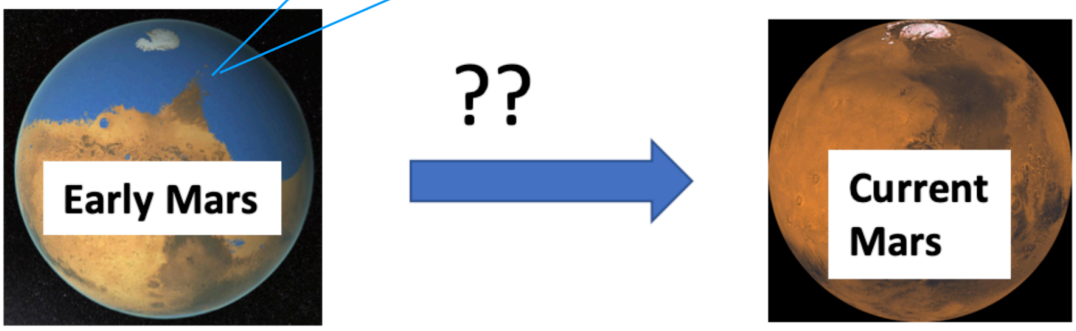
How did H_2O on early Mars go away?

H : O = 2 : 1 ?



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In-situ detection of early Noachian nitrogen-bearing organics from Martian carbonates

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Origin and preservation of organic material on Mars is a hot topic among planetary science. Martian organic records were identified from both Martian regolith and several meteorites. Allan Hills (ALH) 84001, a unique early Noachian igneous rock, is known to contain trace amounts of carbonates that precipitated through low-temperature hydrous alteration at ~4.0 –3.9 Ga on Mars. Nitrogen, an essential element for all terrestrial life, is an infromative geochemical tracer for co-evolutions of planetary systems. Here we report micrometer-scale in-situ analyses of nitrogen K-edge X-ray absorption near-edge structure (N μ-XANES) on the ALH carbonates for the first time.

Brown-orange colored carbonates on a rock fragment of ALH 84001, 248, were observed under an optical microscope in a class 100 clean room at the Earth-Life Science Institute, Tokyo Tech. The carbonates were fragile and easily peeled off by our new handpicking method. To reduce experimental contaminations, in addition, the surface of the carbonates was sputtered for ~1 μm depth using Ga ion beam of FIB-SEM at Extraterrestrial Sample Curation Center, JAXA. A silicate grain from the same rock was prepared in the same manner for contamination check. The N μ-XANES analysis was conducted at BL27SU of SPring-8 synchrotron facility. Several N-bearing inorganic and organic compounds were analyzed as references. The X-ray beam was cut by closing slit to 10 μm (V) ×30 μm (H). The energy range for the μ-XANES analysis was 385 –425 eV with a step of 0.2 eV.

XANES spectra of ALH cargbonates present two prominent absorptions at 398.9 eV and 399.9 eV with additional smaller peaks at 400.7–402 eV. The features do not match to $NaNO_3$, NH_4Cl, or N_2, but are consistent with those of organic nitrogens. ALH carbonates seems to contain a variety of N-bearing organics, whereas contribution of inorganic N is insignificant. In contrast, the ALH silicate and other possible contaminants do not present any N-related features, suggesting the experimental contamination is negligible. Previous bulk destructive analyses of ALH 84001 reported the severe contamination of carbon (mainly, organic carbon) from Antarctic ice/meltwater. It is difficult to exclude all possible contaminants, though, our *in-situ* analytical technique reduces the risk of Antractic contamination by focusing on the fresh interiors of the samples.

If the N-bearing organics are from Mars, they hould have survived for 4 Ga. Strong oxidants, such as percheorate and nitrate, exist on present Martian regolith and in younger meteorites. However, our ALH carbonates do not present NO_x features, suggesting that the 4-Ga fluid was less oxidic. Thermodynamically estimated forms of N in that fluid are N_2(aq) and NH_4^+, suitable for the co-existing N-bearing organic matter. The organics were subsequently trapped into ALH carbonates and preserved at Martian subsurface.

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Possible origins for Martian organics are A) *in-situ* synthesis and/or B) meteoritical supply. In case A, fixation of N from N_2 is required at first. Although oxidized N is found on Mars, reduced N species have not been found due to their instability. However, some abiotic paths for NH_3 and CN, proposed for Hadean Earth, could be applied on early Mars. Once NH_3 is formed, it behaves as key starting chemical for more complex N-bearing molecules. Meteoritic supply (B) is also plausible. Carbonaceous chondrites, as well as comet and IDPs contain a variety of N-bearing molecules. Large amounts of tham may have been supplied onto early Mars, although their flux are not determined. Whatever the origin, the presence of organic and reduced N indicates the importance of ‘Martian nitrogen-cycle’. We expect that further hidden records of Martian nitrogen-cycle will be acquired by future exploration and sample return missions, as well as advanced analyses of meteorites.

Ref: Koike et al. (in prep.) and references therein.

Keywords: Carbonates, Nitrogen speciation, Martian organic records, in-situ analysis, Allan Hills 84001

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Liquid Groundwater on Mars Across Time & Implications for Subsurface Habitability

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There is little debate as to whether liquid water has been shaping the Martian surface in early time and that groundwater was a major source of that water [e.g., Fassett and Head, 2011; Edwards and Ehlmann, 2015; Salese et al., 2019]. The modern Martian subsurface has had and still has the potential to enable environments with stable liquid groundwater. The possibility of such modern-day liquid underground waters has gained more interest since the claim of a potential subsurface lake beneath the South Polar Layered Deposits on Mars with MARSIS [Orosei et al., Science 2018]. However, due to attenuation, orbiting radar such as MARSIS have difficulties to detect groundwater beneath a depth of a few hundred meters away from the poles. As estimates of the average groundwater table are generally far beyond a depth of 1 km [Clifford et al., JGR, 2010], it is possible that Martian groundwater might be much more widespread but has so far remained undetected. Thus, a new opportunity to study the hydrology and habitability of the deep Martian subsurface across time awaits.

We show results of 4D (*three dimensions in space and across time*) interior models of Mars that self-consistently compute the subsurface thermal profile, groundwater stability depth, porosity, and permeability as a function of location and planet age across the last 4.5 billion years. The two models used are (**A**) a 3D spherical full mantle convection [Plesa et al., JGR, 2016] and (**B**) a preliminary parameterized thermal evolution model both coupled to a 3D crustal model that is compatible with today's gravity and topography data. The spherical full mantle convection model explicitly considers both lateral variations of the crustal and mantle heat flow contributions, which can lead to regional perturbations that can shift the groundwater table closer to the surface. The advantage of the parameterized model on the other hand is the inclusion of various uncertainties in initial conditions, rheology, subsurface rock composition, thermal properties of crust and mantle, radiogenic heart source distribution, and groundwater chemistry (variable amounts of Ca- and Mg-perchlorates and chlorides as well as sulfates).

We show how groundwater levels vary as a function of location on Mars today and across time, and discuss implications for the deep subsurface habitability of Mars across time, from the Noachian to modern day.

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Keywords: Mars, Hydrology, Evolution, Habitability

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[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS07] Aqua planetology

convener:Yasuhito Sekine(Earth-Life Science Insitute, Tokyo Institute of Technology), Hidenori Genda(Earth-Life Science Institute, Tokyo Institute of Technology), Keisuke Fukushi(Institute of Nature & Environmental Technology, Kanazawa University), Tomohiro Usui(Japan Aerospace Exploration Agency)

This proposed session covers a wide range of topics related to chemical reactions and dynamics involving water on planetary bodies; for instance, water-rock-organics interactions within planetesimals, distribution of water in the early Solar system, hydrological and biogeochemical processes on Earth and terrestrial planets, geochemical cycles, redox-pH gradients, and habitability on early Mars and icy moons, and theory to understand how to build habitable aquaplanets.

[MIS07-07] Potential Positive Feedback Mechanisms in an Anoxic Environmental System of a Planet with CO_2-CH_4 Atmosphere

*Yasuto Watanabe[1], Eiichi Tajika[1], Kazumi Ozaki[2], Peng Hong[3] (1.The University of Tokyo, 2.Toho University, 3.Chiba Institute of Technology)

[MIS07-08] Sulfur species in carbonates of a 4.1-billion-year old Martian meteorite constraining conditions of water on ancient Mars

*Kajitani Iori[1,2], Ryoichi Nakada[3], Mizuho Koike[1], Gaku Tanabe[4], Tomohiro Usui[1,5], Tetsuya Yokoyama[4], Keisuke Fukushi[6] (1.Institute of Space and Astronautical Science, 2.The University of Tokyo, 3.Japan Agency for Marine-Earth Science and Technology (JAMSTEC), 4.Tokyo Institute of Technology, 5.Earth-Life Science Institute, Tokyo Institute of Technology, 6.Kanazawa University)

[MIS07-09] Experimental and thermodynamic approach on aqueous alteration of synthetic chondrite under reducing and low temperature conditions: Implication for aqueous alteration in meteorite parent bodies

*Sakiko Kikuchi[1], Takazo Shibuya[1] (1.Japan Agency for Marine-Earth Science and Technology)

[MIS07-10] Geo-electrochemical Decomposition of Amino Acids on Icy Planetesimals Reproduces Organics in Carbonaceous Meteorites

*LI Yamei[1], Norio Kitadai[1,2], ryuhei nakamura[1], Yasuhito Sekine[1] (1.Earth-Life Science Institute, Tokyo Institute of Technology, 2.Japan Agency for Marine-Earth Science and Technology)

[MIS07-11] Reduction of U(VI) to U(IV) by Fe(II)-bearing smectite

*Yoshio Takahashi[1], Jing Sun[1], Takafumi Hamamoto[2], Takayuki sasaki[3] (1.The University of Tokyo, 2.NUMO, 3.Kyoto University)

[MIS07-12] Fluorescence spectroscopy is a tool for tracing dissolved organic carbon in hot spring ecosystems

*Hilairy Ellen Hartnett[1], Joshua Nye[1] (1.Arizona State University)

Potential Positive Feedback Mechanisms in an Anoxic Environmental System of a Planet with CO_2-CH_4 Atmosphere

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A system of aqua planet like the Earth has several important feedback mechanisms, including a negative silicate weathering feedback (Walker, 1981) and a positive ice-albedo feedback (e.g., North, 1975), which affect the climate stability, hence habitability of life. In the case of the Earth, anoxic marine microbial ecosystem is considered to have dominated for more than ~1.0 Gyr (e.g., Olson, 2006). On such a planet, carbon dioxide (CO_2) and biogenic methane (CH_4) might be two of the most likely greenhouse gases (Haqq-Misra et al., 2008). High concentrations of both CO_2 and CH_4 are considered to be detectable biosignatures in exoplanets thanks to chemical disequilibrium between them (e.g., Krissansen-Totton et al., 2018); thus, the climate stability of anoxic exoplanetary environmental systems is important for future explorations. One of the characteristic features of the anoxic environmental system of the Archean Earth is that biological activity may have been limited by the electron donor (i.e. H_2, Fe^{2+}, and CO) (e.g. Kharecha et al., 2005). This means that, the production of methane by decomposition of organic carbon through methanogenesis is controlled by the amount of the electron donor and the burial efficiency of organic carbon. The burial efficiency of organic carbon depends on temperature, which might have worked as a positive feedback in the climate system through an effect on global carbon cycle (Stanley, 2010; Finnegan et al., 2012). The other important characteristic feature is that aerosol particles composed of hydrocarbons ("haze") are formed in the atmosphere once methane exceeds some critical level (CH_4/CO_2 > ~0.1) (e.g. Trainer et al., 2006; Pavlov et al., 2001). Previously, formation of the hydrocarbon haze on the Earth-like planet is considered to work as a negative feedback, which stabilizes the planetary climate (Pavlov et al., 2001; Zerkle et al., 2012). However, how these feedback mechanisms affect the global carbon cycle in the anoxic environmental system of the planet has not been investigated. Here we investigated possible feedback mechanisms in the anoxic environmental systme of the Earth-like planet, using a coupled model of atmosphere photocheistry-marine microbial ecosystem-global carbon cycle, in which the photochemical model *"Atmos"* (Arney et al., 2016) is coupled with an anoxic marine microbial ecosystem model (Ozaki et al., 2018). We show that, because a decrease of temperature promotes burial of organic carbon, consumption of carbon from the atmosphere-ocean system is promoted and methane production is suppressed. Because both processes lead to cooling of the planet, this mechanism could work as a positive feedback in the anoxic environmental system of the planet. Further, if haze is formed in the atmosphere under low pCO_2 condition, removal of haze particles from the atmosphere decreases the pCO_2, which also works as a positive feedback in the climate system. We discuss how much these potential positive feedback mechanisms could have affected the climate stability together with the silicate weathering feedback and the ice-albedo feedback in the anoxic environmental system of the planet, and how they could have helped the onset of glacial events in the Early Earth.

Keywords: Carbon Cycle, Climate Stability

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Sulfur species in carbonates of a 4.1-billion-year old Martian meteorite constraining conditions of water on ancient Mars

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Introduction

Geological and geomorphological evidence suggests the presence of liquid water on the Martian surface in the past [1]. A 4.1-billion-year old (Ga) Martian meteorite, Allan Hills (ALH) 84001 [2], has trace amounts of carbonates (ALH carbonates) that are interpreted to have formed from Martian near-surface fluids at ~3.9 –4.0 Ga [3, 4]. Carbonates on Earth can contain trace amounts of sulfur [5]. Sulfur, a redox-sensitive element, is a promising tracer for constraining the oxidation process. In this study, we conducted sulfur K-edge X-ray absorption near edge structure (μ-XANES) analyses to estimate a possible redox condition of the aqueous fluids in the 4 Ga Martian near-surface system.

Methods

Sulfur K-edge XANES spectra were measured at BL27SU of SPring-8. The X-ray beam was focused to a final spot size of 15 (H) ×15 (V) μm^2. Thermodynamic calculations were performed to estimate Eh-pH conditions of the relevant aqueous and mineral species at 293K [6].

Results and Discussion

The μ-XANES spectra showed a diagnostic signature of oxidized sulfur [S(VI)] in all of the analytical points (N = 30). X-ray absorption peaks corresponding to S(−II) and S(IV) were observed in 2 and 26 analytical spots, respectively. XANES spectra indicated that a possible explanation for the presence of S(VI) in the carbonates is a substitution of sulfate ion (SO_4^{2-}) for carbonate ion (CO_3^{2-}) during precipitation of carbonates (i.e., carbonate associated sulfate: CAS) [5]. Results of the thermodynamic calculations suggested that conditions of the fluid that formed ALH carbonates range from approximately 9 to 11 for pH and −0.5 to 0.8 for Eh (V). The S(IV) signature may be either ｉ) the analytical artifact (e.g., photoreduction of sulfate), or ii) an endogenous sulfite phase in the carbonates. The S(−II) signature is explained by the presence of iron-sulfide microcrystals [7].

An incorporation mechanism of sulfur into the ALH carbonates was proposed based on the results of our μ-XANES analyses and the thermodynamic calculations. The water-rock reaction with the parent rock of ALH 84001 gradually increased the pH of the fluid and precipitated CAS-bearing ALH carbonates. The microcrystals of iron-sulfide were mixed into the ALH carbonates during the formation. The possible source of the CAS-forming fluid in ancient Mars is either groundwater [8] or surface water [1]. In either case, this water source should have been isotopically exchangeable to the atmosphere [9].

The virtue of our model is that it would provide a plausible explanation about the missing carbon sink proposed by atmospheric escape models [10,11]. The source water should have had originally an acidic

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to neutral pH condition under which any carbonates are unstable. The original acidic/neutral pH condition suggests that the carbonate formation should have taken place underground in ancient Mars, implying the existence of subsurface carbonate storage as a dominant carbon sink even in the present Mars.

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Keywords: Mars, meteorite, sulfur, XANES

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Experimental and thermodynamic approach on aqueous alteration of synthetic chondrite under reducing and low temperature conditions: Implication for aqueous alteration in meteorite parent bodies

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1. Japan Agency for Marine-Earth Science and Technology

The presence of hydrous minerals in chondrites has been considered as an important evidence for the former presence of liquid water in parent bodies. However, the detailed aqueous evolution history of parent bodies (e.g., temperature, fluid composition, water/rock ratio) are still poorly constrained, partly because the alteration processes of chondritic rock are not well defined and very few relevant experimental data are available. In this study, the alteration process and secondary mineral assemblage of chondritic rock are studied by the combination of alteration experiments and thermodynamic calculations. We especially focused on aqueous alteration at low temperature and reducing conditions, which were indeed suggested for some meteorite parent body but has been rarely experimentally examined in previous studies. The experiments were conducted at temperatures of 25 and 80 ºC for time periods between 1 to 460 days, using synthetic chondrite (mixtures of olivine, enstatite, glass, Fe_{metal}, and troilite) as a starting material.
Our experiments up to 460 days showed that chondrite-water reactions caused a series of mineral dissolution, secondary mineral formation, and changes in water chemistry even at low temperatures and short duration of time. Especially, the formation of pyrrhotite was notable during the first few days of the experiments while the formation of saponite was evident after 100 days in the experiment at 80 ºC. Transmission electron microscope observation revealed that fine-grained saponite and secondary-formed Si-rich amorphous phases densely covered the surface of the primary minerals both at 80 ºC and 25 ºC up to 470 days. The Fe/Mg ratios of the saponites formed at 80 ºC were higher than those formed at 25 ºC, and the highest Fe/Mg ratios were observed in saponites encrusting the primary troilite at 80 ºC. These results suggest that Fe^{2+} provided from troilite induced the formation of Fe-rich saponites, which is consistent with the rapid increase of HS^- in fluid from the start of the experiments and formation of pyrrhotite at 80 ºC. All of the secondary minerals observed from our alteration experiments were consistent with those expected from thermodynamic calculations. However, the formation of serpentine, which is one of the most dominant secondary minerals expected from thermodynamic calculations, was not observed in our experiments up to 460 days, probably because serpentine formation might be kinetically much slower than that of saponite at low temperature. The dominance of pyrrhotite and saponites and their morphological characteristics observed from our alteration experiments show similarities with those in some CV chondrite and micrometeorites, which formation might be explained by their alteration of reducing water at low temperatures and by short duration of time. Therefore, our findings will contribute to better constraints on the temperature and timescales of aqueous alteration in the meteorite parent bodies.

Keywords: chondrite, aqueous alteration, saponite

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Geo-electrochemical Decomposition of Amino Acids on Icy Planetesimals Reproduces Organics in Carbonaceous Meteorites

*LI Yamei[1], Norio Kitadai[1,2], ryuhei nakamura[1], Yasuhito Sekine[1]

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Organics in carbonaceous meteorites are the remnants of primitive solar system chemistry and parent-body processes. Amino acids are ubiquitously found in carbonaceous chondrites, and their genesis and conversion have important implications on the origin of biomolecules, the geophysical evolution and the geochemical processes that occurred in their parent bodies (icy planetesimals).

In Murchison meteorite and several reported carbonaceous meteorites, in addition to amino acids, other types of water-soluble, low molecular weight compounds make a complex suite that includes hydroxycarboxylic acid, aliphatic monoamines, monocarboxylic acids, alcohols, and others. However, the synthetic origin for their formation leading to their occurrence in meteorites remain poorly understood, becoming a long-standing enigma.

It has been largely considered that water-rock interactions cause the alteration of organic distribution and associated minerals in carbonaceous bodies, however, how does energy transduction proceed in such environment and how the chemical processes have shaped the organic distributions remain poorly understood. Here we report that geo-electrochemical processes can decompose aliphatic amino acids into monocarboxylic acids, alcohols, amines, and hydroxycarboxylic acids. Iron and nickel sulfides work as effective catalysts for the redox-mediated activation of amino acids. Such geo-electrochemical processes are driven spontaneously by the water-rock interactions, which generate steep redox, pH and chemical gradients between the interior and exterior of the icy planetesimals.

Keywords: Icy Planetesimals, Carbonaceous Meteorites, Amino Acids, Aqueous Alteration, Geo-electrochemistry

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Reduction of U(VI) to U(IV) by Fe(II)-bearing smectite

*Yoshio Takahashi[1], Jing Sun[1], Takafumi Hamamoto[2], Takayuki sasaki[3]

1. The University of Tokyo, 2. NUMO, 3. Kyoto University

Environmental behavior of uranium (U) is highly important in geochemistry and environmental chemistry from various aspects such as paleoredox change in the earth history, microbial effect on its behavior, and radioactive waste management. On the other hand, many studies have been conducted recently on the reduction of various metal ions in the presence of smectite that retains ferrous iron within the layer structure, possibly due to the reduction effect by the oxidation of ferrous ion into the ferric ion.

In this study, we studied reduction of U(VI) to U(IV) by Fe(II)-bearing smectite. Smectite (Kunipia) originally containing mainly Fe(III) was treated by dithionate under reducing condition in a glove box with O_2 conc. less than 10 ppm. Iron K-edge XANES spectra proved that iron in the smectite was reduced nearly completely to Fe(II). Moreover, Fe K-edge EXAFS showed that 1st coordination sphere of Fe(II) in the layer structure is similar to that of Fe(III) in the structure before reduction. This may suggest that Fe(III) in the layer structure was reduced to Fe(II) with keeping its site within the structure.

Uranyl solution was prepared from uranyl nitrate. The synthetic Fe(II)-bearing smectite washed with Milli-Q water was added into the uranyl solution at pH 8, and the mixture was stirred in the glove box for various elapsed times from 1 to 24 hours. The smectite recovered by filtration was immediately washed by Milli-Q water and packed into a polyethylene bag, which was sent to SPring-8 for the measurement of XAFS at U LIII-edge at BL01B1. Based on the linear combination fitting of U LIII-edge XANES spectra of the samples using U(IV)O2 and U(VI)O2 solution as endmembers, we found that U(VI) was reduced to U(IV) and distributed to the solid phase even after 1 hour. On the other hand, U species in the solid phase prepared by mixing of uranyl solution and original Kunipia without reduction was not reduced to U(IV). These results revealed that Fe(II)-bearing smectite can be a strong reductant agent which can reduce U(VI) to U(IV).

Similar reduction can be expected to saponite (Fe(II)-bearing trioctahedral smectite), which is abundant in aqua planet. Based on this study, it is strongly expected that the reduction reaction caused by the Fe(II)-bearing smectite plays an important role on the various chemical reactions in water.

Keywords: smectite, reduction, uranium

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Fluorescence spectroscopy is a tool for tracing dissolved organic carbon in hot spring ecosystems

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1. Arizona State University

Dissolved organic matter (DOM) in hot spring systems is a complex, dynamic pool of molecules with multiple sources and fates. Recently, we developed a novel, validated PARAFAC model for hot spring DOM that revealed both standard humic and protein-like material as well as a fluorphore uniquely found in acidic springs (pH < 4; [1]). Here we assess dissolved carbon concentration and DOM fluorescence characteristics for ~200 hydrothermal features in Yellowstone National Park that represent a diversity of hot spring types (hydrothermal only, acid-sulfate, alkaline-chloride, metoric influenced, etc.). Bulk dissolved carbon concentrations range from low micromolar levels up to millimolar levels with higher concentrations generally associated with more acidic springs. DOM composition is quite variable across the range in pH and temperature of the springs we sampled.

Fluorescence analysis reveals multiple sources of organic carbon that can be used as tracers of terrestrial and hydrothermal carbon inputs. These additional organic tracers allow an analysis of carbon source and mixing across hot sping types. Plots of dissolved carbon content as a function of sulfate, chloride, and pH (**Fig. 1**) confirms the expected patterns in mixing that can be identified using sulfate and chloride alone [2]. However, fluorescent DOM is a sensitive tracer of surface derived organic matter and allows us to distinguish mixing between different source types even when they have similar sulfate-chloride. DOM fluorescnece also allows us to assess the extent to which mixing has occurred subsurface without terrestrial influence vs. at the surface manifestation of the spring. This new tracer provides insight to the complexity of terrestrial hydrothermal systems and may prove useful for future studies of dissolved organic matter in planetary oceans.

[1] J Nye, E Shock, H Hartnett (2020 in press) *Org. Geochem.* doi.org/10.1016/j.orggeochem.2019.103964

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Keywords: hydrothermal, dissolved organic carbon, mixing, spectroscopy

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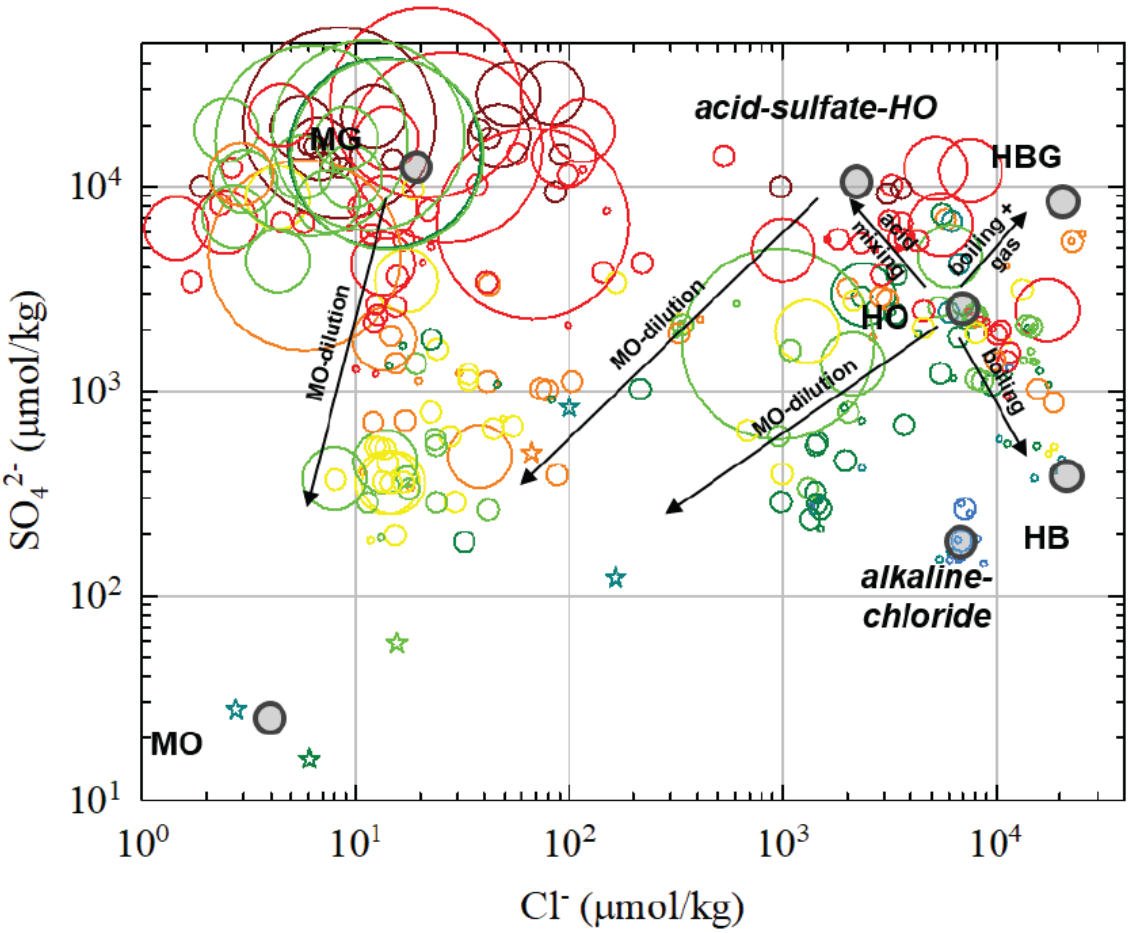

Fig. 1: Hot spring dissolved carbon concentration (open circles, symbol size ∝ concentration; range: 15–3000 µM) plotted in molal [$SO_4^{=}$] vs. [Cl] space. Color scale is pH (red-orange: pH<4; yellow-green: 4<pH<7; blue: pH>7). Mixing trends and fluid types from [2] are overlain as arrows and shaded circles.

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[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS07] Aqua planetology

convener:Yasuhito Sekine(Earth-Life Science Insitute, Tokyo Institute of Technology), Hidenori Genda(Earth-Life Science Institute, Tokyo Institute of Technology), Keisuke Fukushi(Institute of Nature & Environmental Technology, Kanazawa University), Tomohiro Usui(Japan Aerospace Exploration Agency)

This proposed session covers a wide range of topics related to chemical reactions and dynamics involving water on planetary bodies; for instance, water-rock-organics interactions within planetesimals, distribution of water in the early Solar system, hydrological and biogeochemical processes on Earth and terrestrial planets, geochemical cycles, redox-pH gradients, and habitability on early Mars and icy moons, and theory to understand how to build habitable aquaplanets.

[MIS07-13] Coupling Geochemistry to Magnetic Induction, Gravity, and Seismology in Icy Ocean Worlds

★Invited Papers

*Steven Douglas Vance[1], Bruce G Bills[1], Mark P Panning[1], Corey Cochrane[1], Krista Soderlund[2], Tom Nordheim[1], J. Michael Brown[3], Baptiste Journaux[3], Marshall Styczinski[3], Carol Paty[4], Saikiran Tharimena[1], Mohit Melwani Daswani[1], Marc Neveu[5], Keith Chin[1] (1.NASA Jet Propulsion Laboratory, California Institute of Technology, 2.University of Texas, Austin, 3.University of Washington, Seattle, 4.University of Oregon, Eugene, 5.NASA Goddard Space Flight Center)

[MIS07-14] The Effect of Pore Structure on Water Infiltration under Different Gravity

*Yasushi Mori[1], Long Thanh Bui[1] (1.Graduate School of Environmental and Life Science, Okayama University)

[MIS07-15] Deep-seated hydrothermal circulation beneath the rdige axis: a case study of crustal diopsidite from Oman ophiolite

*Norikatsu Akizawa[1], Akira Miyake[2], Akira Tsuchiyama[3,4], Yusuke Yokoyama[1], Takahiro AZE[1], Hisashi Asanuma[5] (1.Atmosphere and Ocean Research Institute, The University of Tokyo, 2.Graduate School of Science, Kyoto University, 3.Research Organization of Science and Technology, Ritsumeikan University, 4.Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, 5.Geochemical Research Center, The University of Tokyo)

[MIS07-16] Constraint of salt compositions on Europa's surface from observations using Subaru telescope and laboratory experiments

*Shuya Tan[1,2], Yasuhito Sekine[1], Masayuki Kuzuhara[3,4], Taisei Kurosaki[5], Takashi Kikuchi[5], Hisayuki Suematsu[5], Tetsuya Hama[6], Yoshio Takahashi[2] (1.Earth-Life Science Institute (ELSI), Tokyo Institute of Technology, 2.Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, 3.Astrobiology Center, NINS, 4.National Astronomical Observatory of Japan (NAOJ), 5.Extreme Energy-Density Research Institute (EDI), Nagaoka University of Technology, 6.Komaba Institute for Science, The University of Tokyo)

[MIS07-17] Field investigation on capturing of lake water salts within surface ice on ice-covered saline lakes in Mongolia: Implications for icy shell compositions of Solar System icy bodies.

*Masahiro Yoda[1,2], Yasuhito Sekine[1,3], Keisuke Fukushi[3,4], Takuma Kitajima[4], Baasansuren Gankhurel[4], Davaadorj Davaasuren[5], Daigo Shoji[1], Yoshio Takahashi[2] (1.Earth-Life Science Institute of Tokyo Tech, 2.Department of Earth and Planetary Science, The University of Tokyo, 3.Institute of Nature and Environmental Technology, Kanazawa University, 4.Graduate School of Natural Science and Technology, Kanazawa University, 5.National University of Mongolia)

[MIS07-18] Water vapor plumes at Jupiter’s moon Europa - what we know and what we do not know

★Invited Papers

*Lorenz Roth[1] (1.KTH Royal Institute of Technology, Stockholm, Sweden)

Coupling Geochemistry to Magnetic Induction, Gravity, and Seismology in Icy Ocean Worlds

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In icy ocean worlds the hydrosphere comprises a major fraction of the bulk volume. For example, Ganymede's H_2O-rich shell occupies about 75% of its total volume. To understand the global geophysical properties of such worlds thus requires information on the petrology and geochemistry of ices and fluids in detail commensurate to the sensitivity of planned geophysical investigations. However, with the planned implementation within less than 16 years of the *Europa Clipper*, *JUICE*, and *Dragonfly* missions to Europa, Ganymede, and Titan, respectively, key information is almost entirely absent. Electrical conductivity data to significant pressures are only available for aqueous $MgSO_4$, but NaCl may be a more likely main component of the oceans. Most available data extend only to very low salinity and modest temperatures. Adding to this difficulty, ice hydrates are likely to trap significant amounts of ionic material, but the thermodynamic and seismic properties of such materials have not been studied extensively. We have developed geophysical models for icy ocean worlds that incorporate available thermodynamic data, allowing us to evaluate the radial structures for different assumed compositions and thermal states. By exploring the bounds placed by available and yet-to-be-obtained geophysical data, this forward modeling approach helps to identify which experimental measurements are most needed.

Keywords: Ocean Worlds, Geophysics, Habitability

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The Effect of Pore Structure on Water Infiltration under Different Gravity

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It is actively performed these days about research on life activities under different gravitational effects, such as long-term stays on the space station and life exploration on other planets. Life activity always requires a water retention by a porous body, and studying how liquids behave in regolith (soil) will contribute to elucidating the environment of the water planet. The outermost layer of the earth is called soil, not regolith. Our previous report showed that the presence of tubular pores formed by plants greatly affects infiltration process and organic matter conservation on 1G earth. The pores extending vertically downward play a certain role in conservation of water and organic matter and also supporting plant growth. It is known that infiltration would be poor under the micro-gravity condition, thus water infiltration and water holding properties would also change under the different gravity, such as 1/3 on Mars and 1/6 on Moon.

In this research, we applied pseudo gravity to soil column by rotating centrifuge tube horizontally. Toyoura Standard soil was used to imitate the regolith on the planet and water tank with a pin-hole touched on the soil surface so that water was supplied only when pseudo gravity applied. In this experiment, artificial macropore was created in the soil column to examine how vertical tubular pore effects water infiltration. 1,1/2,1/3,1/4,1/6 and zero gravity were applied to examine the infiltration reach and see how break through structure (macropore) affects the reach distance. Two dimensional simulation was also conducted to check the infiltration process.

The results showed that infiltration reach decreased as the gravity decreased. Infiltration was very small with zero gravity. These were explained that, when the gravity decreased, capillary force would become relatively large compare to inertial force. Thus most of the water was absorbed by bulk soil before it reaches to the deeper profile. However when there were macropore structure, like plant root created macropore, infiltration reach was kept large compare to control condition. Macrpore structure could work to maintain the inertial force and conduct the water to deeper profile effectively. These were also presented in the 2D simulation that infiltration reach maintained large even with the small gravity if the column has macropore structure inside. These results showed that, break through structure, tubular pore plays a role to conduct the water to deeper profile. It might be a small effect but in the long run, the effect would be large. The reports said that during the Silurian period, first lichens and then vascular plants appeared on terrestrial area. During this process, root created macropore could play certain role to keep moisture in the early soil. This could be also true for the planet evolution. Small gravity could not conduct the water to deeper profile effectively, however, if there is vertical pore structures, moisture could be kept under the ground, avoiding precious water to escape to the atmosphere.

Keywords: Micro-gravity, Regolith, Soil, Infiltration, water conservation

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Deep-seated hydrothermal circulation beneath the rdige axis: a case study of crustal diopsidite from Oman ophiolite

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Hydrothermal circulation beneath the ridge axis plays a significant role in the exchange of energy and mass between the solid Earth and the oceans. The hydrothermal circulation occurs when seawater intrudes downward into the oceanic crust through fractures, and becomes buoyant rising rapidly back to the seafloor. In recent times, deep-seated hydrothermal circulation down to crust/mantle boundary has been introduced regarding geological investigations and numerical models. The deep-seated hydrothermal circulation can be one of the necessary processes maintaining plate tectonics due to mantle hydration lowering mantle viscosity. In order to assess the reaction mechanisms of the deep-seated hydrothermal circulation and the host rocks beneath the ridge axis, we present a series of intense investigations for aqueous fluid inclusions in crustal diopsidites from Oman ophiolite. The crustal diopsidite is considered as a reaction product between gabbro (lowermost crustal material) and seawater-derived hydrothermal fluids en route from the mantle to the crust. We estimated the formation age of the crustal diopsidite at 97.48 ±2.3 Ma using U-Pb geochronology of titanite in the crustal diopsidite. Indeed, this age overlaps with the timing of the formation of the ophiolite crust. Considering that Cr-rich minerals such as chromian spinel (Cr-spinel) and chromian garnet (uvarovites) are contained in the crustal diopsidites, the hydrothermal fluids involved transported Cr from the mantle. A few micrometer-sized inclusion of aqueous fluid with chromian spinel grains was frozen with a nitrogen gas-cooled cold stage, and investigated with a focused ion beam equipped with a scanning electron microscope and an energy dispersive X-ray spectrometer (cryo-FIB-SEM-EDS system). The results showed that the Cr-spinel-bearing aqueous fluid inclusion contains Cl. Regarding the mass and chemical composition of the Cr-spinels in the aqueous fluid inclusion, Cr content in the aqueous fluid was estimated at ~71400 ppm. Although Cr is considered relatively insoluble in aqueous fluids, solubility of Cr was enhanced due to complexation reactions with Cl contained in the seawater-derived hydrothermal fluids.

Keywords: Hydrothermal water, Moho, cryo-FIB-SEM-EDS, microthermometry, Chromium

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Constraint of salt compositions on Europa's surface from observations using Subaru telescope and laboratory experiments

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The surface of Europa has been recently observed in wavelength of 1.5-2.5 μm with large ground-based telescopes, Keck and VLT (Fischer et al., 2015; Ligier et al. 2016). Those observed reflectance spectra suggest that the existence of chlorides on Europa's geologically active regions, called chaotic terrains. Although those salts would reflect the chemical compositions of the subsurface ocean (e.g., Zolotov et al., 2009), the detailed compositions (i.e., cations and redox state) are not well constrained due to the lack of observations with wide wavelength ranges. Chlorides on the surface could experience dehydration or oxidation to form oxychlorines, such as perchlorates, triggered by irradiations of UV and high-energy particles (e.g., Johnson et al., 2019). However, those are poorly investigated based on laboratory experiments.

Here, we perform high-spectral observations for Europa's surface in the wavelength of 0.95-1.5 μm using the Subaru telescope and IRCS. This provides reflectance spectra of the surface with high-spatial resolution of 200-400 km/pixel, including chaotic terrains. Our results show no remarkable peaks of hydrated salts in the observed spectra. This strongly suggests that surface salts are anhydrous sodium chlorides (e.g., NaCl and/or $NaClO_4$).

We also conduct laboratory experiments to simulate irradiations for surface hydrochlorides at low temperatures. We irradiated UV or electron (~10 keV) onto mixtures of H_2O ice and chlorides (NaCl) at low temperatures (~100 K) using a high-vacuum experimental system. In addition, irradiated higher-energy electron (~2.0 MeV) onto frozen salt solutions with the pulsed power generator “ETIGO-III” (Tokuchi et al., 1998). Our preliminary results show no clear evidence of formation of oxychlorines from NaCl or its mixture with H_2O ice. Given the dose rate of electron onto Europa's surface (Paranicas et al., 2009), the irradiation doses in the experiments correspond to < ~100 years on the surface. These results suggest that little oxychlorines would be formed in chaotic terrains in this short timescale.

Keywords: Europa, Subsurface ocean, Infrared observation, Laboratory experiment, Surface irradiation

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Field investigation on capturing of lake water salts within surface ice on ice-covered saline lakes in Mongolia: Implications for icy shell compositions of Solar System icy bodies.

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Geologically-active icy bodies in the Solar System, such as Europa, Enceladus, and Ceres, possess (or possessed) subsurface oceans under the icy crusts. These icy crusts may contain salts through trapping of oceanic water. If salts are contained, they could affect the rheology of the icy crust, surface material evolution, and internal evolution. Subsurface oceanic water could be trapped within ice grains at the interface between the ocean and icy crust as same as sea ice on the Earth (Spaun and Head., 2001). Intrusion of oceanic water into cracks and fractures in the icy crust is also suggested (Pappalardo and Barr., 2004). However, no field investigations have been conducted to evaluate both of these salt trapping processes.

Here, we report results of field survey to ice-covered lakes, the Orog and Olgoy lakes, in Mongolia to investigate water capturing within ice upon freezing. These lakes are saline closed-basin lakes. The surface is completely covered with ice in winter. Upon freezing, surface ice can be pressurized due to volume expansion of the ice, possibly forming cracks and fractures within the ice.

We performed field surveys to these lakes in February 2019 and January 2020. We collected the ices and underlying lake water at different locations of the lakes. The obtained vertical profile of salt contents and their mineral compositions from the ice samples are compared with our calculation results of brine capturing model coupled with low-temperature aqueous geochemical model. From the comparison, salt contents at the bottom are several times higher than calculation of brine captured model. We discuss about possibilities which can produce this variation of vertical profiles about salt contents (e.g. crack formation). We also argue the effect of trapped salt within icy crust to surface and interior evolution in icy bodies.

Keywords: Icy bodies, Surface evolution, Interior evolution

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Water vapor plumes at Jupiter’s moon Europa - what we know and what we do not know

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The geologically young ice crust of Jupiter's moon Europa reveals a variety of features that indicate past geological activity. Below the ice there is a global ocean of saline liquid water, detected through magnetic induction signals measured by the Galileo spacecraft. In December 2012, far-ultraviolet (FUV) spectral imaging of Europa by the Hubble Space Telescope revealed localized emission surpluses consistent with a transient H_2O abundance in a small region above the southern anti-Jovian hemisphere. Following this detection of water vapor aurora, several studies claimed supporting evidence for the existence of plumes at Europa. We compare the different studies on Europa’s plumes from the UV observations to the Galileo magnetic field measurements and the searches for thermal anomalies of the icy surface. At the end, we elaborate on possible scenarios for plume sources and processes at Europa and discuss if a comparison to the plumes of Saturn’s moon Enceladus is useful.

Keywords: Cryovolcanism, Europa, Jupiter

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[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS08] Paleoclimatology and paleoceanography

convener:Yusuke Okazaki(Department of Earth and Planetary Sciences, Graduate School of Science, Kyushu University), Benoit Thibodeau(University of Hong Kong), Akitomo Yamamoto(Japan Agency for Marine-Earth Science and TechnologyAtmosphere and Ocean Research Institute), Hitoshi Hasegawa(Faculty of Science and Technology, Kochi University)

Past environmental changes and events at multi-decadal to tectonic timescale toward an understanding of Earth climate system by an integration of terrestrial and marine proxy studies and numerical modeling will be discussed. This session includes a special series of presentations on the ocean circulation under climate change in the past, present and future relating to MOC, ventilation and hypoxia. We welcome a variety of paleo-environmental studies from a wide range of background. We hope that this session will provide an opportunity to promote communication between participants from multidisciplinary field.

[MIS08-01] Beryllium isotopes from marine and lake sediments indicate melting of the West and East Antarctic Ice Sheet during the 4.2 Ka BP climate event

★Invited Papers

*Adam David Sproson[1,2], Yusuke Yokoyama[1,2], Yoshinori Takano[2], Rebecca Totten Minzoni[3], Bethany Behrens[1], Yosuke Miyairi[1], Takahiro AZE[1] (1.Atmosphere and Ocean Research Institute, The University of Tokyo, 2.Department of Biogeochemistry, Japanese Agency for Marine-Earth Science and Technology, 3.Department of Geological Sciences, The University of Alabama)

[MIS08-02] Reconstruction of the ice sheet history based on glacial geomorphology and surface exposure dating on the Soya Coast, Lützow-Holm Bay, East Antarctica

*Moto Kawamata[1], Yusuke Suganuma[2,1], Koichiro Doi[2,1], Keiji Misawa[2,1], Motohiro Hirabayashi[2], Akihisa Hattori[1], Takanobu Sawagaki[3] (1.Department of Polar Science, School of Multidisciplinary Science, SOKENDAI (The Graduate Unversity for Advanced Studies), 2.National Institute of Polar Research, 3.Hosei University)

[MIS08-03] A portable system for acquisition of low-distortion sediment core images using computer vision and deep learning for post-processing

*Stephen Obrochta[1], Szilárd Zsolt Fazekas[2], Morén Jan[3] (1.Akita University Graduate School of International Resource Science, 2.Akita University Engineering Department, 3.Okinawa Institute of Science and Technology)

[MIS08-04] Paleoenvironmental evolution and diagenesis of the Miocene Onnagawa Formation from mineral and elemental fluctuations

*Jumpei Yoshioka[1], Junichiro Kuroda[2], Ryuji Tada[1,3], Kenji Matsuzaki[2] (1.Department of Earth and Planetary Science, the University of Tokyo, 2.Department of Ocean Floor Geoscience, Atmosphere and Ocean Research Institution, the University of Tokyo, 3.Yunnan University)

[MIS08-05] Reconstruction of paleoclimatic signals from groundwater in large aquifers-a case study in Leizhou peninsula, Southern China

*Shaoheng Li[1], Jianyao Chen[1], Dioni Cendon[2], Florian Freundt[3], Zongyu Chen[4], Guomin Yang[5], Shuang Xiao[2] (1.School of Geography and Planning, Sun Yat-sen University, Guangzhou, China, 2.Australian Nuclear Science and Technology Organisation, Kirrawee, Australia, 3.Institute of Environmental Physics, Heidelberg University, Im Neuenheimer Feld 229, 69120 Heidelberg, Germany, 4.Institute of Hydrogeology and Environmental Geology, Chinese Academy of Geological Sciences, Shijiazhuang, China, 5.Hefei National Laboratory for Physical Sciences at the Microscale, University of Science and Technology of China, Hefei, China)

Beryllium isotopes from marine and lake sediments indicate melting of the West and East Antarctic Ice Sheet during the 4.2 Ka BP climate event

*Adam David Sproson[1,2], Yusuke Yokoyama[1,2], Yoshinori Takano[2], Rebecca Totten Minzoni[3], Bethany Behrens[1], Yosuke Miyairi[1], Takahiro AZE[1]

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The 4.2 ka BP climate event was a ca. 200 to 300 year period of synchronous abrupt megadrought, cold temperatures, and windiness that were manifest globally, coincident with societal collapses in the Northern Hemisphere, the most famous of which include the Egyptian Old Kingdom, Akkadian Empire and Harappan civilization [1]. Approximately 3 to 4 m of global sea-level equivalent melting occurred at the same time [2]. However, the melt water contribution from the Greenland and Antarctic ice sheets, and the response of the Southern Hemisphere, to the 4.2 ka BP event is not well understood. Here, we present the authigenic Be isotope composition of lake and marine sediments from the Lützow-Holm Bay (EAIS) and the Ferrero Bay (WAIS), respectively [3-5].

Meteoric ^{10}Be is produced in the atmosphere by cosmic rays and delivered to the Earth and ocean surface via dust and precipitation. In Antarctica, these sources of ^{10}Be become locked up in ice sheets and are subsequently released to the continental shelf during periods of melting and freshwater discharge, where they adhere to suspended particles in the water column and subsequently accumulate on the basin floor [6]. Stable ^{9}Be is present in silicate rocks and is released during subglacial weathering, with little simultaneous release of ^{10}Be, and transported to the oceans via meltwater outflow [7]. When Be is incorporated into the authigenic phase of marine sediments, the ^{10}Be/^{9}Be reflects that of the overlying water column [8], which in turn reflects the relative dominance of freshwater flux and/or subglacial weathering.

When ^{10}Be/^{9}Be ratios and ^{10}Be data from Lake Maruwan Oike, Lake Skallen and the Ferrero Bay are compiled with previous data from the Wilkes Subglacial Basin [9] and Ross Sea [10], they reveal a large increase in ^{10}Be abundance coincident with approximately 4 to 5 Ka BP, suggesting widespread meltwater discharge and destabilisation of parts of the WAIS and EAIS during this time. Such reorganisation of Antarctic ice sheets could be linked with a southern migration of the ITCZ, possibly caused by variations in ENSO. This would have caused a strengthening of the Southern Hemisphere westerlies which, in turn, would have caused enhanced upwelling of warm intermediate waters onto the shelf leading to increased marine ice shelf instability and melting [2, 9] suggesting possible Antarctic contribution to global sea-level rise.

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Keywords: Beryllium, Holocene, Antarctica, Sea-Level, Weathering, 4.2 Ka event

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Reconstruction of the ice sheet history based on glacial geomorphology and surface exposure dating on the Soya Coast, Lützow-Holm Bay, East Antarctica

*Moto Kawamata[1], Yusuke Suganuma[2,1], Koichiro Doi[2,1], Keiji Misawa[2,1], Motohiro Hirabayashi[2], Akihisa Hattori[1], Takanobu Sawagaki[3]

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The retreat history of the East Antarctic Ice Sheet (EAIS) since the Last Glacial Maximum is important for the identification of forcing mechanisms for ice sheet behavior, constraining models that seek to predict the future trajectory of the ice sheet, and for estimating rates of sea-level change. Geomorphological studies and surface exposure dating (SED) will provide direct evidence of the timing and the history of ice retreat on coastal oases and nunatak regions in East Antarctica. Recent studies have reported retreat ages based on SED in the southern part of Soya Coast, Lützow-Holm Bay, East Antarctica. However, the retreat processes of the ice sheet remain unclear, because reported ages are only from four locations and insufficient geomorphological consideration. Here we report evidence of rapid retreat of the EAIS during the early-mid Holocene based on the geomorphological observation and SED of the Soya Coast (Skarvsnes, Skallen, and Telen). Samples from 29 erratics and three bedrock surfaces were analyzed for SED. The ages of erratic from Skarvsnes are predominantly in the range 6–9 ka, whereas bedrock ages are 14 and 21 ka. On the other hand, the ages of erratic from Skallen are predominantly in the range 5–8 ka, the ages of the bedrock is 7 ka agree within a range of erratics ages. From our dating and geomorphological results, we indicated that the ice sheet experienced rapid surface lowering at least 400 m a.s.l. while flow direction had changed by bedrock topography during the early-mid Holocene (5–9 ka). The differences in exposure ages derived from bedrock and erratic taken from the same location suggest inheritance in the ages of the bedrock acquired during ice-free periods prior to the last deglaciation, which is consistent with geomorphological features (=reflect the different conditions of the basal ice sheet). The potential mechanism of the rapid retreat of the EAIS in these areas is thought to be the marine ice sheet instability due to an inflow of the warm circumpolar deep water via the deep submarine valley. Our results demonstrate rapid ice sheet thinning as a consequence of marine ice sheet instability may lead to ice surface lowering of hundreds meters. We emphasize the ocean-ice sheet interaction is even more important for understanding the mechanisms and improving predictions of future fluctuations of EAIS.

Keywords: East Antarctic Ice Sheet, Glacial geomorphology, Surface exposure dating

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A portable system for acquisition of low-distortion sediment core images using computer vision and deep learning for post-processing

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While imaging the split surface of sediment cores is standard procedure across a range of geoscience fields, obtaining high-resolution, continuous images with very little distortion has traditionally required expensive and fragile line-scanning systems that may be difficult or impossible to transport into the field. Thus many researchers take photographs of entire core sections, which may result in distortion, particularly at the upper and lower edges. To overcome this issue, we constructed an inexpensive, rigid, manually-actuated camera sliding frame to take a series of overlapping images of a split sediment core. We then developed a set of open source tools for seamlessly stitching together the photographs using computer vision techniques. The resulting composite image contains less distortion than a single photograph of the entire core section. The method allows for detection of and correction for variable camera tilt and rotation between adjacent pairs of images. We trained a deep neural network to post-process the image to automate the tedious task of segmenting the sediment core from the background, while also detecting the location of the accompanying scale bar and cracks or other areas of coring-induced disturbance. A color reflectance record is then generated from the isolated core image, ignoring variations from e.g., cracks and voids.

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Paleoenvironmental evolution and diagenesis of the Miocene Onnagawa Formation from mineral and elemental fluctuations

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Middle to Late Miocene (16.0-5.3Ma) marks one of the three major cooling steps during Cenozoic. In this cooling event, siliceous sediments with high organic contents were widely deposited along the North Pacific margins, which has been attributed to enhanced primary productivity and/or preservation of diatoms. The Miocene Onnagawa Formation represents the deposition of those siliceous sediments in the northern Japan Sea. It was reported that siliceous rocks in the Onnagawa Formation showed meter-scale rhythmical bedding reflecting fluctuations in productivity of diatoms and flux of terrigenous materials. Furthermore, it was also reported that parts of highly siliceous rocks in the Onnagawa Formation showed centimeter-scale black bands. However, the age and the cause of their occurrence has not been understood.

We executed construction of a continuous lithologic columnar section, collection of samples at 20 cm intervals, and performed mineralogical and geochemical analyses with X-ray diffraction (XRD) and X-ray fluorescence (XRF) in the process of cyclostratigraphy for the precise dating of the Onnagawa Formation. Here we mainly present the XRD and XRF data.
The obtained columnar section is 130 m in thickness and divided into 5 lithologic units. It briefly displayed a calcareous part, a muddy part, and a siliceous part from the bottom to the top. Our samples were taken from the siliceous part in the uppermost ~60 m-thick interval (62-121 m interval from the bottom). The XRD data clearly indicate that most of the siliceous samples consist mainly of opal-CT, which derives from biogenic opal, and some taken from 62-66 m interval contain no opal-CT but are enriched in quartz. It suggests that the stratigraphic interval locates in the transition of silica diagenesis between “opal-CT zone” and “quartz zone”. The peak position of opal-CT in the XRD data also shows that the lower part underwent silica diagenesis more strongly than the upper, which is consistent with no occurrence of opal-CT and the increase in quartz at the lowest part. Furthermore, it was confirmed that the m-scale rhythmical bedding reflected the abundance in biogenic silica. We will discuss the paleoclimatic significance of fluctuations of biogenic silica and other elements, and the influence of silica diagenesis using the XRD and XRF data.

Keywords: biogenic silica, the Onnagawa Formation, Miocene cooling, silica diagenesis, XRD, XRF

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Reconstruction of paleoclimatic signals from groundwater in large aquifers-a case study in Leizhou peninsula, Southern China

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The past is the key to the future, Knowledge of the paleoclimate is essential to understand the present climate and project potential future climate scenarios. Groundwater in aquifers, though as a low time-resolution archive, can provide valuable information regarding past climate change. In this study, 13 deep monitoring wells were chosen for water sampling during our first fieldwork in Leizhou peninsula, a (sub)tropical area in southern China. Multiple tracers (^{3}H, ^{4}He, ^{14}C, ^{81}Kr, ^{85}Kr) were applied for accurate groundwater dating and the concentration of noble gases dissolved in groundwater was measured for paleotemperature reconstruction. Stable isotopes (^{2}H, ^{13}C, ^{18}O), major ions and other geochemical properties were also analyzed for these samples. According to the preliminary results, most groundwater samples' age is located in the dating range of ^{14}C and shows a relatively continuous record through the past 30,000 years. A possible recharge gap during LGM (Last Glacial Maximum) is identified and may indicate a quite cold and dry environment during this period in Leizhou peninsula. Paleotemperature revealed by the physically-based NGT (Noble Gas Thermometer) method shows that at least an environment temperature difference of 3.4 ℃ exists between the cold period and the present. A detailed comparison between NGTs, excess air (represented by ΔNe) and ^{18}O indicates that the major controlling factor of stable isotopes (^{2}H and ^{18}O) in local groundwater might be the amount of precipitation rather than temperature, therefore the signals of ^{18}O in groundwater can be interpreted as the change of moisture. Together with the NGTs, it is possible to reconstruct the paleoclimate information (including the climate state of warm/cold and wet/dry) through the groundwater archive in this study area. In addition, the groundwater dating results and recharge history revealed by this study can assist in local groundwater resource management and exploitation.

Keywords: Paleoclimate reconstruction, Groundwater , Multiple tracers, Noble gases, Stable isotopes

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[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS08] Paleoclimatology and paleoceanography

convener:Yusuke Okazaki(Department of Earth and Planetary Sciences, Graduate School of Science, Kyushu University), Benoit Thibodeau(University of Hong Kong), Akitomo Yamamoto(Japan Agency for Marine-Earth Science and TechnologyAtmosphere and Ocean Research Institute), Hitoshi Hasegawa(Faculty of Science and Technology, Kochi University)

Past environmental changes and events at multi-decadal to tectonic timescale toward an understanding of Earth climate system by an integration of terrestrial and marine proxy studies and numerical modeling will be discussed. This session includes a special series of presentations on the ocean circulation under climate change in the past, present and future relating to MOC, ventilation and hypoxia. We welcome a variety of paleo-environmental studies from a wide range of background. We hope that this session will provide an opportunity to promote communication between participants from multidisciplinary field.

[MIS08-06] Climate conditions of the past 200 years recorded in a tufa from Tokunoshima, Kagoshima Prefecture

*Akira Murata[1], Hirokazu Kato[1], Akihiro Kano[1] (1. Department of Earth and Planetary Science, The University of Tokyo)

[MIS08-07] Preliminary results of 10.5 m core record from lake Olgoy, Valley of the Lake in Mongolia

*Uyangaa Udaanjargal[1], Noriko Hasebe[1], Davaadorj Davaasuren, Yudai Igarashi[1], Keisuke Fukushi[1], Hitoshi Hasegawa[2], Baasansuren Gankhurel[1], Nagayoshi Katsuta, Shuuhaaz Ganbat, Ichinnorov Niiden (1.Kanazawa University, 2.Kochi University)

[MIS08-08] Sea Levels and coastal evolutions during the Medieval Climate Anomaly related to the construction and the abandonment of the ancient harbor “Tangseong”, western coast of Korea Peninsula, presumed by diatom analysis

*Kaoru Kashima[1], Dong-Yoon Yang[2], MIn Han[2] (1.Department of Earth and Planetary Sciences, Kyushu University, 2.Korea Institute of Geoscience & Mineral Resources (KIGAM))

[MIS08-09] Diatom composition and distribution in surface sediments of the Laptev and East-Siberian seas and their changes during last decades

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[MIS08-10] Impact of catastrophic natural events on accumulation of diatoms in sediments of Amur Bay, Sea of Japan

*Irina Aleksandrovna Prushkovskaya[1], Ira Borisovna Tsoy[1] (1.Pacific Oceanological Institute, Far Eastern Branch, Russian Academy of Sciences)

[MIS08-11] Carbon, oxygen and neodymium isotope characterization of recent benthic foraminifers around Okinawa-jima, southwestern Japan.

*Andros Daniel Cruz Salmeron[1], Hideko Takayanagi[1], Shigeyuki Wakaki[2], Hitomi Uchimura Wakaki[3], Takuya Itaki[4], Tsuyoshi Ishikawa[2], Yasufumi Iryu[1] (1.Tohoku University, 2.JAMSTEC, 3.Kochi University, 4.AIST)

Climate conditions of the past 200 years recorded in a tufa from Tokunoshima, Kagoshima Prefecture

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Tufa, a carbonate deposit developed in a stream setting in a limestone area, is potential for a paleoclimate archive. Annual layering and high growth rate of several mm/year of the tufa enable high-resolution analysis. A problem is that the tufas at stream settings hardly grow continuously over a period of 20 years. On the other hand, a longer continuous record can be expected from tufas at a cascade setting where the tufas grow from the bottom of waterfall. A cascade tufa is rare in Japan but developed at Obaru beach in Tokunoshima, Kagoshima Prefecture. This study analyzed a 49.2 cm long tufa in order to reconstruct climatic conditions.
The cascade tufa exhibits irregular growth surfaces, and analyses for the clear annual lamination indicates a growth rate of 2.35 mm/year. Applying this rate, the 49.2 cm long specimen corresponds to 209 years. While counting of densely-calcified summer bands evaluates the depositional period 187 years. Comparing isotopic records of the tufa from other sites, the Obaru beach tufa has a relatively high $\delta^{18}O$ due to the high value of rainwater, and has very high $\delta^{13}C$ reflected from the cultivation of sugar cane. Our analyses provide some insights into the potential of the tufa record. First, decreasing trend of $\delta^{13}C$ since the 1960’s is the Suess Effect by combustion of fossil fuels. While high $\delta^{13}C$ extended back to the bottom of the sample indicates that sugar cane cultivation has sustained from the 1840’s. $\delta^{18}O$ values can be correlated to rainfall amount rather than air temperature. This relation infers amount of rainfall for the period before meteorological observation; low rainfall in 1840-1870 and high rainfall in 1870-1890. In addition, a conglomeratic texture in the 1960’s most likely corresponds to a tsunami by Chile Earthquake in 1960. This study presents the longest climatic record from the modern tufa. Finding more appropriate samples will further improve the length and resolution of the tufa records.

Andrews, J. E. (2005). Palaeoclimatic records from stable isotopes in riverine tufas: Synthesis and review. *Earth-Science Reviews*, 75(1-4), 85-104.

Keywords: tufa, climate conditions, paleoclimate

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Preliminary results of 10.5 m core record from lake Olgoy, Valley of the Lake in Mongolia

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Mongolia is located in center of the Central Asia and it provides an important key archive for the research of climate characteristics inside continents. Lake sediments are an excellent archive to study long-term fluctuations of environmental conditions. Lake is the subject to a variety of extrinsic and intrinsic forcing variables that regulate the history of the lake, such as climate, watershed bedrock geology and geomorphology, tectonic and volcanic activity, vegetation, aquatic biota, and human activities (Gierlowski-Kordesch, 2004). Numerous studies have been conducted in a different part of Mongolia to reconstruct the past climate and environmental changes (Klinge and Sauer, 2019).

The Olgoy is one of the permafrost lakes located in the southern edge of the Khangai mountains in the valley of the lakes where their environment is characterized by an extreme climate, and less number of existing studies are found. The study with 10.5 m long sediment core retrieved from Olgoy lake is expected to assess the regional paleo environment. The sedimentary features are investigated along the core and include whole and mineral grain size, water, organic matter, carbonate and amorphous silica contents, and variation in elemental concentrations scanned by the ITRAX. Sedimentary ages were estimated by OSL, IRSL and Carbon-14 datings.

The short core analyses which revealed that the temperature is a dominant climate factor of sediment characteristics in Olgoy lake, as high temperature corresponds to coarse grain size, and low carbonate and amorphous silica concentrations. The upper part of Ology long core is characterized by the relatively stable elemental intensities, a decreasing trend in carbonate with coarsening whole-grain size, and suggests temperature drop based on the short core interpretation. Fluctuations of Zr and Rb (2 m and 7.5 m) indicates the allogenic aeolian inputs (Yu et al., 2017). The fluctuation of the high values of the Al/Si and Rb/Sr could be an index of the intense weathering process. Periods with S influx and water content increases could be explained in relation to permafrost melting.

Keywords: lake, sediment characteristics, age dating

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Sea Levels and coastal evolutions during the Medieval Climate Anomaly related to the construction and the abandonment of the ancient harbor “Tangseong”, western coast of Korea Peninsula, presumed by diatom analysis

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The trading by sailing ships was one of the most important methods in East Asia since the ancient period for commercial and culture exchanges. It was often called as the “Marine Silk Road”, the sailing connection routs between China, Korea, Japan and Southeast Asian countries. Tangseong was one of the biggest ancient fortresses along the western coast of Korean Peninsula. The archeological excavation since 1998 revealed several stages of buildings of the United Silla period (AD668-935) including the observatory tower, called “Manghaeru” for overlooking coasts and Yellow Sea. It was “Dang Hang Seong” written in the historic document by Wonhyo (617-686 AD), and prospered as the military and commercial center of marine trading between Korean and China crossing Yellow Sea. According to sedimentation of delta, Tangseong was remained, and it was about 2.5 km far from the present sea coast.

The alluvial lowland, north of Tangseong was presumed to be the ancient bay used as a harbor for the trading ships. KIGAM (Korea Institute of Geoscience and Mineral Resources) has started the geologic surveys with 22 undisturbed drilling cores at the lowland since 2017, and obtain 24 C-14 dating and 18 OSL dating from the cores at the lowland and surroundings. We selected the following six cores for the analysis of diatom and Chyrysophyceae assemblages. All cores presumed to insert marine clay within the core by their lithological observation.

The previous data of the relative sea level during the Medieval Climate Anomaly at Korea Peninsula were limited. Although a lot of coastal drillings surrounding western coasts of Korea Peninsula but the evidences to presume the past sea level could hardly be found in the sediments. In Tangseong area, at DS17-09 core, the front of the castle hill slope, we found the thin marine deposit at the United Silla period (AD668-935) and Goryo period (AD935-1392) by diatom analysis. The marine deposit overlaid by freshwater marsh sediment, and successive brackish layers from marine to freshwater were kept well as the sediments. The marine top level was 4.6 m amsl. It was the high tide level at the United Silla period (AD668-935) and Goryo period (AD935-1392) during the Medieval Climate Anomaly. Although the ancient tidal range under the ancient bay topography of Tangseong was not calculated yet, the sea level at there might be a little higher (about 20 cm) than the present level.

At the United Silla period (AD668-935), the trading ships sailed using tidal current from the Yellow Sea, going through the narrow entrance of the bay, into the bay. The small castle was set at the entrance gate. The TS18-06, located at the west of the entrance, was erosional stage during the United Silla period (AD668-935). The erosional level of the site was leveled about -4.5m amsl. Because the high tide level of there was presumed 4.6m amsl (DS17-09 site), at least 9m water depth was kept at the high tide. It would be enough water depth for sailing trading ships. The bay entrance was narrow, and the bay was kept stable water space for suitable environment for anchoring ships. The marine deposit at DS17-09 was only 1.5m thickness, presumable water depth at the high tide was 1-1.5 m. The trading materials were

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transshipped to small bottom flat boats from the sailing ships to the Fortress.

The harbor deposits (Zone A) at DS17-09 was buried soon and became a shallow intertidal flat (Zone B, C) and freshwater marsh (Zone D, E) corresponded to the abandonment of the fortress during the Goryo period (AD935-1392). Finally, it was covered by freshwater flooding deposits from the hill slope during Joseon Period (1392–1897). At the same period, DS18-06, located at east of the entrance gate of the bay, restarted the sedimentation of delta deposits (deposition of Zone II, DS18-06). The lowland north of the fortress was buried and was used as reclamation farm lands.

Keywords: Archaeology, Diatom, Coastal evolution, Korea, Sea level change, the Medieval Climate Anomaly

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Diatom composition and distribution in surface sediments of the Laptev and East-Siberian seas and their changes during last decades

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The marine Arctic is warming in recent decades much faster than the rest of the planet (Kattsov, Semenov, 2014). There is mounting evidence that the Arctic is now experiencing an unprecedented degree of environmental change including sea-ice loss and other cryospheric features (Charkin et al., 2017). This region is characterized by unique ice-rafted sedimentogenesis, which is determined by the environment, climate and biota (Lisitzyn, 2010). Diatom algae are the main primary producer of organic matter in the Arctic seas. Diatom species composition and abundance in surface sediments mirror modern parameters of marine environments (Crosta, 2010; Krause et al., 2018, etc.) and can be used in paleoreconstructions.

The first extensive studies of diatoms in the surface sediments of the Laptev and East-Siberian seas were conducted using materials from the 80's and 90's of the last century (Polyakova, 1997; Cremer, 1998; Tsoy, 2001, etc.). We have studied diatoms from recent sediments obtained on the cruises of the Il’ichev Pacific Oceanological Institute in the Laptev and East-Siberian seas in 2016 and 2018 (R/V Akademik M.A. Lavrentyev), and 2019 (R/V A. Zhilinsky) and compare new and previous data. Diatom assemblages typical for different regions of studied seas were revealed using cluster analysis.

In the Laptev Sea, the maximum diatom content is observed to the east of the Lena River Delta, and minimum –on the continental slope. In the East Siberian Sea (ESS), the content of diatoms varied considerably, increasing from the west to the east.

The surface sediments of the continental slope of the Laptev Sea under the influence of the cold Transpolar Current and the warm North Atlantic Current are dominated by the planktonic-benthic species *Paralia sulcata* and subdominated by the pelagic arcto-boreal species *Actinocyclus curvatulus*. Further south, in the sediments of the outer shelf, the sub-dominant is the neritic cold-water species *Melosira arctica,* the predominance of which is a striking feature of Arctic-sub-ice community (Poulin et al., 2014). The surface sediments of these areas, sampled at the end of the last century, contained the diatom assemblage dominated by the arcto-boreal neritic species *Thalassiosira antarctica* (Cremer, 1999). We have identified a similar assemblage at stations located at 2.5˚to the south, to the north-west of the Lena Delta. The assemblage dominated by freshwater *Aulacoseira subarctica* is common in the Lena River avandelt in the Buor-Khaya Gulf. The brackish-water species *Thalassiosira hyperborea* dominates in sediments of the eastern part of Buor-Khaya Gulf, the Dm. Laptev Strait, and the western part of the ESS. This region previously noted a high content of the brackish-water species *Thalassiosira baltica* (Obrezkova et al., 2014), in the samples obtained in 2018, its content is insignificant.

In the ESS, the area to the north of the Indigirka River is characterized by the dominance of *M. arctica*. Earlier in this area *T. hyperborea* was marked almost as a monodominant (Polyakova, 1997). In the eastern part of the ESS, *T. antarctica* dominates, and the content of cryophilic species is growing.

Change of dominant species observed in the surface sediments of the studied seas are noticeable in areas affected by the North Atlantic Current, which indicates that its influence may have increased in recent

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decades due to global warming.

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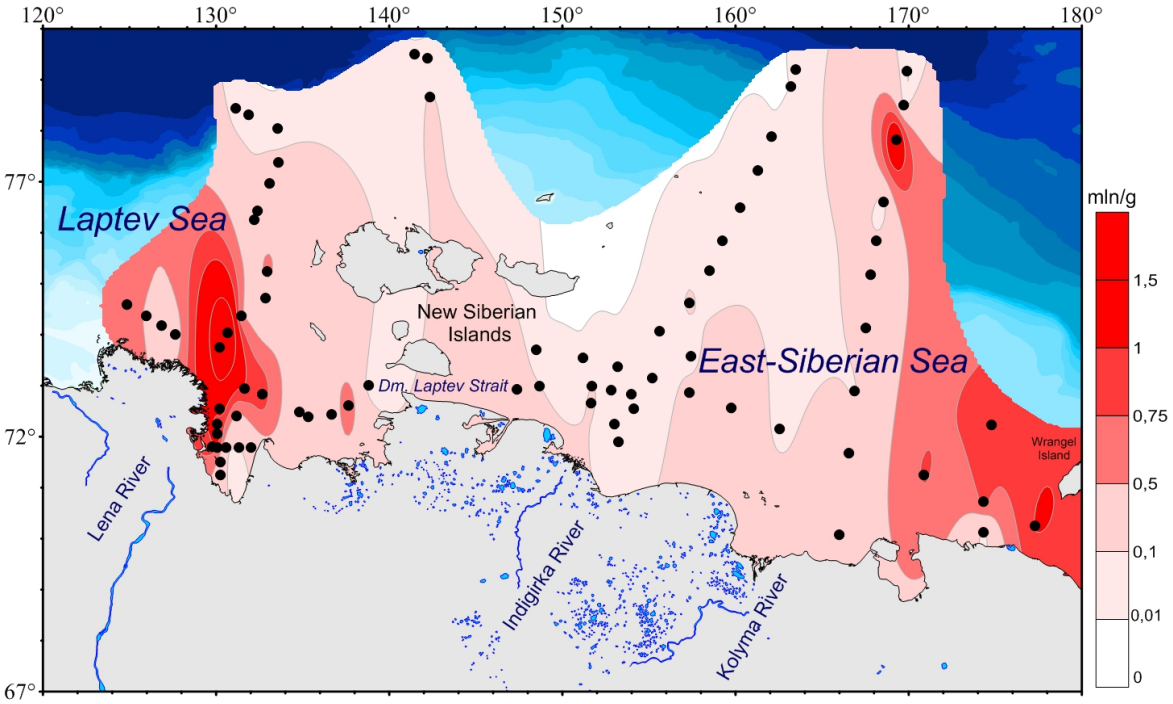
Keywords: diatoms, surface sediments, Laptev Sea, East Siberian Sea, last decades, cluster analysis



The quantitative diatom distribution (valves per gram of dry sediment) in the surface sediments of the Laptev and East Siberian seas. Points mark sampling stations.

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Impact of catastrophic natural events on accumulation of diatoms in sediments of Amur Bay, Sea of Japan

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The Amur Bay is an interior bay of extensive the Peter the Great Bay (Sea of Japan), located on zone of influence of various nature events, which often lead to catastrophic results on the coast and reflected in sediments (Fig. 1). The Razdolnaya River has significant impact on the sediment accumulation in the Amur Bay.
The study of sediments in the Amur Bay (Cores A12-4, A12-5, and LV66-3) using X-Ray Spectral Scanning were revealed layers with abnormally low bromine (Br) content which exclusively associated with marine organic matter. These layers were formed when the Razdolnaya River runoff enhanced input of terrestrial matter during extreme floods caused by tropical cyclones or typhoons (Astakhov et al., 2015; Kalugin et al., 2015). The time of formation of the layers coincides with known recorded extreme floods in the Vladivostok and the Razdolnaya River basin during the passage of typhoons, such us Irving (1979), Judy (1989), Melissa (1994). This observation was used to identify paleotyphoons in the shelf sediments with a homogeneous lithological composition.
Diatoms are a major component of the Amur Bay plankton ecosystem and abundant in sediments. The study of diatoms in the same cores (A12-4, A12-5, LV66-3) allowed us to reconstruct the conditions of sediment accumulation over the past 150 years (Tsoy et al., 2015; Prushkovskaya, 2019) and in the late Holocene (Prushkovskaya, Tsoy, 2019). Diatoms are a powerful indicator of environmental change because they respond rapidly to changes in many ecological characteristics. We analyzed sharp drops in the number of diatoms in studied sediment cores over the past 150 years. It was found that the drops coincide with low Br content associated with extreme floods and typhoons. It is noted that the intensity and frequency of typhoons has been increasing since the 1960s in the Amur Bay due to global warming. In the sediments that have formed the last 5000 years noted different frequency of minima content diatoms coincided with corresponding flood signals (Astakhov et al., 2019). The minimum diatom concentrations in the late Holocene sediments also were at the same time with paleofloods and paleotyphoons in the adjacent areas (Bazarova et al., 2018; Lyaschevskaya, 2016; Ganzei et al., 2015). During warmer periods of the late Holocene, the frequency of diatom content drops increases, during cold periods –decreases. These observations will be used in future studies to recognize extreme events in the past.
This work was supported by the Ministry of Science and Education of Russia (№. AAAA-A17-117030110033-0), the RSF (№. 18-77-10017), and partially the FEB RAS (№. 18-1-008)

Keywords: diatoms, Amur Bay, late Holocene, accumulation of sediments

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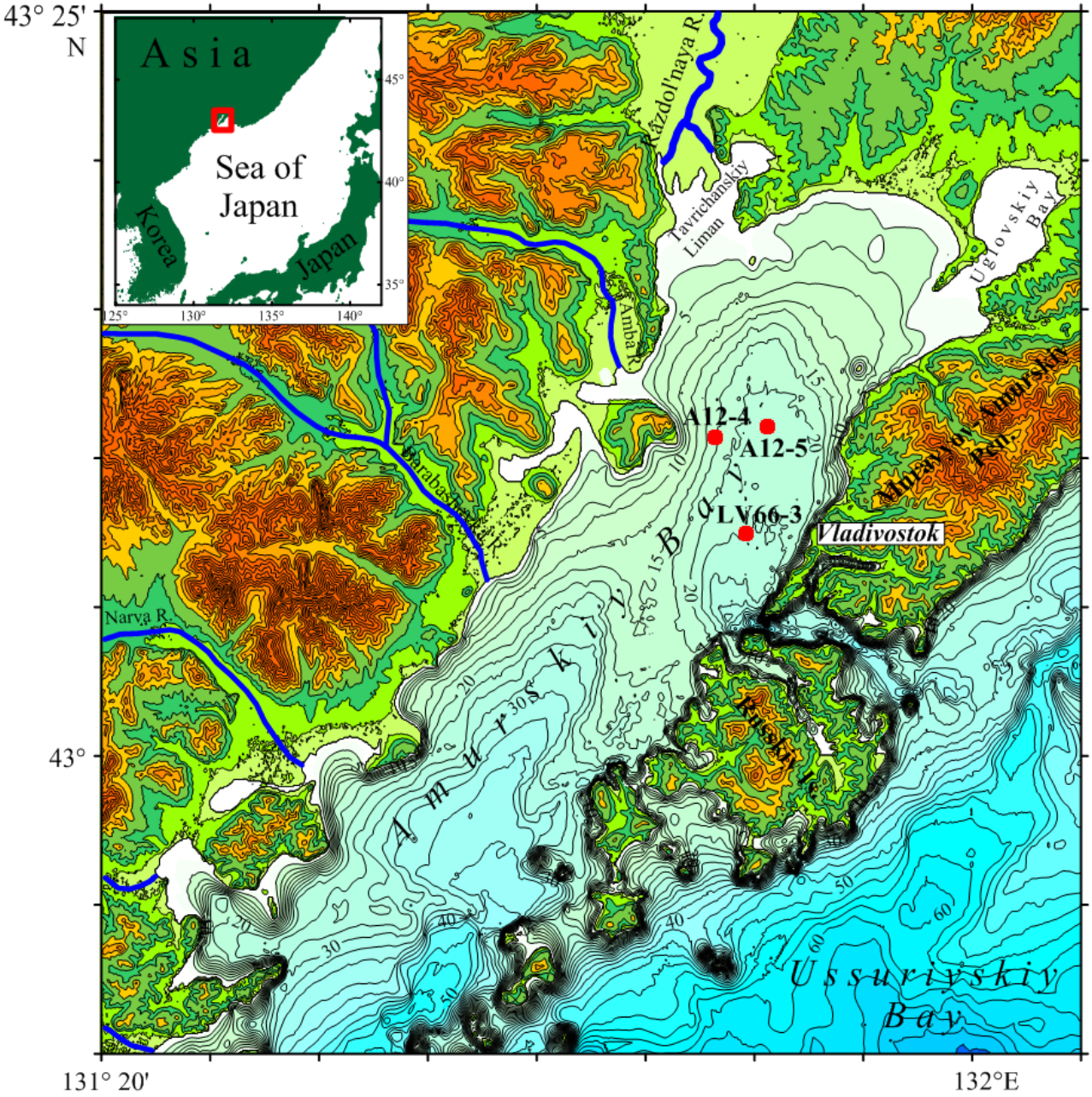

Fig. 1. Geographic locations of the studied cores A12-4, A12-5, and LV66-3 from the Amur Bay, Sea of Japan

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Carbon, oxygen and neodymium isotope characterization of recent benthic foraminifers around Okinawa-jima, southwestern Japan.

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The Kuroshio Current (KC) is the most important in the Northwestern Pacific, because it controls the Northeast-Asia climate by providing subtropical warm water. Although the KC is classified as oligotrophic, it carries elements from southern regions that promote the development of biodiversity and ecological niches around the Ryukyu Islands. The influence of the KC at low sea-level stands during glacial periods, especially in the Last Glacial Maximum, has been demonstrated to be weaker by several scientific methods.
There are limited geochemical studies on Neodymium (Nd) isotope composition around the Okinawa Trough although it is useful to detect water-mass variations and movement. We plan to delineate late Cenozoic paleoceanographic evolution of the KC in the Ryukyu Islands based on Nd isotopes of sediments and benthic foraminifers. This work was performed as the first step to this purpose and aimed to present detailed information on the carbon and oxygen isotope composition of the deep-water benthic foraminifers, *Cibicidoides wuellerstorfi* and *Hoeglundina elegans* and Nd isotope composition of mixed benthic foraminifers. Three water masses were identified based on our data: Kuroshio Surface Water (0-200m), Kuroshio Tropical Water (200-600m) and Kuroshio Intermediate Water (below 600m). The composition of the surface water is determined by mixing of the KC water and waters from Taiwanese and Chinese rivers. Subsurface water composition is controlled by the vertical mixing between the surface water and the intermediate water. The intermediate water is a mixture of the North Pacific Intermediate Water and South China Sea Intermediate Water.

Keywords: Neodymium, Oxygen stable isotopes, Carbon stable isotopes, Kuroshio current, Benthic Foraminifera

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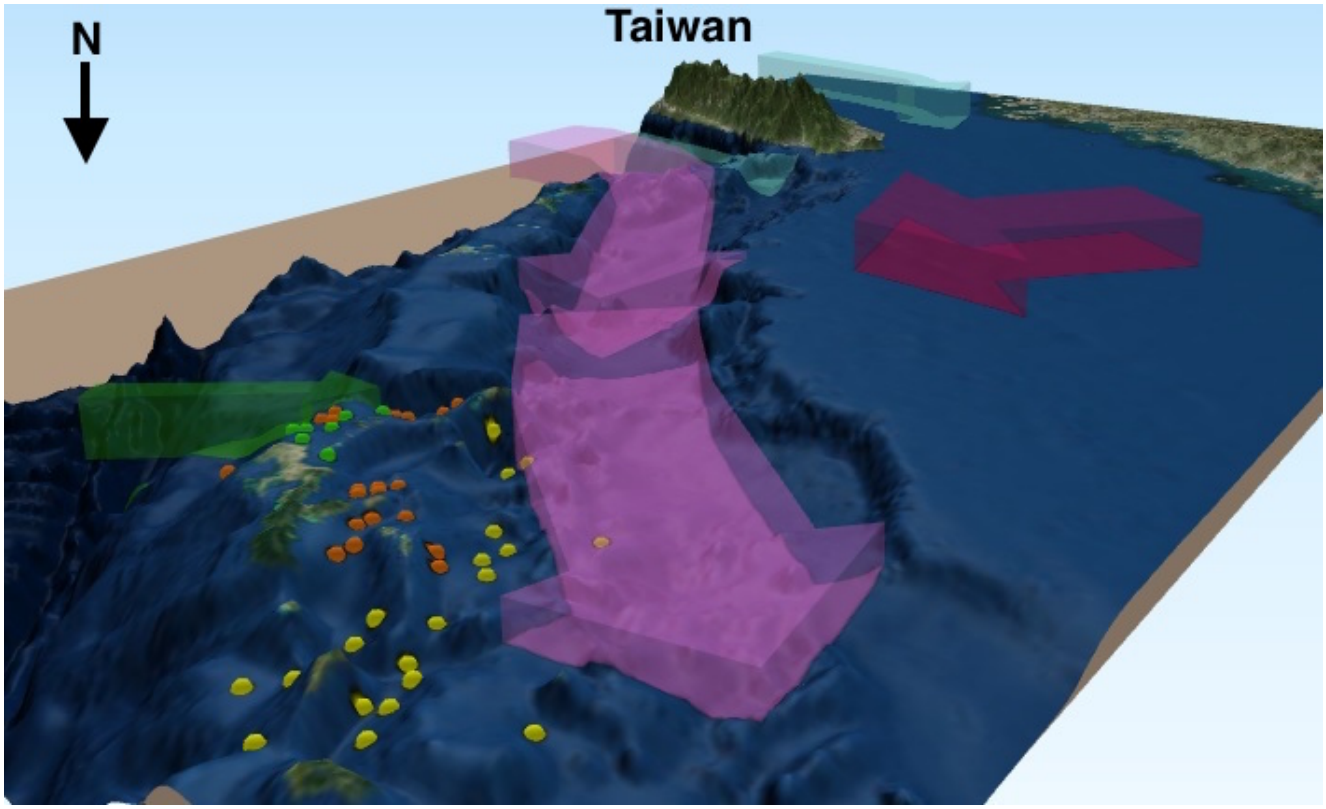

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[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS08] Paleoclimatology and paleoceanography

convener:Yusuke Okazaki(Department of Earth and Planetary Sciences, Graduate School of Science, Kyushu University), Benoit Thibodeau(University of Hong Kong), Akitomo Yamamoto(Japan Agency for Marine-Earth Science and TechnologyAtmosphere and Ocean Research Institute), Hitoshi Hasegawa(Faculty of Science and Technology, Kochi University)

Past environmental changes and events at multi-decadal to tectonic timescale toward an understanding of Earth climate system by an integration of terrestrial and marine proxy studies and numerical modeling will be discussed. This session includes a special series of presentations on the ocean circulation under climate change in the past, present and future relating to MOC, ventilation and hypoxia. We welcome a variety of paleo-environmental studies from a wide range of background. We hope that this session will provide an opportunity to promote communication between participants from multidisciplinary field.

[MIS08-12] Ecosystem response to Cretaceous OAEs - the continental perspective

★Invited Papers

*Ulrich Heimhofer[1] (1.Leibniz University Hannover, Germany)

[MIS08-13] Carbon and hydrogen isotopes of C_{40} alkenones and C_{41} *n*-alkane from OAE2 interval of IODP Site U1516 in southern high latitude

*Takashi Hasegawa[1], Akiko S. Goto[1] (1.Faculty of Geoscience and Civil Engineering, Institute of Science and Engineering, Kanazawa University)

[MIS08-14] Millennial-scale climate instability in ‘hothouse’ state: implication from mid-Cretaceous and Quaternary lacustrine records in Mongolia

*Hitoshi Hasegawa[1] (1.Faculty of Science and Technology, Kochi University)

[MIS08-15] The history of Earth's biospheric productivity: a biogeochemical modeling perspective

★Invited Papers

*Kazumi Ozaki[1] (1.Toho University)

Ecosystem response to Cretaceous OAEs - the continental perspective

*Ulrich Heimhofer[1]

1. Leibniz University Hannover, Germany

Cretaceous oceanic anoxic events (OAEs) were marked by persistent marine anoxia–euxinia and globally significant burial of sedimentary organic matter (‘black shales’), associated with major perturbations of the global carbon cycle and likely linked to LIP volcanism. The most pronounced and widespread events are the Early Aptian OAE1a (~121 Ma) and Cenomanian-Turonian OAE2 (~94.5 Ma), both of which were associated with hyperthermal conditions, i.e. significant sea-surface temperature (SST) warming in the range of several degrees. Warm ocean surface and bottom waters in combination with attenuated meridional temperature gradients resulted in reduction of an already sluggish oceanic circulation and were an important driver of organic-carbon accumulation in the world oceans during OAEs.

Despite significant progress in our understanding of the causes and consequences of Cretaceous OAEs in the marine realm, information on the response of continental ecosystems is scarce. Due to the absence of OAE-equivalent continental sequences, the response of terrestrial vegetation can only be studied from palynological assemblages retrieved from marine strata. At present, available spore-pollen OAE records are exclusively derived from northern hemisphere mid-latitude sites located in the western Tethys region.

For the Early Aptian OAE1a, continuous and taxonomically differentiated palynological data-sets are restricted to core and outcrop material from the Belluno (Italy) and Maestrat basins (Spain). Existing records show similar stratigraphic trends in spore-pollen assemblages with a marked increase in thermophile and drought-adapted conifer pollen (*Classopollis* spp.) at the very onset of the OAE1a, followed by a stepwise decline during the main phase of organic carbon accumulation. Above the organic-rich interval, the assemblage is characterized by dominance of bisaccate (Belluno Basin) or araucaria-type (Maestrat Basin) conifer pollen interpreted to reflect subsequent cooling in the aftermath of OAE1a.

Spore-pollen data covering the Cenomanian-Turonian OAE2 interval is reported from the Southern Provencal Basin (France) and Iberian Trough (Spain). In contrast to the gymnosperm-dominated vegetation of the Early Aptian, early Late Cretaceous mid-latitude vegetation already contains significant amounts of angiosperms (dominantly Normapolles-type forms). In the Southern Provencal Basin, combined evidence from TEX_{86} analyses and spore-pollen assemblages documents the dynamics of mid-latitude vegetation to the hyperthermal conditions associated with OAE2. A transient phase of climatic instability and cooling during the exceptionally warm OAE2 episode is marked by the proliferation of open, savanna-type vegetation rich in angiosperms at the expanse of conifer-dominated forest ecosystems.
Despite the exceptionally warm temperature estimates characterizing both mid-Cretaceous OAEs, the continental hinterland (i.e. the palaeo-European archipelago) supported a rich and diverse vegetation, adapted to persist under elevated temperatures. Life-limiting conditions for plant growth due to heat stress associated with OAEs might have persisted in continental interior regions of the subtropics or close to the equator. The changes in terrestrial vegetation observed across the mid-Cretaceous OAEs indicate that volcanogenic global warming severely impacted continental ecosystems resulting in significant compositional and ecological changes and highlight the importance of deep-time data in assessing long-term vegetation response to global climate warming.

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Keywords: Cretaceous, palynology, oceanic anoxic events, hyperthermal, vegetation

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Carbon and hydrogen isotopes of C_{40} alkenones and C_{41} *n*-alkane from OAE2 interval of IODP Site U1516 in southern high latitude

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Coisiderable concentrations of C_{40} alkenones (tetracontadienones) and C_{41} normal alkane (n-alkane) were observed in black shale sediments from Oceanic Anoxic Event 2 interval of IODP Site U1516 in Southern high latitude. About five permil difference of carbon isotope values of the molecules indicates that they have separate origins. The carbon isotope stratigraphy of the C_{40} alkenones shows ~2.5-3 permil increase in the expected interval of well known carbon isotope excursion for OAE2, filling gap of a carbonate-free interval. Although its origin is not identified yet, C_{41} n-alkane marks the highest concentration among detected n-alkanes in some samples and has characteristic carbon and hydrogen isotope values. The carbon isotope value ranging between -34 and -36 permil is not comparable to that of higher plant-derived C_{29} n-alkane (between -26 and -30 permil) or algal C_{18}-C_{20} n-alkanes (between -29 and -32 permil). Although its long and straight-chained structure comparable with C_{40} alkenones and their co-occurrences, C_{41} n-alkane cannot be a derivative of the alkenones. Carbon isotope values of the alkenones are largely different from that of C_{41} n-alkane and rather close to that of terrestrial or algal n-alkanes. On the other hand, hydrogen isotope values of C_{40} n-alkane are close to that of algal n-alkanes suggesting similar hydrological setting of their syntheses. Both C_{40} alkenones and C_{41}n-alkane show high concentration only in the black layers in the OAE2 interval. As source rock analysis by the on-board scientists showed high hydrogen index (HI) for the black mudstone layers from OAE2 interval, both C_{41} n-alkane and C_{40} alkenones are interpreted to be algal in origin. It is concordant with the expected origin of long chain alkenones (haprophytes). It should also be noted that the concentration of n-alkanes derived from higher plants (C_{27}, C_{29} and C_{31} n-alkanes) are also high in the black layers implying productivity not only of sea surface but also of land area both increased.

Keywords: OAE, Cretaceous, IODP, carbon isotope, hydrogen isotope, alkenone

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Millennial-scale climate instability in ‘hothouse’ state: implication from mid-Cretaceous and Quaternary lacustrine records in Mongolia

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Understanding of past climate variability and stability under exceptionally warm ‘hothouse’ conditions is essential for future climate projections. An annually laminated lacustrine record of Early Aptian (ca. 123–119 Ma) in southeast Mongolia provides evidence of millennial-scale extreme drought events during the mid-Cretaceous, resembling the abrupt climate fluctuations during the last glacial (e.g., Dansgaard-Oeshger cycle). We also present evidence of drastic environmental change during the last glacial from two lake sediment records in northern and southern Mongolia. Our findings, in conjunction with comparison of last glacial records, point to a previously unidentified mode of millennial-scale climate instability in the polar-ice-free ‘hothouse’ state. This climate instability is likely linked to reduced high-latitude ocean ventilation and switching of deep-water formation sites.

Keywords: Climate instability, hothouse, mid-Cretaceous

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The history of Earth's biospheric productivity: a biogeochemical modeling perspective

*Kazumi Ozaki[1]

1. Toho University

The modern Earth's biosphere is powered by the oxygenic photosynthesis, which can extract electrons from ubiquitous water molecules, maintaining a large net primary production (NPP) of ~100 Gt C every year. So productive are the effects of life itself on this planet that they bootstrap themselves into a highly productive state through recycling the materials, with the result that life plays a critical role in the chemical composition of the atmosphere. Perhaps even more remarkably, the interplay between life and the atmosphere has been occurring continuously for nearly 4 billion years and will continue to the future. However significant gaps remain in our mechanistic understanding of Earth's atmospheric evolution, and in particular the cause-and-effect relationships with evolving biosphere. Here, I use a suite of biogeochemical models to evaluate the history of the activity level of the biosphere. First, I employ the simple Earth system model of biogeochemistry (CANOPS) in order to constrain the oceanic biological productivity during the mid-Proterozoic. Using a stochastic approach (Monte Carlo simulation) with existing constraints on seawater SO_4^{2-} levels, NPP was estimated at 22^{+18}_{-10}% (1*sigma*) of the present value, providing a simple explanation for the protracted oxygenation of the Earth's atmosphere. Our model requires a scarcity of the primary nutrient (phosphorus) in the ocean interior (<~10% of the present value). While our results provide a comprehensive and statistically robust picture of the mid-Proterozoic Earth system that is consistent with available geologic records, further mechanistic understanding of the P cycle in the anoxic oceans is required to fully understand the stabilization mechanism of atmospheric O_2 during the Proterozoic. Next, a simplified photochemistry-ocean ecosystem model is employed to evaluate productivity on the early Earth before the advent of oxygenic photosynthesis. The results suggest that NPP was ~0.1% and 1% that of the modern Earth for non-photosynthetic (chemotrophic) biosphere and anoxygenic photosynthetic biosphere, respectively. The extremely low NPP fluxes produced by our model imply that the geological fluxes of reductants, rather than light or nutrients, would have been the limiting factor for biological productivity. Our biogeochemical models suggest that the Earth's biosphere overcame limitations for their activity through Earth history and have affected the chemical composition of the atmosphere.

Keywords: Net Primary Production, Biogeochemical cycles, Earth history

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[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS08] Paleoclimatology and paleoceanography

convener:Yusuke Okazaki(Department of Earth and Planetary Sciences, Graduate School of Science, Kyushu University), Benoit Thibodeau(University of Hong Kong), Akitomo Yamamoto(Japan Agency for Marine-Earth Science and TechnologyAtmosphere and Ocean Research Institute), Hitoshi Hasegawa(Faculty of Science and Technology, Kochi University)

Past environmental changes and events at multi-decadal to tectonic timescale toward an understanding of Earth climate system by an integration of terrestrial and marine proxy studies and numerical modeling will be discussed. This session includes a special series of presentations on the ocean circulation under climate change in the past, present and future relating to MOC, ventilation and hypoxia. We welcome a variety of paleo-environmental studies from a wide range of background. We hope that this session will provide an opportunity to promote communication between participants from multidisciplinary field.

[MIS08-16] Change in the Atlantic Meridional Overturning Circulation over the last 1,500 years

★Invited Papers

*Benoit Thibodeau[1] (1.The University of Hong Kong, Division of Earth and Planetary Sciences & SWIRE Institute of Marine Science)

[MIS08-17] Simulating the Atlantic Meridional Overturning Circulation of the glacial period with comprehensive climate models

★Invited Papers

*Sam Sherriff-Tadano[1] (1.Atmosphere and Ocean Research Institute, the University of Tokyo)

[MIS08-18] **Deglacial productivity changes reflect XRF Br fueled by Cordilleran Ice Sheet dynamics**

*Md Nurunnabi Mondal[1], Keiji Horikawa[2], Katsuya Nejigaki[3], Hideki Minami[4], Masafumi MURAYAMA[5], Osamu Seki[6], Yusuke Okazaki[7] (1.a. Graduate School of Science and Engineering for Education, University of Toyama, Japan, b. Department of Fisheries Management, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Bangladesh, 2.Graduate School of Science and Engineering for Research, University of Toyama, Japan, 3.Graduate School of Integrated Arts and Sciences, Kochi University, Japan, 4.School of Biological Science and Engineering, Tokai University, Japan, 5.Faculty of Agriculture and Marine Science, Kochi University, Japan, 6.Institute of Low Temperature Science, Hokkaido University, Japan, 7.Graduate School of Science, Kyushu University, Japan)

[MIS08-19] Ventilation change in the southern Bering Sea since the last glacial maximum

*Yusuke Okazaki[1], Hirofumi Asahi[2] (1.Department of Earth and Planetary Sciences, Graduate School of Science, Kyushu University, 2.Center for Advance Marine Core Research, Kochi University)

Change in the Atlantic Meridional Overturning Circulation over the last 1,500 years

*Benoit Thibodeau[1]

1. The University of Hong Kong, Division of Earth and Planetary Sciences & SWIRE Institute of Marine Science

The Atlantic meridional overturning circulation (AMOC) is a key component of the global climate system as it transports warm waters to the high latitudes which allow the formation of intermediate and deep Atlantic water masses. Models have predicted a slowdown, or even a collapse of the AMOC under global warming and increased freshwater flux. While some field data are available for the last decade, they do not provide the perspective required to evaluate the present state of AMOC against its natural variability. Moreover, until recently the intensity of the AMOC beyond the last century was mostly unknown, which also limited our understanding of the present state of the AMOC. Over the past year research groups managed to develop paleo reconstruction of the AMOC strength and highlighted the fact that the 20th century AMOC is significantly weaker than it was over the last millennium (Rahmstorf et al., 2015; Thibodeau et al., 2018) and that this weakening is of unprecedented amplitude over this period (Caesar et al., 2018; Thibodeau et al., 2010).

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Rahmstorf, S., Box, J.E., Feulner, G., Mann, M.E., Robinson, A., Rutherford, S., Schaffernicht, E.J., 2015. Exceptional twentieth-century slowdown in Atlantic Ocean overturning circulation. Nat. Clim. Chang. 5, 475–480. https://doi.org/10.1038/nclimate2554

Thibodeau, B., de Vernal, A., Hillaire-Marcel, C., Mucci, A., 2010. Twentieth century warming in deep waters of the Gulf of St. Lawrence: A unique feature of the last millennium. Geophys. Res. Lett. 37. https://doi.org/10.1029/2010GL044771

Thibodeau, B., Not, C., Zhu, J., Schmittner, A., Noone, D., Tabor, C., Zhang, J., Liu, Z., 2018. Last Century Warming Over the Canadian Atlantic Shelves Linked to Weak Atlantic Meridional Overturning Circulation. Geophys. Res. Lett. 45, 12,376-12,385. https://doi.org/10.1029/2018GL080083

Keywords: AMOC, Stable Isotope, Geochemistry, Climate Change

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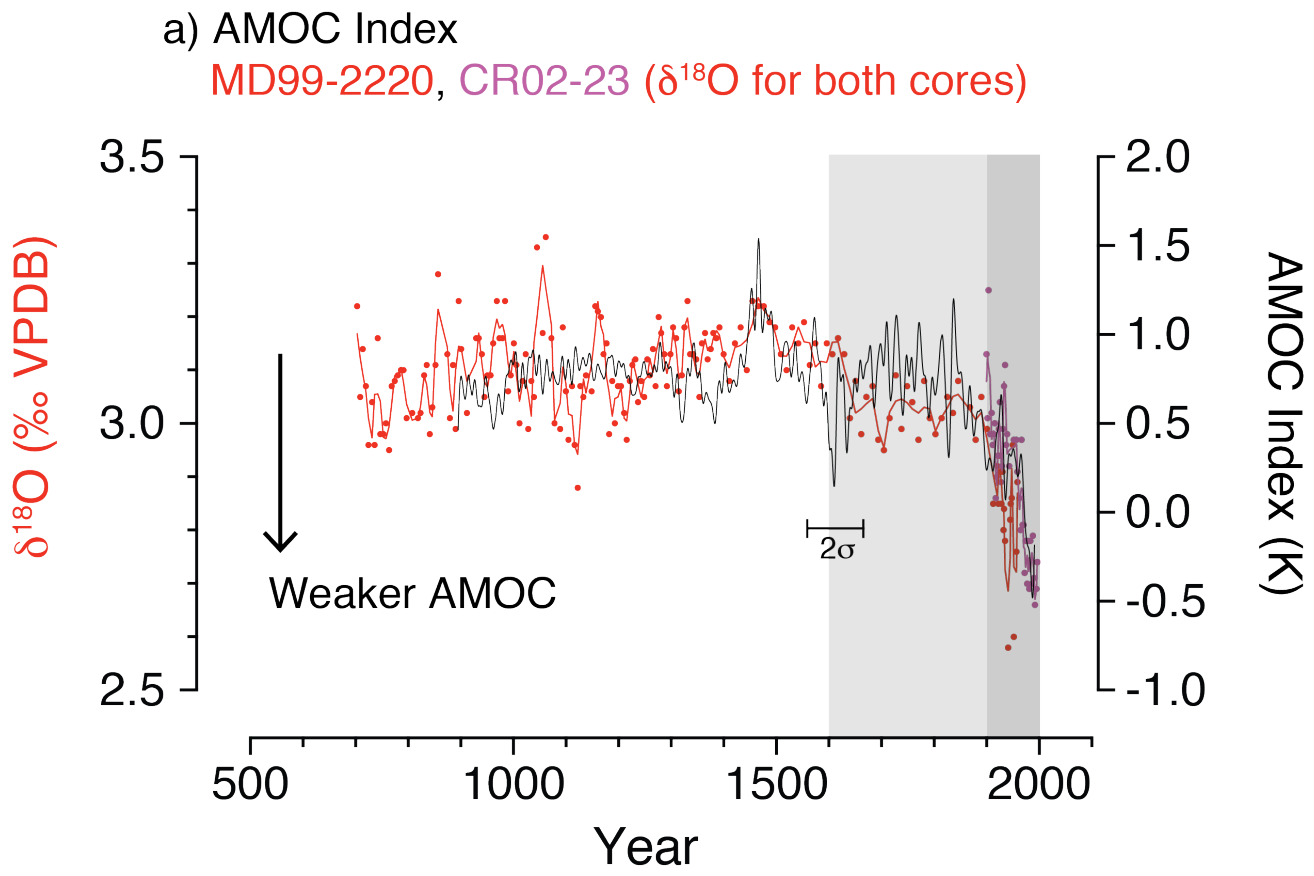

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Simulating the Atlantic Meridional Overturning Circulation of the glacial period with comprehensive climate models

*Sam Sherriff-Tadano[1]

1. Atmosphere and Ocean Research Institute, the University of Tokyo

The Atlantic Meridional Overturning Circulation (AMOC) plays a critical role on the climate system through its impact on heat transport and carbon cycle. There are abundant evidences from sediment cores showing a drastic reorganisation of the AMOC during the past glacial period. Especially at the Last Glacial Maximum (LGM), it has been shown that the AMOC has shoaled compared with that of the modern, and that the North Atlantic Deep Water was replaced by the southern sourced bottom water. Along with the proxy studies, many efforts have been maid in the modelling community in simulating the AMOC at the LGM to understand the dynamics of the glacial AMOC. However, most comprehensive climate models simulated a deepening of the AMOC, which contradicts the proxy evidences. In this presentation, the author will review previous climate modelling studies of the LGM AMOC and their recent progresses. A particular focus will be paid upon the roles of glacial ice sheets and Southern Ocean on the AMOC, both of which are key components in understanding the glacial AMOC.

Keywords: AMOC, Climate model, LGM

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Deglacial productivity changes reflect XRF Br fueled by Cordilleran Ice Sheet dynamics

*Md Nurunnabi Mondal[1], Keiji Horikawa[2], Katsuya Nejigaki[3], Hideki Minami[4], Masafumi MURAYAMA[5], Osamu Seki[6], Yusuke Okazaki[7]

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During the last deglaciation, the Cordilleran Ice Sheet (CIS) was rapidly melted and supplied a huge amount of meltwater to the coastal areas in the northeast Pacific. The timing of decay of the CIS and its impact on productivity in adjacent coastal areas in the northeastern North Pacific is not well known and has been under investigation. Here, to further constrain the timing of decay of the CIS and its impact on productivity, we generated high-resolution XRF core scanner data together with a multiple set of destructive geochemical data, such as planktonic foraminiferal oxygen and carbon isotope, and Sr-Nd-Pb isotopes of bulk sediments from core CL14PC in the Gulf of Alaska (59˚ 33.35´N, 144˚ 09.35´W, water depth 690 m), the northeastern Pacific.

We found that δ^{18}O of both -*Neogloboquadrina pachyderma* (sinistral) and *Globigerina bulloides* gradually decreased at ~16.7 cal ka BP and then sharply decreased at 14.8 cal ka BP, corresponding to the onset of the Bølling-Allerød. Before the onset of the Bølling-Allerød, there were three pronounced IRD (ice-rafted debris) layers at ~16.49, ~16.17 and ~15.65 cal ka BP, suggesting that gradual warming conditions might have caused multistep collapses of the coastal ice lobes of the CIS. However, lower TOC, higher organic carbon/total nitrogen ratios during this period indicate lower primary productivity. Probably, lower temperatures, increased water turbidity, and increased stratification should be the key variables for suppressing primary productivity.

During the Bølling-Allerød (14.8–13.0 cal ka BP) and the early Holocene (Preboreal, 11.7–10.8 cal ka BP), both foraminiferal δ^{18}O records decreased, with exhibited prominent peaks up to 1.9 ‰and 1.88 ‰at 14.57 cal ka BP, and 1.93‰ and 1.65‰ at 14.14 cal ka BP (may reflect two discrete episodes of very high meltwater input) for *N. pachyderma* (sinistral) and *G.bulloides*, respectively, suggesting that increased temperature and low salinity, and due to the abrupt warming during this period triggered rapid decay of the CIS and discharges of meltwater. The fact that XRF Br counts are highly correlated with TOC contents in our core supports that Br counts can be used as a proxy of productivity. The high-resolution Br counts and TOC data showed high productivity at 14.8–13.0 cal ka BP and 11.7–10.8 cal ka BP corresponding to the regional expressions of Bølling-Allerød and Preboreal, respectively.

Keywords: Paleoproductivity, XRF Br, Meltwater, Cordilleran Ice Sheet, Gulf of Alaska, Deglaciation

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Ventilation change in the southern Bering Sea since the last glacial maximum

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1. Department of Earth and Planetary Sciences, Graduate School of Science, Kyushu University, 2. Center for Advance Marine Core Research, Kochi University

From the last glacial maximum to the early deglacial period between 18 and 15 ka, corresponding to Heinrich Stadial 1, well-ventilated watermass down to ~2000 m was reconstructed in wide are of the western North Pacific. The potential ventilation sources are the Bering Sea and the Okhotsk Sea, both are marginal seas of the subarctic Pacific. To constrain the ventilation source, we reconstructed the ventilation record of deep water at 2400 m depth on the Bowers Ridge in the southern Bering Sea. over the past 25 kyr from radiocarbon measurements of coexisting planktic and benthic foraminiferal shells in sediment. Sediment core BOW-9A was obtained during KH99-3 cruise by R/V Hakuho-maru in summer 1999. The Δ14C changes were consistent with the atmospheric record, suggesting that no massive mixing of old carbon from the abyssal reservoir occurred throughout the glacial to deglacial periods. During Heinrich stadial 1, the Δ14C activity did not show enhanced ventilation during the early deglacial period between 18 and 15 ka, corresponding to Heinrich Stadial 1. This suggests that the early deglacial ventilation source of the North Pacific was not the Bering Sea but the Okhotsk Sea.

Keywords: ventilation, Bering Sea, glacial termination

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[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS08] Paleoclimatology and paleoceanography

convener:Yusuke Okazaki(Department of Earth and Planetary Sciences, Graduate School of Science, Kyushu University), Benoit Thibodeau(University of Hong Kong), Akitomo Yamamoto(Japan Agency for Marine-Earth Science and TechnologyAtmosphere and Ocean Research Institute), Hitoshi Hasegawa(Faculty of Science and Technology, Kochi University)

Past environmental changes and events at multi-decadal to tectonic timescale toward an understanding of Earth climate system by an integration of terrestrial and marine proxy studies and numerical modeling will be discussed. This session includes a special series of presentations on the ocean circulation under climate change in the past, present and future relating to MOC, ventilation and hypoxia. We welcome a variety of paleo-environmental studies from a wide range of background. We hope that this session will provide an opportunity to promote communication between participants from multidisciplinary field.

[MIS08-21] Planktonic foraminiferal analysis of the Plio-Pleistocene sequence at IODP Site U1499: Response of the northern South China Sea environment to the intensity of the East Asian monsoon after Pliocene

*Mizuki Kitamura[1], Akira Furusawa[1], Hiroki Hayashi[1] (1.SHIMANE University)

[MIS08-22] Rapid and precise carbon dioxide clumped isotope composition analysis by tunable infrared laser differential absorption spectroscopy

*David L Dettman[1], Zhennan Wang[1], Jay Quade[1], David D Nelson[2], J Barry McManus[2], Katharine W Huntington[3], Andrew J Schauer[3], Saburo Sakai[4] (1.Univ. of Arizona, Dept. of Geosciences, 2.Aerodyne Research Inc., Boston, Massachusetts, 3.Univ. of Washington, Dept. of Earth and Space Sciences, 4.Japan Agency for Marine-Earth Science and Technology, Inst. of Biogeochemistry)

[MIS08-23] Holocene biomass burning history reconstructed from the Lake Suigetsu sediments

*Song Lu[1], Yoshie Nakai[1], Youhei Yamashita[2], Tomohisa Irino[2], Yuzo Miyazaki[3], Ryuji Tada[4], Takeshi Nakagawa[5] (1.Graduate School of Environmental Science, Hokkaido University , 2.Faculty of Environmental Earth Science, Hokkaido University, 3.Institute of Low Temperature Science, Hokkaido University , 4.Department of Earth and Planetary Science , Graduate School of Science, The University, of Tokyo , 5.Research Center for Palaeoclimatology, Ritsumeikan University)

[MIS08-24] Pollen isotope records from Lake Suigetsu, Japan

★Invited Papers

*Keitaro Yamada[1], Takayuki Omori[2], Ikuko Kitaba[3], Yamasaki Akiteru[4], Takeshi Nakagawa[3] (1.Research Organization of Science and Technology, Ritsumeikan University, 2.The University Museum, The University of Tokyo, 3.Research Centre for Palaeoclimatology, Ritsumeikan University, 4.Fukui Prefectural Satoyama-Satoumi Reserch Institute)

Planktonic foraminiferal analysis of the Plio-Pleistocene sequence at IODP Site U1499: Response of the northern South China Sea environment to the intensity of the East Asian monsoon after Pliocene

*Mizuki Kitamura[1], Akira Furusawa[1], Hiroki Hayashi[1]

1. SHIMANE University

The South China Sea (SCS) is a marginal sea located in the tropical zone of the western Pacific. The East Asian monsoon affects the climate system in this area by the prevailing seasonal winds. Such influence of the East Asian monsoon is expected to be stronger during the glacial period and weaker during the interglacial period. During the IODP Exp. 367, drilling of Site U1499 was conducted near the outer shelf of the northern SCS in 2017. As an onboard result of this site, sediments from Oligocene to Present were recovered and the upper sequence especially contains abundant foraminiferal fossils. Kitamura et al. (2018, JpGU) examined the planktonic foraminiferal assemblage of the stratigraphic interval from approximately 4 to 1 Ma at this site and reconstructed the water mass changes. As a result, they reported a remarkable increase of cold-water species at approximately 1.4 Ma. However, several previous studies on SCS indicated that a big change of planktonic foraminiferal assemblage occurred in the Mid-Pleistocene Transition (MPT). Recently, the age-depth model of the present site has been refined by an astronomical tuning study. Then, it needs further reevaluations of the significance of the planktonic foraminiferal change in the upper part of Site U1499. The purpose of the present study is to clarify temporal changes of the planktonic foraminiferal assemblage from approximately 5 Ma to present and evaluate the coastal upwelling in the northern SCS associated with the intensity of the East Asian winter monsoon associated with the glacial-interglacial changes. As a preliminary result, 85 species belonging to 19 genera of planktonic foraminifera were detected from 30X-7W to 12H-1W (ca. 4.55 to 1.17 Ma). According to multivariate analyses of the foraminiferal assemblage, we determined the temporal change into four stages: Stage A (ca. 4.5 to 4.0 Ma), Stage B (ca. 3.3 to 2.5 Ma), Stage C (ca. 2.0 to 1.5 Ma) and Stage D (ca. 1.5 to 1.2 Ma). The species composition of Stage A implies that the oceanographic condition of that time was characterized by highly stratified ocean. At the next Stage B, the thermocline was deepened and SCS was occupied by a subtropical oligotorophic water. In turn, relatively cold components of planktonic foraminifera were increased during the Stage C. This change might correspond to the global cooling of the Pliocene and Pleistocene boundary. After that, the Stage D is characterized by alternative changes between subtropical surface components and cold-temperate components caused by the glacial-interglacial changes.

Keywords: South China Sea, East Asian monsoon, Planktonic foraminifera, International Ocean Discovery Program

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Rapid and precise carbon dioxide clumped isotope composition analysis by tunable infrared laser differential absorption spectroscopy

*David L Dettman[1], Zhennan Wang[1], Jay Quade[1], David D Nelson[2], J Barry McManus[2], Katharine W Huntington[3], Andrew J Schauer[3], Saburo Sakai[4]

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Carbon dioxide clumped isotope thermometry is a relatively new and important technique in carbonate isotope geochemistry. The degree of heavy isotope clumping (e.g., $^{16}O^{13}C^{18}O$) beyond an expected random distribution can be related to the temperature of calcite precipitation. Unlike carbonate "paleotemperature" calculations, there is no need to constrain the isotopic composition of the water in which the carbonate grew. In addition, the independent temperature estimate, when combined with carbonate $\delta^{18}O$ values, allows us to constrain paleowater $\delta^{18}O$ values. However, the use of isotope ratio mass spectrometry (IRMS) to do these measurements remains relatively rare because it is time-consuming and costly. We have developed an isotope ratio laser spectrometry method using tunable infrared laser differential absorption spectroscopy (TILDAS) and describe our latest results using both gaseous carbon dioxide samples and CO_2 derived from carbonate minerals. The TILDAS instrument has two continuous wave lasers to directly and simultaneously measure four isotopologues involved in the $^{16}O^{13}C^{18}O$ equilibrium calculation. Because each isotopologue is independently resolved, this approach does not have to correct for isobaric peaks, i.e. separate families of absorbance peaks exist for $^{16}O^{13}C^{18}O$ and $^{17}O^{12}C^{18}O$, even though both molecules have a mass of 47 AMU. The gas samples are trapped in a low volume (~250 ml) optical multi-pass cell with a path length of 36 meters. Raw data are collected at 1.6 kHz, providing 96,000 peak-area measurements of each CO_2 isotopologue per minute. With a specially designed sampling system, each sample measurement is bracketed with measurements of a working reference gas, and a precision of 0.01‰ is achieved within 20 minutes, based on four repeated measurements. The total sample size needed for a complete measurement is approximately 15 μmol of CO_2, or 1.5 mg of calcite equivalent. TILDAS reported $\Delta_{16O13C18O}$ values show a linear relationship with theoretical calculations, with a very weak dependence on bulk isotope composition. The performance of the TILDAS system demonstrated in this study is competitive with the best IRMS systems and surpasses typical IRMS measurements in several key respects, such as measurement duration and isobaric interference problems. This method can easily be applied more widely in stable isotope geochemistry by changing spectral regions and laser configurations, leading to rapid and high precision (0.01‰) measurement of conventional stable isotope ratios and $\delta^{17}O$ in CO_2 gas samples.

Keywords: clumped isotope, isotopologue, carbonate thermometry

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Holocene biomass burning history reconstructed from the Lake Suigetsu sediments

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Behavior of black carbon (BC) is crucial for the earth surface environment because it could cause global warming by absorbing sunlight in the atmosphere. BC is originated from incomplete combustion of biomass or fossil fuels. Combustion in natural processes is incomplete due to local limitation of oxygen during the fire, which leads to the formation of organic fire residues. As burning (or pyrolysis) is a continuous process, it results in different types of compounds with no clear boundaries, and also no single defined structure. Depending on the degree of combustion, these organic fire residues can be called: elemental carbon (EC), soot, black carbon (BC), and charcoal. Although biomass burning is related to the volume of vegetation, frequency of ignition events, connectivity of the fuel bed, and human activities would be a main determining factor. Therefore, biomass burning history in the Holocene time-scale is important for researches of climate change as well as the related past human activities revealed from archaeology.

Observed degradation rates of BC in the natural environment are much lower than those of the organic carbon. Increasing the fire temperature of the biomass burning leads to a decrease of BC degradability due to higher degree of condensation of hydrocarbons. Even under the strong weathering condition in the tropical climate, EC can be stable for more than a century. Although the previous fire researches (paleoclimate rather than modern ecology) reconstructed the amount of BC or charcoals from sediments, the temperature of BC formation has not been discussed well.

Objective of this study is understanding the controlling factors of the thermal character of BC such as aging and provenance in relation to the variabilities of vegetation and human activity in the hinterland as well as burning temperature. For this purpose, BC in the bulk samples are determined with thermal optical transmittance and benzene polycarboxylic acid methods for SG-12 core sediments collected from the Lake Suigetsu. Preliminary results show that fire temperature of soot was higher during stronger East Asian summer monsoon periods for the last 15 kyr.

Keywords: Biomass burning, Thermal optical transmittance, Benzene polycarboxylic acid, Lake Suigetsu

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Pollen isotope records from Lake Suigetsu, Japan

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Interactions of atmosphic, marine, terrestrial, and cryospheric realms are important factors in considering mechanisms of climate change (Lowe et al., 2008). Climatic leads and lags between these realms are keys to understand triggers and responses of climate change. Pollen analysis is one of the most widely used methods to provide terrestrial proxy (e.g. IPCC, 2013). However, vegetation sometimes responds with inertia to the climate change, which implies that the obtained terrestrial proxy based on pollen assemblage potentially contain lags (e.g. Williams et al., 2002).

Stable isotope analysis can be a solution to this issue. Fossil pollen grains are composed of extremely chemically inert biopolymer of sporopollenin including carbon, oxygen and hydrogen (e.g. Li et al., 2019) and potentially provides isotopic signals which has applications within palaeoclimatology (Loader and Hemming, 2004). In spite of these potentials, pollen isotope analysis had not been used routinely due to the difficulty of high-purity extraction of fossil pollen grains from sediments. In order to solve this problem, in this study, we established a method to extract fossil pollen grains using cell sorter and measured pollen stable isotope ratios. We then tested the method with the varved sediments from Lake Suigetsu, Japan.

Lake Suigetsu (35˚35'N, 135˚53'E, 0 m a.s.l.), Fukui prefecture, central Japan, is one of Mikata Five lakes, which measures 3 km east-west by 3 km north-south and the maximum water depth of ca. 34 m. Lake Suigetsu preserves annually laminated sediments over the last ca.70 kyr with a significant number of event layers. Two long cores (SG93, SG06) have previously been recovered from the centre of the lake (Takemura et al., 1993; Nakagawa et al., 2012) and an exceptionally precise age model has been established for the cores through a combination of over 800 radiocarbon ages and high precision varve counting (Staff et al., 2011; Marshall et al., 2012; Schlolaut et al., 2012; Bronk Ramsey et al., 2012; Schlolaut et al., 2018).

In this study, we extracted pollen fossils from the well-dated SG06 cores using cell sorter. Cell sorter is able to separate specified particles using electrostatic deflection using differences in size, shape, and fluorescence as diagnostic keys. Pollen fossils can be sorted using cell sorter because sporopollenin which constitute fossil pollen grains are naturally auto-fluorescent (Tennant et al., 2013). After pre-treatments with acid, alkali, heavy media, and sieves, pollen-enriched suspension was introduced into cell sorter to make high-purity pollen pellets. In this study, we collected about half a million grains of pollen per sample. After drying and weighing, $\delta^{18}O$ of the pollen pellets were measured using High Temperature Conversion Elemental Analyzer (TC/EA, Thermo Scientific) in the University of Tokyo.

Pollen grains were extracted at >98% purity (based on number of particles) and were composed of multiple pollen species. The percentage ratios of pollen types were distorted after extraction by cell sorter, but the major components as well as their relative dominance stayed similar. We measured $\delta^{18}O$ of more than 40 such highly concentrated pellets of fossil pollen grains. Pollen $\delta^{18}O$ fluctuates in rough synchronism with those of NGRIP and Hulu Cave. However, pollen $\delta^{18}O$ values are inversely correlated with Hulu $\delta^{18}O$ and have much larger amplitude. The isotope fractionation mechanism of pollen $\delta^{18}O$ is not yet fully understood. However, these results indicate that pollen isotopic changes have potential to

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become sensitive indicator of past terrestrial climate. Investigating correlation between modern pollen isotope values and instrumentally observed weather/climate, as well as species-dependencies, is the next step towards more robust interpretation of the pollen $\delta^{18}O$ fluctuations.

Keywords: Pollen, flow cytometer, stable isotope, Lake Suigetsu, varve

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[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS09] Interdisciplinary studies on pre-earthquake processes

convener:Katsumi Hattori(Department of Earth Sciences, Graduate School of Science, Chiba University), Dimitar Ouzounov(Center of Excellence in Earth Systems Modeling & Observations (CEESMO) , Schmid College of Science & Technology Chapman University, Orange, California, USA), Jann-Yenq LIU(Department of Space Science and Engineering, National Central University, Taiwan), Qinghua Huang(Peking University)

This session expands the interdisciplinary discussions on preparation process of earthquake and earthquake predictability by presenting the latest progress in studying the physically based pre-earthquake phenomena. New observations from space and ground have provided evidences, which may enhance better understanding of tectonic activity. The session anticipates talks that include but not limited to observations and analyses of seismic, electrical, electromagnetic, electro-chemical and thermodynamic processes related to stress changes in the lithosphere along with their statistical and physical validation. Presentations on the latest observational results associated with major earthquakes obtained by different methodologies are welcomed. The topics of the session are as follows but not limited.

 -General discussion on earthquake preparation process and the physics of pre-earthquake signals
 - Theory, modeling, laboratory experiments, computational simulation for generation and propagation of pre-earthquake signals and their connection with seismic cycle
 - Multi-parameter observations, detection, and validation of pre-earthquake signals
 - Cross-disciplinary studies, practical and technical approaches for better understanding of earthquake preparation processes and their connection with seismicity

[MIS09-01] Prediction of Geomagnetic Daily Variations

*Suqin Zhang[1] (1.Institute of Geophysics, China Earthquake Administration)

[MIS09-02] **Evaluation of the 2017 *M* 6.6 Jinghe earthquake epicenter based on the Parkinson vector**

*aisa yisimayili[1,2], Chieh-Hung Chen[1], Zhiqiang Mao[1] (1.China University of Geosciences, 2.Earthquake Agency of Xinjiang Uygur Autonomous Region)

[MIS09-03] Seismogenic structures in western Yunnan revealed by three-dimensional magnetotelluric imaging

Tao Ye[1,2], Xiaobin Chen[2], *Qinghua Huang[1] (1.Peking University, 2.Institute of Crustal Dynamics, China Earthquake Administration)

[MIS09-04] **Seismo-conductivity anomaly associated with the 2017 M_S 7.0 Jiuzhaigou earthquake**

*Zhiqiang Mao[1], Chieh-Hung Chen[1], Suqin Zhang[2], Aisa Yisimayili[3] (1.China University of Geosciences, 2.Institute of Geophysics, China Earthquake Administration, 3.Earthquake Agency of Xinjiang Uygur Autonomous Region)

[MIS09-05] The ULF waves possibly related to earthquakes in geomagnetic field from CSES and SWARM satellites

★Invited Papers

*Xuemin Zhang[1], Yulin Zhou[1] (1.Institute of Earthquake Forecasting, China Earthquake Administration)

[MIS09-06] Statistical analysis of pre-earthquake electromagnetic anomalies in the Ultra Low Frequency (ULF) range

★Invited Papers

*Sheldon Dwight Warden[1,2], Laura MacLean[1], Jim Lemon[1], Dan Schneider[1] (1.QuakeFinder, 250 Cambridge Avenue (Suite 204), Palo Alto, CA 94306-1555, United States, 2.Hyperion Geophysical Services, 7 rue de Châtenois, 67100, Strasbourg, France.)

Prediction of Geomagnetic Daily Variations

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Since 2008, many geomagnetic observatories have been built in China. The variety and time span of observations are increasing, which has provided abundant and valuable geomagnetic data for scientific research. However, rapid urbanization and construction development has negatively affected the geomagnetic observation environment. The magnetic field observations are subject to disturbances of several nT to several hundreds nT caused by infrastructure construction, vehicles, subway and light rail, high-voltage DC power lines, factory operations and so on. It is important to identify and exclude disturbances from massive data.

In this study, we have analysed how the magnetic disturbances relate to various influencing factors mentioned above. In addition, Natural Orthogonal Method (NOC), Space Weighting Method and Long Short-Term Memory Recuttent Neural Network (LSTM RNN) are utilised to develop a geomagnetic daily variation model based on geomagnetic data obtained from 30 observatories of Geomagnetic Network of China from 2017 to 2018. We will compare the daily variations calculated by the model and those measured by the observatories. Finally, we hope the results could be used to correct the observatory data for a significant part of the disturbances.

Keywords: geomagnetic daily variation, Natural Orthogonal Method, disturbances

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Evaluation of the 2017 *M* 6.6 Jinghe earthquake epicenter based on the Parkinson vector

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Relationships between observation data at geomagnetic stations and earthquakes have been widely reported when the space environment, instrument failure, and other factors are excluded. In this work, The Parkinson vectors derived from 3-component geomagnetic data at 4 stations were obtained via the magnetic transfer function and discussed with respect to the location (82.89˚E, 44.27˚N) and the depth (16 km) of the M 6.6 earthquake on August 9, 2017 in Xinjiang. To mitigate artificial disturbances, low noise data during the 23:00 –5:00 LT are utilized. We compute the background distribution and monitoring distribution using the azimuth of the Parkinson vectors at 0.005 –0.01 Hz at each station within an entire study period of 2017 and a 15-day moving window to determine the anomalous azimuths of high-conductivity materials. The analytical results show that the epicenter is located in high conductor anomaly 15 days before the earthquake. The anomaly becomes unclear about 6 days before and remains insignificant after the earthquake. The similar results can also be observed in Taiwan. The agreement of conductivity changes before earthquakes in different region sheds lights on forecasting locations of forthcoming earthquakes via changes of underlying electrical conductivity during earthquakes. This manuscript makes a preliminary discussion on the earthquake event, and more earthquake cases are needed to determine the efficiency of detection of seismo-electromagnetic anomalies using the Parkinson vector.

Keywords: The Jinghe M6.6 earthquake, Seismo-electromagnetic anomalies, Parkinson vectors

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Seismogenic structures in western Yunnan revealed by three-dimensional magnetotelluric imaging

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Influenced by the extrusion of Tibetan blocks and Indo-Burmese collision, the region in western Yunnan is associated with active seismicity and Quaternary volcanoes. Based on broadband magnetotelluric data collected in western Yunnan, we obtain a three-dimensional crustal electrical resistivity model after various data processing and three-dimensional inversion test. The above resistivity model reveals the seismogenic structures of the moderate and strong earthquakes in this tectonic region. We investigate the possible relationship between the seismicity and the electrical structure in western Yunnan region. The results indicate that earthquakes in this region tend to occur in the transition zone between the resistive and conductive structures. Our results also show that one resistive body imaged at the mid-lower crust may have blocked the previously proposed crustal channel flow along this intra-continental block boundary to the east of Tibetan Plateau. Our resistivity model suggests a bifurcation of the crustal flow in western Yunnan. This bifurcated crustal flow structure may play an important dynamical role in the seismogenesis of the earthquakes in western Yunnan.

Keywords: Seismogenic structures, magnetotelluric

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Seismo-conductivity anomaly associated with the 2017 M_S 7.0 Jiuzhaigou earthquake

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Changes of underlying conductivity around hypocenters are considered to be a potential source of seismo-electromagnetic anomalous phenomena. In this study, Parkinson vectors computed by 3-component geomagnetic data recorded at nine geomagnetic stations via magnetic transfer function are utilized to monitor the conductivity changes during the 2017 M_S 7.0 Jiuzhaigou earthquake. To mitigate artificial disturbances, low noise data during the 23:00 –5:00 LT are utilized. We compute the background distribution and monitoring distribution using the azimuth of the Parkinson vectors at 0.005 –0.01 Hz at each station within a one-year of 2017 and a 15-day moving window, respectively. The background distribution is subtracted from the monitoring distributions to mitigate the influences of underlying inhomogeneous tectonic structures. The obtained difference distributions binned by 10˚ within 400 km from each station are superimposed during 45 days before and after the earthquake to construct integrated maps. The superimposition results show that an intersection of seismo-conductivity anomaly is distributed in the area (i.e., 104.00˚E, 33.86˚N) about 70 km away from the epicenter 17 days before the earthquake. The anomaly becomes unclear about 7 days before and remains insignificant after the earthquake. These results suggest the changes of underlying conductivity near the hypocenter can be simultaneously detected by numbers of magnetometers before the Jiuzhaigou earthquake. The variations of the seismo-conductivity anomaly during the earthquake lights on a promising candidate of the pre-earthquake anomalous phenomena.

Keywords: Parkinson vector, Seismo-conductivity anomalies, The Jiuzhaigou earthquake

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The ULF waves possibly related to earthquakes in geomagnetic field from CSES and SWARM satellites

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The China Seismo-Electromagnetic satellite (CSES, also named as Zhangheng-1 or ZH-1) is the first Chinese space-borne platform dedicated to geophysical field exploration and earthquake research by monitoring the space electromagnetic environment. It was launched on February 2, 2018, with the operating duration time near to 2 years until now. The CSES is a 3-axes-stablished satellite, with a circular Sun-synchronous orbit at the altitude of 507km and inclination about 97.4º, ascending and descending node at LT02:00 and LT14:00 respectively. Eight scientific payloads are installed onboard CSES, including high precision magnetometer (HPM), Search-coil magnetometer (SCM), Electric field detector (EFD), GNSS radio occultation receiver (GOR), High energetic particle package (HEP), Langmuir probe (LAP), Plasma analyzer package (PAP), and Tri-band beacon (TBB). Three main products are obtained, consisting of vector and scalar electromagnetic field, in-situ plasma parameters, and electron density profiles. All payloads are designed to work in the region within latitude of ±65º, and the burst mode will be automatically switched on over all of China and the Circum-Pacific and Eurasia seismic belts. Here we will mainly introduce some new earthquake results from HPM of CSES. SWARM satellite was launched in Nov. 2013 with three ones at different altitudes, continuously longer than 6 years. Its scientific objective mainly focused on the geomagnetic field model, so the geomagnetic field observation data is the main product from the Vector Field Magnetometer (VFM) and Absolute Scalar Magnetometer (ASM) on this satellite.

During 2018 to 2019, there took place three earthquakes with magnitude around 6.0 in west China, including the Mojiang Ms 5.9 earthquake on Sep. 12 2018 in Yunnan province, Motuo Ms6.2 on Apr. 24 2019 in Tibet Autonomous Region, Changning Ms6.0 on Jun. 17 2019 in Sichuan Province. Here we mainly analyzed the geomagnetic field observations on CSES and SWARM. Firstly we select the CSES and SWARM orbits within the seismic preparation region by the equation of $\rho = 10^{0.43M}$. Secondly the geomagnetic disturbances were distinguished by removing the multi-point smoothing average data. Thirdly the spectra were calculated to confirm the frequency characteristics of these ULF waves. It is found that before these three earthquakes, some ULF disturbances were clearly detected by satellites near the epicenter. By comparison the multi-satellite observations, the spatial and temporal distributions of these ULF waves in geomagnetic field were studied, and mainly ULF disturbances occurred at dayside, which is greatly different with those nighttime perturbations in plasma parameters from DEMETER and other satellites. The construction and propagation processes of ULF waves were discussed to explain these phenomena finally with multi satellites in different time and altitude of the topside ionosphere, to help us further understanding the seismo-ionospheric coupling mechanism.
This paper is supported by ISSI-BJ (IT2019-33) and National Key R&D Program of China (2018YFC1503506).

Keywords: CSES satellite, ULF waves, geomagnetic field

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Statistical analysis of pre-earthquake electromagnetic anomalies in the Ultra
Low Frequency (ULF) range

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Assessing the statistical significance of electromagnetic anomalies observed prior to earthquakes is a necessary step towards determining whether these perturbations constitute actual earthquake precursors. A Statistical Epoch Analysis (SEA) was recently performed by Han
et al. [2014] to analyze earthquakes happening between 2001 and 2010 near the geomagnetic observatory of Kakioka, Japan; the authors found a statistically significant number of anomalies 6 to 15 days prior to the earthquake day in the region within 100km from the observatory, while no significant pre-earthquake activity was observed for the farther region located between 100km and 216km from the observatory. In the present work, we describe the application of our independent software implementation of their method. Despite using a different outlier rejection scheme, we manage to reproduce the results of Han et al. [2014] for the 2001-2010 interval.

We use our program to run multiple sensitivity studies. The original SEA was applied to a population of events comprising both crustal and mantle earthquakes, assumed to have different triggering mechanisms. We first restrict the analysis to only mantle earthquakes and find that the increased number of anomalies 6 to 15 days prior to the earthquake day is still observed for this subset of earthquakes.

Also, the study of Han et al. [2014] relied on an earthquake catalog maintained by the Japanese Meteorological Agency (JMA). In order to assess the robustness of their results, we use the International Seismological Center (ISC) catalog to independently establish a new list of qualifying “earthquake days”: we find that the anomalous pre-earthquake episode vanishes altogether when using this other catalog. We discuss the impact of source catalog on the results and suggest that future authors test their algorithms against multiple catalogs as a good practice.

Finally, we apply the SEA to a more recent interval, ranging from 2013 to 2018, and find that no significant pre-earthquake episode can be observed for this later time window. We highlight the influence of the March 11, 2011 Tohoku mega-earthquake on the number of qualifying earthquake days in the years following the earthquake and discuss how this may prevent direct comparison between the 2001-2010 interval and the following decade.

Keywords: Pre-earthquake processes, Ultra-Low Frequency magnetic signals, Statistical Epoch Analysis

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[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS09] Interdisciplinary studies on pre-earthquake processes

convener:Katsumi Hattori(Department of Earth Sciences, Graduate School of Science, Chiba University), Dimitar Ouzounov(Center of Excellence in Earth Systems Modeling & Observations (CEESMO) , Schmid College of Science & Technology Chapman University, Orange, California, USA), Jann-Yenq LIU(Department of Space Science and Engineering, National Central University, Taiwan), Qinghua Huang(Peking University)

This session expands the interdisciplinary discussions on preparation process of earthquake and earthquake predictability by presenting the latest progress in studying the physically based pre-earthquake phenomena. New observations from space and ground have provided evidences, which may enhance better understanding of tectonic activity. The session anticipates talks that include but not limited to observations and analyses of seismic, electrical, electromagnetic, electro-chemical and thermodynamic processes related to stress changes in the lithosphere along with their statistical and physical validation. Presentations on the latest observational results associated with major earthquakes obtained by different methodologies are welcomed. The topics of the session are as follows but not limited.

 -General discussion on earthquake preparation process and the physics of pre-earthquake signals
 - Theory, modeling, laboratory experiments, computational simulation for generation and propagation of pre-earthquake signals and their connection with seismic cycle
 - Multi-parameter observations, detection, and validation of pre-earthquake signals
 - Cross-disciplinary studies, practical and technical approaches for better understanding of earthquake preparation processes and their connection with seismicity

[MIS09-07] Statistical analysis of AETA geo-acoustic signal based on Fractal Theory

*Jing Wang[1,2], Shanshan Yong[1,2], Xin'an Wang[1,2], Binyan Ma[1,2], Qinmeng Guo[1,2], Binghui Jiang[1,2], Chao Yang[1,2] (1.Earthquake Monitoring and Prediction Technology Research Center, Peking University Shenzhen Graduate School, Shenzhen, China, 2.The Key Laboratory of Integrated Micro-Systems Science and Engineering Applications, Peking University Shenzhen Graduate School, Shenzhen, China)

[MIS09-08] Statistical study on correlation between AETA electromagnetic signals and earthquakes

*Qinmeng Guo[1,2], Shanshan Yong[1,2], Xin'an Wang[1,2], Binghui Jiang[1,2], Jing Wang[1,2], Chao Yang[1,2] (1.Earthquake Monitoring and Prediction Technology Research Center, Peking University Shenzhen Graduate School, Shenzhen, China, 2.The Key Laboratory of Integrated Micro-Systems Science and Engineering Applications,Peking University Shenzhen Graduate School, Shenzhen, China)

[MIS09-09] Negentropy anomaly analysis of the borehole strain data associated with the *M*s 7.0 Lushan earthquake

*Zining Yu[1,2], Hattori Katsumi[2], Kaiguang Zhu[1], Chengquan Chi[1], Xiaodan He[1] (1.Key Laboratory of Geo-Exploration Instrumentation, Ministry of Education, Jilin University, Changchun, China, 2.Graduate School of Science, Chiba University, Chiba, Japan)

[MIS09-10] Observations of Backstops in the Overriding Plate During the Megathrust Earthquake Cycle

*Rob Govers[1], Taco Broerse[1], Matthew Herman[1] (1.Utrecht University, Netherlands)

[MIS09-11] **Relationships between seismogenic areas and crustal vibration before earthquakes**

★Invited Papers

*Chieh-Hung Chen[1], Yang-Yi Sun[1], Strong Wen[2], Peng Han[3], Li-Ching Lin[4] (1.Institute of Geophysics and Geomatics, China University of Geosciences, Wuhan, Hubei, China, 2.Department of Earth and Environmental Sciences, National Chung Cheng University,Chia-Yi, Taiwan, 3.Department of Earth and Space Sciences, Southern University of Science and Technology, Shenzhen, China, 4.Science and Technology Policy Research and Information Center Taiwan, Taipei, Taiwan)

[MIS09-12] **Statistical Test of Spatio-Temporal Variation of b Value in Japan**

*weiyun xie[1], Peng Han[2], Katsumi Hattori[1] (1.chiba university, 2.Southern University of Science and Technology)

Statistical analysis of AETA geo-acoustic signal based on Fractal Theory

*Jing Wang[1,2], Shanshan Yong[1,2], Xin'an Wang[1,2], Binyan Ma[1,2], Qinmeng Guo[1,2], Binghui Jiang[1,2], Chao Yang[1,2]

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Geo-acoustic signal is one promising precursor phenomena for short-term earthquake prediction. Our team developed a system named AETA which can observe the electromagnetic disturbance and geo-acoustic signal. We have deployed more than 221 observation stations in China and acquired much data in past 3 years. In previous observation, we found that the geo-acoustic signal is quiet most of time. However, when some fluctuation happened, seismic events also happened before or in the days of following in many cases. In order to verify this specific correlation between geo-acoustic and seismicity, we conducted statistical analysis on geo-acoustic data (GD).

In this paper, AETA stations which were installed before 1th Jan 2018 and has more than 10 seismic events within 200km around were chosen. The number of stations is 101. We extract features of geo-acoustic signal by Fractal dimension (FD) which is a method to describe the chaos degree of data. Then mark the anomalies of FD feature by sliding interquartile algorithm. In the end, we use Superposed Epoch Analysis (SEA) to test the statistical correlation between geo-acoustic anomalies and seismicity.

The statistical studies show that for 56 stations, more than half of the chosen stations (55.45%), there is a statistical correlation between geo-acoustic and seismicity. Their anomalies were more likely to appear before and after earthquakes within ±15 days which is demonstrated by the days of anomalies exceeding random_mean+2σ. Among these stations, 36 stations which is 62.5% of 56 stations, exceed the significant level before the earthquake. This means somehow AETA effectively captured the pre-seismic geo-acoustic signal, which is important for us to do earthquake prediction research.

Sometimes the impact of background noise on geo-acoustic signal is too strong to be ignored and quite different in different stations. This explains why some stations may not perform well in SEA, but we believe that seismic signal will be extracted from AETA by multiple signal processing methods. In future, we will improve the recognition rate of seismic anomalies for each station by suppressing the noise, with the increase in the amount of AETA data and the successive deployment of AETA stations over the world.

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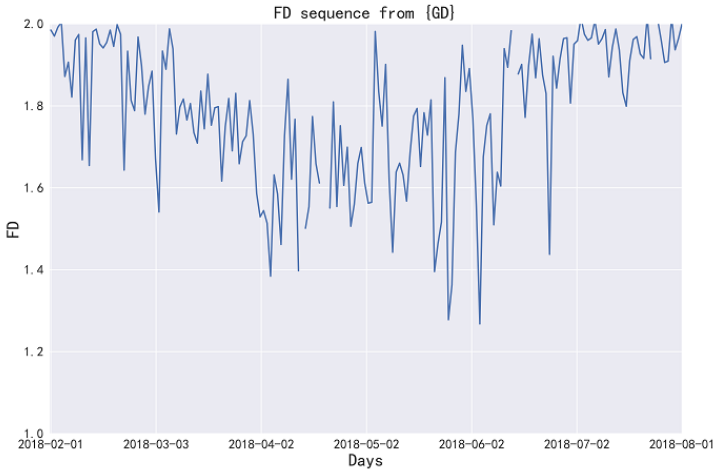

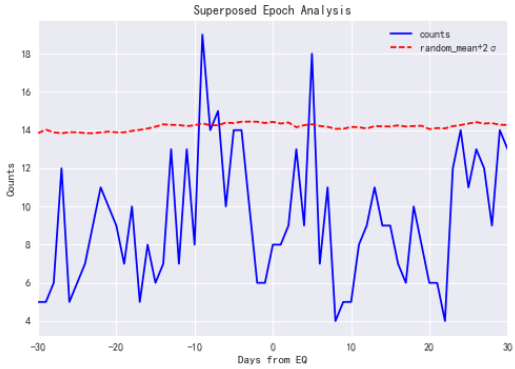

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Statistical study on correlation between AETA electromagnetic signals and earthquakes

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The seismic electromagnetic precursor has been considered as an effective means of the impending and imminent earthquake prediction. Our team developed a multi-component seismic monitoring system, which is named as AETA. Since the end of 2016, AETA has successively installed more than 200 sets in China. In previous studies, researchers used different methods to detect anomalies in AETA electromagnetic disturbance data and found pre-seismic anomalies in retrospective studies of the 2017 Jiuzhaigou Ms7.0 earthquake.
In order to further verify the correlation between AETA electromagnetic disturbance anomalies and local seismicity, we conducted statistical analysis on 20 AETA stations with installation periods more than two and a half years and abundant earthquake cases. Only earthquake events with epicenter distances within 500km and Es exceed 10^7 were considered. First, we used a modified sliding PCA method to obtain the abnormal values of AETA electromagnetic disturbances, and performed 0/1 encoding based on whether the abnormal values exceed median+2IQR to obtain a sequence reflecting the electromagnetic abnormal signals. And then, Superposed Epoch Analysis (SEA) has been applied to test seismic electromagnetic anomalies at 20 stations. Statistical results have indicated that the ratio of stations showing statistically significant correlation between electromagnetic disturbance anomalies and earthquakes reached 75%. For 65% of stations, their anomalies were more likely to appear before earthquakes rather than after them. The periods when statistical result of 5 day counts was significant varied from station to station. The above results have illustrated that the electromagnetic observation with AETA is useful and has a possibility of improving local earthquake forecasting.
From a large number of earthquake cases around the world, the asynchronous phenomenon of electromagnetic signals exists. That is to say, some stations can’ t receive abnormal signals and the time when the abnormal signals were received by different stations from the same earthquake was not synchronized. In future, we will work to fully excavate the seismic anomaly pattern of each station. How to comprehensively consider anomalies of multiple stations to make a more accurate estimation of three seismic factors is another focus of future research. With the accumulation of earthquake cases, we believe that more clearly anomalous patterns at each station will be found and more accurate prediction will be made.

Keywords: Seismic electromagnetic precursor, AETA, Superposed Epoch Analysis(SEA)

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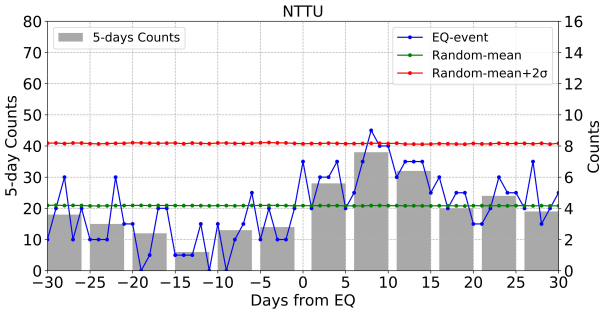

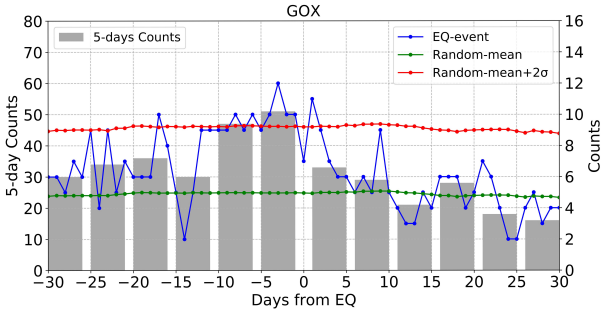

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Negentropy anomaly analysis of the borehole strain data associated with the *M*s 7.0 Lushan earthquake

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Several YRY-4 borehole strainmeters have been installed in Sichuan province, China, aiming at monitoring the crustal activities associated with earthquakes. In order to verify the existence of strain precursors preceding the Lushan earthquake, we investigate the negentropy of the borehole strain data during 2011-2013.

First, some local factors that could affect the strain are ruled out, such as environmental disturbances, we analyze the strain responses to air pressure as well as solid tides and water level which were recorded on one YRY-4 strainmeter. Based on a state-space model according to the observations of the strainmeter, we remove the strain response to air pressure, in addition to those due to water level changes and the solid tides by Kalman filter. To investigate whether the remained strain changes are related to the Lushan earthquake, we introduce the approximate negentropy as an easily computable non-randomness measure to give evidence of strain changes and illustrate the instability of the underground of the earthquake zone. Generally, the appearance of a pre-catastrophic state can be characterized by significant higher non-randomness in terms of approximate negentropy.

Negentropy analysis of 6 stations of the southwest end of the Longmenshan fault zone have been performed. The nearest GZ station is 77 km away from the epicenter, and the epicenter distances of other stations are 270-728 km. The statistical results at GZ station of cumulative counts of negentropy anomaly show acceleration about 6 to 4 months prior to the earthquake, implying there are non-random changes in the borehole strain data, which is similar to the previous results. In addition, after the earthquake, the anomalies increase briefly and recover to a quiet state. Besides, XM and ZT stations appear a significant surge from October 2012 to 2013, which is consistent with the first period anomaly extracted from GZ station. However, the distant stations doesn’ t show anomaly acceleration, probably due to the distance.

Furthermore, we compare the anomaly acceleration rate of each station. The results indicate that as the epicenter distance increases, the acceleration rate becomes less significant, suggesting the negentropy anomalies are more sensitive near the Lushan earthquake epicenter. In other words, the anomalies of the borehole strain data dependent on the Lushan earthquake epicenter. Therefore, we conclude that there may be strain precursors before the Lushan earthquake and the negentropy analysis have potential capability in the study of earthquake precursors.

Keywords: borehole strain, state-space model, approximate negentropy, acceleration rate

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Observations of Backstops in the Overriding Plate During the Megathrust Earthquake Cycle

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Recent seismological and geodetic observations, as well as sophisticated regional models, indicate that similar physical processes are active during the earthquake cycle at different subduction margins. Part of the observed complexity at these margins is controlled by the fact that they are in different stages of the earthquake cycle. The observations capture critical physical processes like (partial) locking of the plate interface, the detailed co-seismic slip, and mantle relaxation and afterslip.

We analyze geodetic observations along sections of the South America, Japan, and Sunda trenches during the interseismic part of the megathrust earthquake cycle. The results show that overriding plates shorten from the trench to a “backstop”, where interseismic velocities become close to zero. Stress accumulation in the overriding plate is controlled by the distance to the backstop. In most, but not all, regions, the backstop location from trench-perpendicular GPS velocities agrees with that from trench-parallel velocities. The distance of this interseismic backstop to the trench varies along major subduction margins. We explore what controls this distance by correlating backstop location with locking area on the plate contact, with boundaries of tectonic blocks in the overriding plate (mechanical contrasts), and with estimates of the recurrence time of the largest events.

An enigmatic observation is that co-seismic geodetic displacements of great earthquakes, including the 2004 Sumatra earthquake, the 2010 Maule earthquake, and the 2011 Tohoku earthquake extended into the overriding plates well beyond what we infer to be the backstops. We use cyclic 3D geodynamic models to further understand and quantify these correlations. Co-seismic and subsequent slip on the subduction interface are dynamically (and consistently) driven. This setup allows us to access the sensitivity of the geodetic signals to mechanical components of the overriding plate and the slab system. We conclude that gradients in the effective elastic thickness of the overriding plate explain the observations.

Keywords: interseismic, geodetic velocities, earthquake cycle

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Relationships between seismogenic areas and crustal vibration before earthquakes

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Earthquake catalogs with a duration of 10 years in Taiwan and Japan are constructed by using dense seismic arrays that are utilized to determine seismogenic zones in this study. We assume that entire earthquakes are “crack” in the crust. In contrast, earthquakes with relatively-large (M >= 3) magnitude are “break”. The “cracks” occurred within epicentral distances ranging from 0 km to 400 km during a period of 60 days before and after the “beaks” that are utilized to construct spatiotemporal seismicity maps. We superimpose entire spatiotemporal seismicity maps and find that the increase seismicity initially concentrates in the fault zones. The increase seismicity gradually expands outward to over 50 km away from the epicenters approximately 40 days before the “breaks” and become more rapidly around the fault zones approximately 20 days before. These suggest that seismogenic zones, which can be referred to areas with increase seismicity, associated with the “breaks” being more than 50 times to regions of the fault rupture. We compute resonant frequencies of areas with increase seismicity by using a resonant frequency model. Resonant frequencies vary from ~3×10^{-4} Hz to ~10^{-3} Hz (i.e., variable frequency) that can be observed along with changes of the areas migrating from exterior areas to approach the fault zones. The variable frequency can also be supported by the observation of continuous seismic waveforms through superimposition processes. These results suggest that the variable frequency of ground vibrations is a function of the areas with increase seismicity leading to earthquakes.

Keywords: Foreshocks, Seismogenic zones, Crustal vibrations, Crustal resonance

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Statistical Test of Spatio-Temporal Variation of b Value in Japan

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The Gutenberg-Richter (GR) law: *log10NM=a-bM* denotes the relationship between the frequency-magnitude distribution (FMD), in which N is the cumulative number of earthquakes with magnitude equal to or larger than M. Constant b measures difference in the relative proportion of small and large earthquakes and shows the variation of seismicity activity and stress evolution before earthquake. Many studies show that b-value decreased prior to great earthquakes. Since the b value depends very much on the magnitude of completeness (Mc), we investigated the spatial variation of Mc in Japan, combining the maximum curvature (MAXC) technique and the bootstrap approaches. Then, for the area that has approximately equal Mc value, we check the temporal variation of Mc and apply its maximum to calculate b values. This process helps the computation of b value in this area and its uncertainty can be computed more properly.

We used the bootstrap approach to generate reference b values and applied the Akaike Information Criterion (AIC) to assess the spatial variation of b values of the area statistically. Here, we define the P(ΔAIC≧2) value, where P(ΔAIC≧2) means that the percentage of ΔAIC between the b value at the target space and time and that of the reference is larger or equals to 2. This gives the significance level of difference between target and the reference periods. In the area, we narrowed a target area depending on P(ΔAIC≧2), after that we quantified the temporal variation of the target area and discuss the precursor of the large earthquake occurred in this area. Also, the spatial distribution of ΔAIC between reference and the period prior to the main shock will also be investigated. In this paper, we will demonstrate capability of the proposed method. A case study of the 2016 Kumamoto Earthquake (M7.3) shows a statistically clear decrease in b value and large increase of P(ΔAIC≧2) value few months before the main shock. It indicates that the b value with statistical assessment may emerge positive impact for forecasting a future large earthquake.

Keywords: b value, Mc, AIC

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[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS09] Interdisciplinary studies on pre-earthquake processes

convener:Katsumi Hattori(Department of Earth Sciences, Graduate School of Science, Chiba University), Dimitar Ouzounov(Center of Excellence in Earth Systems Modeling & Observations (CEESMO) , Schmid College of Science & Technology Chapman University, Orange, California, USA), Jann-Yenq LIU(Department of Space Science and Engineering, National Central University, Taiwan), Qinghua Huang(Peking University)

[MIS09-13] The latest results of CSES mission

★Invited Papers

*Zeren Zhima[1], Xuhui Shen[1], Jianping Huang[1] (1.Institute of Crustal Dynamics, China Earthquake Administration)

[MIS09-14] Seismo-ionospheric precursors (SIPs) of the TEC associated with the 21 September 1999 M7.3 Chi-Chi earthquake and the statistical analyses on SIPs in Taiwan

*YUN-CHENG WEN[1], JANN-YENQ Liu[1] (1.Institute of Space Science, National Central University, Taiwan)

[MIS09-15] **The three-dimensional ionospheric tomography in Japan using the adaptive Kalman Filter algorithm**

*Rui Song[1], Katsumi Hattori[2], Xuemin Zhang[3], Chie Yoshino[2] (1.Graduate School of Science and Engeering, Chiba University, 2.Graduate School of Science, Chiba University, 3.Institute of Earthquake Forecasting, China Earthquake Administration)

[MIS09-16] **FORMOSAT-5/AIP observe seismo-ionospheric precursors and ionospheric storms**

*JANN-YENQ Liu[1,2,3], FU-YUAN CHANG[1,2], YUN-CHENG WEN[2], Yuh-ING Chen[4], Chi-Kuang Chao[1,2], Loren Chang[1,2] (1.Center for Astronautical Physics and Engineering, National Central University, TAIWAN, 2.Graduate Institute of Space Science and Engineering, National Central University, TAIWAN, 3.Center for Space and Remote Sensing Research, National Central University, TAIWAN, 4.Graduate Institute of Statistics, National Central University, TAIWAN)

[MIS09-17] Transient Effects in Atmosphere and Ionosphere Associated with January 2020 Caribbean Earthquakes

*Dimitar Ouzounov[1], Sergey Pulinets[2], Alexander Rozhnoi[3], Maria Solovieva[3], Katsumi Hattori[4], Menas Kafatos[1], Patrick Taylor[5] (1.Center of Excellence in Earth Systems Modeling & Observations (CEESMO) , Schmid College of Science & Technology Chapman University, Orange, California, USA, 2.Space Research Institute, Russian Academy of Sciences, Moscow, Russia, 3.The Schmidt Institute of Physics of the Earth, Russian Academy of Sciences, Moscow, Russia, 4.Department of Earth Sciences, Graduate School of Science, Chiba University, Chiba, Japan, 5.NASA Goddard Space Flight Center, Greenbelt, MD, USA)

[MIS09-18] Earth's outgoing longwave radiation variability prior to M ≧ 6.0 earthquakes in the Taiwan area during 2009-2016

★Invited Papers

*Ching-Chou FU[1], Lou-Chuang Lee[1], Dimitar Ouzounov[2] (1.Institute of Earth Sciences, Academia Sinica, 2.Chapman University, One University Drive, Orange, CA, USA)

The latest results of CSES mission

*Zeren Zhima[1], Xuhui Shen[1], Jianping Huang[1]

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The latest results of CSES mission

Zhima, Xuhui Shen, Jianping Huang

The first probe of CSES (China Seismo-Electromagnetic Satellite) mission was launched on February 2nd, 2018 at an latitude of 507 km in the upper ionosphere. The CSES -01 operates 15.2 orbits around the Earth per day by a speed of 7.8 km/s , with a 5-day revisit period for the same area. The orbital period around the Earth is ~ 94.6 minutes. The first-hand scientific observations show that CSES has recorded a number of interesting natural events, showing its good inflight observing capability on natural phenomenon. In this presentation, we mainly introduce CSES’ s observations of the geomagnetic field, the electromagnetic waves, the VLF radio waves, the geomagnetic event and earthquake activities.

Keywords: China seismo-electromagnetic satellite, the electromagnetic field, seismic-ionospheric disturbances

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Seismo-ionospheric precursors (SIPs) of the TEC associated with the 21 September 1999 M7.3 Chi-Chi earthquake and the statistical analyses on SIPs in Taiwan

*YUN-CHENG WEN[1], JANN-YENQ Liu[1]

1. Institute of Space Science, National Central University, Taiwan

This study revisits the total electron content (TEC) derived from ground-based GPS receivers during the 21 September 1999 M7.3 Chi-Chi earthquake. It is found that TEC over the epicenter anomalously/significantly decrease in the afternoon period day 1, 3, and 4 before the Chi-Chi earthquake. We further statistically examine pre-earthquake ionospheric anomalies (PEIAs) of TEC associated with M greater or equal to 5.0 earthquakes in Taiwan about 6 years before the Chi-Chi earthquake (1994/1/1-1999/9/20) and find the characteristic of seismo-ionospheric precursors (SIP) in the polarity (i.e., increase or decrease anomalies), local time, lead time, duration, etc. of these earthquakes. The statistical result shows that the SIP characteristic is TEC significantly/anomalously decreasing in the afternoon period day 1-5 before the M greater or equal to 5.0 earthquakes, which suggests that the anomalies appearing day 1, 3, and 4 before the Chi-Chi earthquake most likely are SIPs. Statistical analyses of z test and ROC (receiver operating characteristic) curve are also applied to find the characteristics of temporal SIPs of TECs in Taiwan during 1994 –2019.

Keywords: Seismo-ionospheric precursor, total electron content, Chi-Chi earthquake, receiver operating characteristic

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The three-dimensional ionospheric tomography in Japan using the adaptive Kalman Filter algorithm

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A regional three-dimensional (3-D) ionospheric tomography was developed in Japan by adopting the Kalman Filter (KF) algorithm, where the adaptive Sage-Husa KF (SHKF) was proposed to deal with the unknown priori information of the noise covariance encountered in the conventional KF (CKF) iterations. Here, slant TEC (STEC) data detected by 55 GPS (Global Positioning System) ground receivers was employed for IED reconstructions with the spatial resolution of 1°×1°×30 km in latitude, longitude and altitude, and temporal resolution of 1 hour, respectively. By comparing the simulated NmF2 (F2 layer peak electron density) during April 3-9, 2018 from SHKF, CKF, and the IRI (International Reference Ionosphere) model with the observed values from 4 Japanese ionosondes, the results demonstrated that SHKF-derived NmF2 was apt to capture the trend of diurnal variations more accurately. Subsequently, annual variation characteristics were studies between the year 2013 (high solar activities) and 2018 (low solar activities). By evaluating the root-mean-square error (RMSE) and correlation coefficient (ρ), bar graphs visually illustrated that the efficiency of SHKF is superior to CKF and IRI during both low and high solar activities. Then, seasonal variations as well as the vertical profiles inverted by SHKF and IRI were investigated successively, where the results also manifested that SHKF was outperformed the other methods. In the end, taking a strong geomagnetic storm happened on 26 August, 2018 as an example, the results indicate that the IED around Japan developed by SHKF-based tomography is promising for ionospheric studies and practical applications.

Keywords: Ionospheric Tomography, Sage-Husa Kalman Filter, Ionospheric Electron Density, Total Electron Content

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FORMOSAT-5/AIP observe seismo-ionospheric precursors and ionospheric storms

*JANN-YENQ Liu[1,2,3], FU-YUAN CHANG[1,2], YUN-CHENG WEN[2], Yuh-ING Chen[4], Chi-Kuang Chao[1,2], Loren Chang[1,2]

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The mission of Advanced Ionospheric Probe (AIP) onboard FORMOSAT-5 (F5) is to detect seismo-ionospheric precursors (SIPs) and observe ionospheric weathers. F5/AIP plasma quantities in nighttime of 22:30 LT (local time) and the total electron content (TEC) of the global ionosphere map (GIM) are used to study SIPs of an M7.3 earthquake in the Iran-Iraq Border area on 12 November as well as two positive storms on 7 and 21-22 November 2017. The TEC and the F5/AIP ion density/temperature significantly increase over the epicenter area on 3-4 November (day 9-8 before the earthquake) and on the two storm days. The significant TEC increases appearing day 9-8 before the earthquake agrees with the temporal SIP characteristic that the TEC significant increases appear day 14-6 before 53 greater than M 5.5 earthquakes in the Iran-Iraq area. This agreement indicates that the temporal SIP of the earthquake has been detected. The significant TEC increases frequently appearing specifically over the epicenter area day 9-8 before the earthquake confirms the SIP being observed, while those frequently occurring at worldwide high-latitudes are signatures of the two positive storms. Significant TEC increase anomalies most frequently appearing in the Iran-Iraq area on 21-22 November (day 10-9 before) is coincidently followed by an M6.1 earthquake on 1 December 2017, which again meets the temporal SIP characteristic. The F5/AIP ion velocity uncovers that the SIPs of the two earthquakes are caused by eastward seismo-generated electric fields, and the two positive storms are due to the prompt penetration electric fields.

Keywords: FORMOSAT-5, advanced ionospheric probe, total electron content, seismo-ionospheric precutsor, ion velocity, plasma

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Transient Effects in Atmosphere and Ionosphere Associated with January 2020 Caribbean Earthquakes

*Dimitar Ouzounov[1], Sergey Pulinets[2], Alexander Rozhnoi[3], Maria Solovieva[3], Katsumi Hattori[4], Menas Kafatos[1], Patrick Taylor[5]

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Several significant earthquakes occurred in the Caribbean in January 2020. The first earthquake with M = 6.4 occurred on January 7 off the coast of Puerto Rico. An earthquake of M7.7 occurred in the Caribbean Sea on January 28, 2020, around 19:10 UT on the island of Jamaica. After 3 hours (21:55), another M 6.1 earthquake (NEIC / USGS) occurred in the Caribbean. We analyze retrospectively four different physical parameters of atmosphere/ionosphere during the time of mentioned earthquake events namely: (i) the lower atmosphere chemical potential (ACP), (ii) outgoing earth radiation (OLR) at the TOA, (ii) GPS/TEC and (iv) the very-low-frequency (VLF/LF) signals at the receiving. We found that in the beginning January 2020, a rapid augment of satellite observed earth radiation in the atmosphere, an anomaly appeared over Puerto Rico on January 6 (1 day before the M6.4), and the maxim anomaly appeared eastward from on January 20 (eight days before the M7.7). The increases in ACP on January 20-23 were measured near the epicentral area of M7.7 and coincided with the anomaly of OLR. For the VLF analysis, we used the amplitude data of the NAU signal (signal frequency 40.75 kHz), which was received at Chapman University in Orange, California. The length of the signal propagation path from the transmitter to the receiver was about 5300 km. A significant decrease in signal amplitude, exceeding the level of two standard deviations, is observed before the January 7 earthquake (M = 6.4) off the coast of Puerto Rico. A more significant anomaly in the VLF signal is observed before the M7.7 of the January 28 earthquake.

The pre-earthquake nature of the signals in atmosphere and ionosphere were revealed by simultaneous analysis of satellite, GPS/TEC, and VLF/LF observations and suggest that they follow a general temporal-spatial evolution pattern, which has been seen in other large earthquakes worldwide.

Keywords: earthquake, Caribian, precursors, OLR, VLF

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Earth’s outgoing longwave radiation variability prior to M ≧ 6.0 earthquakes in the Taiwan area during 2009-2016

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This paper proposed an analysis method, recorded by the National Oceanic and Atmospheric Administration (NOAA) satellites data to trace variations of outgoing longwave radiation (OLR) for finding precursors of the earthquakes. The significance of these observations was explored using data sets of recent M ≧ 6 of earthquakes around Taiwan area from 2009 to 2016. It was found that precursors, was in the form of the persistent hot anomalies distributing near the epicenters, appear approximately 5 to 10 days prior to these earthquakes. We interpret that these thermal sources may originate from electromagnetic and gas emissions associated with pre-seismic processes. This study highlights the potential of OLR anomalous change in earthquake precursor studies, at least in the Taiwan region.

Keywords: National Oceanic and Atmospheric Administration (NOAA), outgoing longwave radiation (OLR), precursor

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[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS10] Coupling between the atmosphere, ionosphere and magnetosphere above thunderstorms

convener:Pasko Victor P(Pennsylvania State University Main Campus), Yukihiro Takahashi(Department of Cosmosciences, Graduate School of Science, Hokkaido University), Mitsuteru Sato(Department of Cosmoscience, Hokkaido University), Teruaki Enoto(RIKEN)

This session will cover all aspects of coupling between lightning, sprites, jets, elves and the atmosphere/ionosphere/magnetosphere system. This includes observations of transient luminous events, associated radio and electromagnetic effects (ULF-VHF), energetic radiation (X ray and gamma ray) effects, and theoretical results on these topics. This includes also studies about the impact of these phenomena at a local or global scale.

[MIS10-01] One TGF and two elves produced by the same thunderstorm system

★Invited Papers

*Nikolai Ostgaard[1], Steve Cummer[4], Andrey Mezentsev[1], Torsten Neubert[2], Victor Reglero[3], Olivier Chanrion[2], Martino Marisaldi[1], Pavlo Kochkin[1], Nikolai Lehtinen[1], David Sarria[1], Carolina Maiorana[1], Chris Skeie[1], Anders Lindanger[1], Yunjiao Pu[4], Chris Eyles[3], Freddy Christiansen[2], Kjetil Ullaland[1], Georgi Genov[1] (1.Birkeland Centre for Space Science, University of Bergen, Norway, 2.National Space Institute, Technical University of Denmark, Denmark, 3.University of Valencia, Spain, 4. Duke University, North Carolina, US)

[MIS10-02] The Global Distribution and Photometric Characteristics of the Intense Lightning and Their Association With Transient Luminous Events

★Invited Papers

*Alfred Bing-Chih Chen[1], Chiawen Chuang[1], Han-Tzong Su[1], Rue-Ron Hsu[1] (1.National Cheng Kung University)

[MIS10-03] Detailed temporal structure of multiple ELVES recorded at the Pierre Auger Observatory

*Roberto Mussa[1,2], Kevin-Druis Merenda[3,2], Lawrence Wiencke[2,3], Collaboration Pierre Auger[2] (1.Istituto Nazionale Fisica Nucleare - Sezione di Torino, Italy, 2.Observatorio Pierre Auger, Malargue, Mendoza , Argentina, 3.Colorado School of Mines, Golden, Colorado , USA)

[MIS10-04] Upward TGF observations with TARANIS XGRE

*Kazuhiro Nakazawa[1], Yuuki Wada[2], Philippe Laurent[3,4], Pierre-Louis Blelly[5], Sébastien Célestin[6], Jean-Louis Pinçon[6] (1.Nagoya University, 2.RIKEN, 3.CEA Saclay, 4.APC, 5.IRAP, Toulouse, 6.LPCEE, Orléans)

[MIS10-05] Downward Terrestrial Gamma-ray Flashes Coincident with Enegetic In-cloud Pulses

*Yuuki Wada[1], Teruaki Enoto[1], Takeshi Morimoto[2], Yoshitaka Nakamura[3], Mitsuteru Sato[4], Tomoo Ushio[5], Kazuhiro Nakazawa[6], Takayuki Yuasa[7], Daisuke Yonetoku[8], Tatsuya Sawano[8], Masashi Kamogawa[9], Hideo Sakai[10], Yoshihiro Furuta[11], Kazuo Makishima[1,12], Harufumi Tsuchiya[11] (1.RIKEN, 2.Kindai University, 3.KCCT, 4.Hokkaido University, 5.Osaka University, 6.Nagoya University, 7.Private Company, 8.Kanazawa University, 9.University of Shizuoka, 10.University of Toyama, 11.Japan Atomic Energy Agency, 12.University of Tokyo)

[MIS10-06] Photodetachment of electrons at sprite altitudes by visible radiation of tropospheric lightning discharges as a mechanism of initiation of sprite streamers

*Victor P Pasko[1], Reza Janalizadeh[1] (1.Pennsylvania State University Main Campus)

One TGF and two elves produced by the same thunderstorm system

*Nikolai Ostgaard[1], Steve Cummer[4], Andrey Mezentsev[1], Torsten Neubert[2], Victor Reglero[3], Olivier Chanrion[2], Martino Marisaldi[1], Pavlo Kochkin[1], Nikolai Lehtinen[1], David Sarria[1], Carolina Maiorana[1], Chris Skeie[1], Anders Lindanger[1], Yunjiao Pu[4], Chris Eyles[3], Freddy Christiansen[2], Kjetil Ullaland[1], Georgi Genov[1]

1. Birkeland Centre for Space Science, University of Bergen, Norway, 2. National Space Institute, Technical University of Denmark, Denmark, 3. University of Valencia, Spain, 4. Duke University, North Carolina, US

On February 8, 2019 the Atmosphere-Space Interaction Monitor (ASIM) passed a thunderstorm system north east of Puerto Rico and observed a TGF and an Elve from the same lightning stroke at the very beginning of a lightning flash. A second Elve was observed 456 ms later but without any signature of a TGF about 300 km south-east of the first Elve.

The strokes associated with the two Elve events were detected by WWLLN and Vaisala, which allows for an absolute timing accuracy of the ASIM measurements of at least 100 us. Images of the lighting strokes support the source locations for the Elves and TGF.

Both the rise time of the UV pulse by ASIM MMIA photometer and radio measurements from Puerto Rico indicate that the first stroke was an intracloud positive while the latter was a cloud-to-ground stroke. The UV emissions from the Elves preceded the optical emissions in 777 nm by

50 us and 90 us, respectively. This can partly be explained by the scattering of 777 nm within the cloud.

Current moments derived from radio measurements at Puerto Rico and Duke University indicate a fast (30 us) and large (200 kA) current pulse emitting an electromagnetic wave that produces an Elve and a slow (1-2 ms) current producing the optical signals.

Keywords: Lightning, Terrestrial Gammaray Flashes, Elves

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The Global Distribution and Photometric Characteristics of the Intense Lightning and Their Association With Transient Luminous Events

*Alfred Bing-Chih Chen[1], Chiawen Chuang[1], Han-Tzong Su[1], Rue-Ron Hsu[1]

1. National Cheng Kung University

Lightning is one of the electrical-discharge phenomena in the lower atmosphere, say stratosphere, and also the main initiator of the transient luminous events (TLEs) occurring in the middle or upper atmosphere. In the past decade, the distribution and occurrence rate of lightning were surveyed by the ground radio detection or spaceborne optical observation. But the spectrophotometric characteristics of lightning were still unrevealed by the limit of the existing ground and space observations. The ISUAL experiment onboard the Taiwanese satellite FORMOSAT-2 is the first space mission dedicated to the study of the TLEs. In addition to the ~42,000 TLEs registered in the ISUAL 12-year mission lifetime, approximately 300,000 intense lightning was also recorded by an intensified imager and a six-bands photometer. Therefore the ISUAL serves only as a TLE but also an intense lightning survey. The valuable spectrophotometric data can help to identify the geographic variation of the lightning characteristics. The exploration of the association with the TLE observed simultaneously, as well as the other lightning surveys, also provide another view on the connection of the TLEs and their parent lightning and will be discussed in this presentation.

Keywords: Lightning, Transient Luminous Event, ISUAL

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Detailed temporal structure of multiple ELVES recorded at the Pierre Auger Observatory

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The Pierre Auger Observatory, located in Malargüe (Argentina), is the largest facility (3000 km^2) for the study of Ultra High Energy Cosmic Rays.
Since 2013, the four sites of the Fluorescence Detector (FD) record ELVES with a dedicated trigger. These UV light emissions are correlated to distant lightning strikes. The length of recorded traces has been increased from 100 us (2013), to 300 μs (2014-16), to 900 μs (2017-present), to progressively extend the observation of the light emission towards the vertical of the causative lightning, and beyond. A large fraction (about one third) of the observed events shows double ELVES within the time window, and in some cases even more complex structures are observed. This report will show the seasonal and daily dependence of the time gap, amplitude ratio, and correlation of the pulse width of the first and second peak in a sample of about five hundred multiple ELVES events recorded during the period 2014-6.

Keywords: ELVES , TLE

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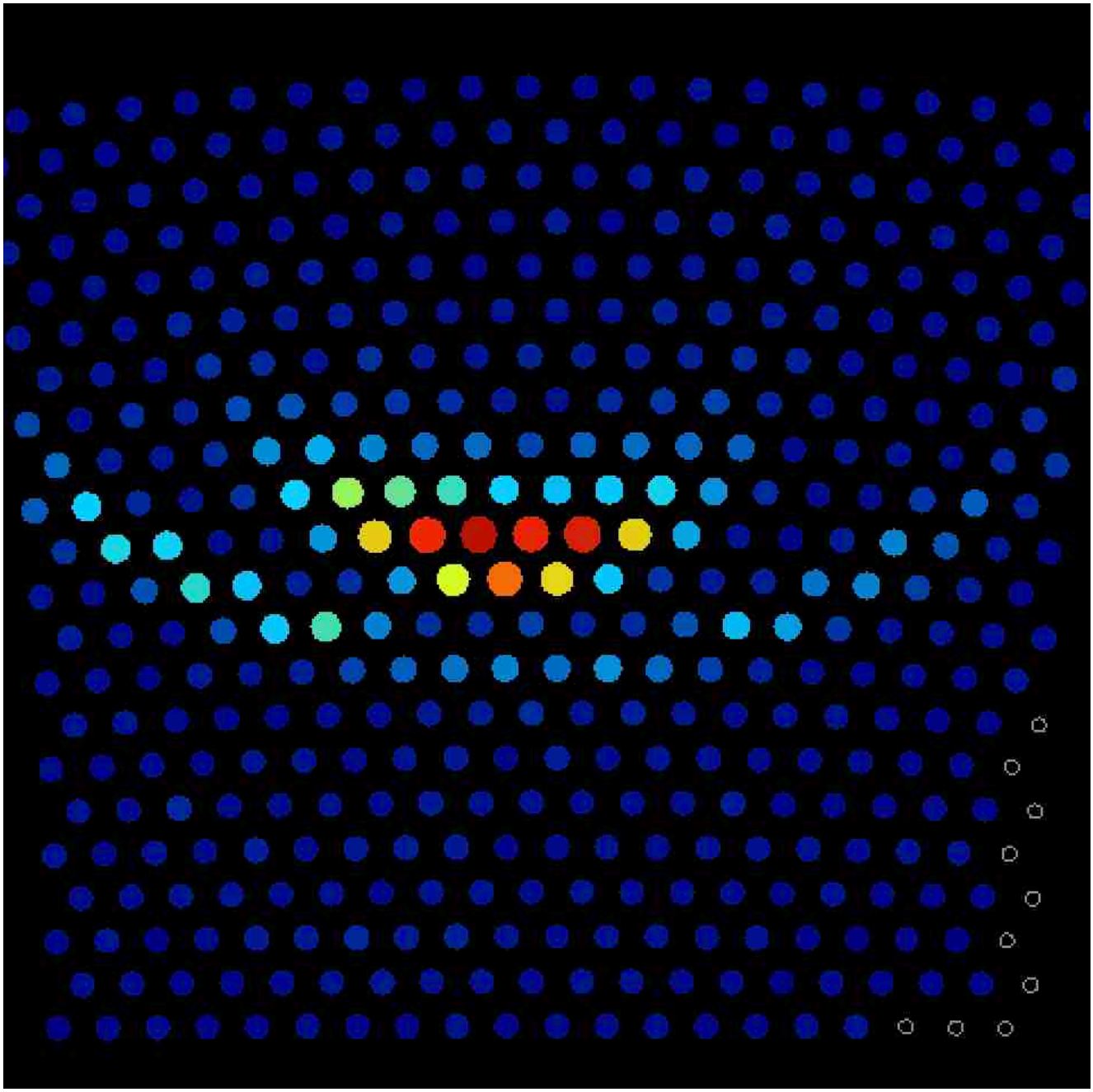

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Upward TGF observations with TARANIS XGRE

*Kazuhiro Nakazawa[1], Yuuki Wada[2], Philippe Laurent[3,4], Pierre-Louis Blelly[5], Sébastien Célestin[6], Jean-Louis Pinçon[6]

1. Nagoya University, 2. RIKEN, 3. CEA Saclay, 4. APC, 5. IRAP, Toulouse, 6. LPCEE, Orléans

TARANIS is a 150 kg class micro-satellite dedicated for observing Terrestrial Gamma-ray Flashes (TGFs) and Terrestrial Electron Beams (TEBs) associated with lightning discharges. The mission at the same time observes Transient Luminous Events (TLEs), as well as optical and radio emission from the lightning discharge. The satellite are planned to be launched into quasi-polar sun-synchronous orbit in the beginning of June this year. We in Japan are contributing to the calibration of the instrument for X-ray, Gamma-ray, and Relativistic Electron detector (XGRE), the main instrument to detect TGFs and TEBs. With from ~50 keV to 10 MeV band width and 425 cm2 effective area averaged on a typical TGF spectrum, XGRE can detect more than 200 TGF per year. Made of fast-decaying LaBr3 scintillator crystals combined with plastic scintillators, XGRE has a high throughput capability, and able to handle intensive gamma-ray pulse (typically < 100 us) of TGFs. As the launch date is nearing, final calibration of the detector is on-going at CNES Toulouse.

TARANIS multi-freuquency and multi-particle observations will provide unprecedented information on relation between TGF and other lightning related phenomena. We also expect a strong synergy with similar multi-frequency on-ground observations of downward TGF.

Keywords: TGF, TARANIS, TEB

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Downward Terrestrial Gamma-ray Flashes Coincident with Enegetic In-cloud Pulses

*Yuuki Wada[1], Teruaki Enoto[1], Takeshi Morimoto[2], Yoshitaka Nakamura[3], Mitsuteru Sato[4], Tomoo Ushio[5], Kazuhiro Nakazawa[6], Takayuki Yuasa[7], Daisuke Yonetoku[8], Tatsuya Sawano[8], Masashi Kamogawa[9], Hideo Sakai[10], Yoshihiro Furuta[11], Kazuo Makishima[1,12], Harufumi Tsuchiya[11]

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Terrestrial gamma-ray flashes (TGFs) are millisecond-long energetic emissions coincident with lightning discharges (Fishman et al., Science, 1994, Smith et al., Science, 2005). In addition to upward-oriented TGFs, which are routinely detected by in-orbit satellites, several ground-based experiments have detected downward-oriented ones (Dwyer et al., GRL, 2004, Hare et al., JGR Atmospheres, 2016, Abbasi et al., JGR Atmospheres, 2018). In particular, downward TGFs during winter thuderstorms in Japan are sometimes powerful enough to trigger photonuclear reactions in the atmosphere (Enoto et al., Nature, 2017, Wada et al., PRL, 2019). Recent studies on TGFs and associated radio-frequency (RF) emissions have presented that a distinct class of RF lightning pulses called “energetic in-cloud pulse” (EIP) are deeply connected to upward TGFs, and have predicted that negative-polarity EIPs could be connected to downward TGFs (Lyu et al., GRL, 2015, 2016). However, the connection between EIPs and downward TGFs has never been reported. We have performed the Gamma-ray Observation of Winter Thunderclouds experiment in coastal areas of the Sea of Japan since 2006 (Tsuchiya et al., PRL, 2007). In Kanazawa, one of our observation sites, two downward TGFs were detected in December 2017 and January 2018. Both TGFs coincided with negative-polarity RF pulses whose peak currents were lager than 150 kA, reported by JLDN. Based on RF waveforms obtained by our broadband low-frequency observation network, they are categorized into negative-polarity EIPs. We present the first report on the connection between EIPs and downward TGFs (Wada et al., JGR Atmospheres, 2020).

Keywords: thunderstorm, terrestrial gamma-ray flash, high-energy atmospheric physics, atmospheric electricity

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Photodetachment of electrons at sprite altitudes by visible radiation of tropospheric lightning discharges as a mechanism of initiation of sprite streamers

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Experimental evidence suggests that a strong lightning discharge is a necessary but not sufficient condition for initiation of sprite streamers [Lang et al., JGR, 116, A10306, 2011]. The strength of the lightning in terms of sprite production potential is usually characterized by a charge moment change (i.e., charge removed by lightning times the altitude from which it was removed), and the existing modeling quantitatively establishes that for experimentally documented levels of charge moment changes the presence of relatively dense plasma irregularities in the mesosphere above thunderstorms is mandatory for the initiation of sprite streamers [Qin et al., JGR, 116, A06305, 2011; GRL, 40, 4777, 2013; Nat. Comm., 5, 3740, 2014]. Although some of the inhomogeneities are documented to appear in the same regions of space as previously formed sprites, and therefore likely represent perturbations left by previous sprite discharges, the exact origin of these inhomogeneities remains unknown. One possibility is that small traces of metallic species existing at sprite altitudes due to meteoric ablation can be ionized by relatively diffuse sprite halos (through electron impact collisions or through photoionization by halo emissions) that often precede formation of sprite streamers [Janalizadeh and Pasko, Abstracts AE21A-08; AE21B-3132; presented at 2018 Fall Meeting, AGU, Washington DC, 10-14 Dec., 2018]. Quick and Krider [JGR, 118, 1868, 2013] provide a comprehensive overview of the available lightning optical pulse data based on the ground [e.g., Guo and Krider, JGR, 87, 8913, 1982], the satellite [e.g., Kirkland et al., JGR, 106, 33499, 2001], and the high-altitude aircraft [e.g., Mach et al., Atmos. Res., 76, 386, 2005] observations. In spite of the significant differences in the sensing technology, the viewing geometry, the effects of clouds and the wavelength dependent absorption of light propagating horizontally and vertically in the atmosphere, the authors have been able to demonstrate consistency (within an oder of magnitude) of different data sets in terms of the median peak powers and the pulse durations [Quick and Krider, 2013]. Quick and Krider [2013] report the median total optical energy (from 400 to 1000 nm, not corrected for atmospheric transmission) for negative first strokes to be 3.6e6 Joules, the median for positive CG strokes 9.3e6 Joules, and the peak for positive CG strokes 2.6e7 Joules. The FORTE satellite median energy is 4.5e5 Joules and the peak is 1e9 Joules [Kirkland et al., 2001]. Following Quick and Krider [2013] we assume that a point lightning source radiates as a perfect black body with 30,000 K temperature [Orville, J. Atmos. Sci., 25, 827, 1968] from altitudes 0 km and 10 km and account for effects of atmospheric absorption along the vertical path toward 70 km altitude. We quantitatively demonstrate that photodetachment of electrons from O-, O2-, and OH- ions at mesospheric altitudes due to optical emissions (400-1000 nm) directly generated by lightning discharges at low altitudes can contribute to formation of initial plasma irregularities required for the initiation of sprite streamers. Additional information on choice of negative ions chosen for this study (i.e., their electron affinities and photodetachment cross sections) is given in a companion abstract on photodetachment by sprite halo emissions presented at this meeting by Janalizadeh and Pasko. We note that we do not consider NO3- ions as these only can be photoionized by UV emissions with wavelength <315.9 nm that are expected to be significantly absorbed for the chosen modeling geometry and therefore are excluded from current analysis.

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[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS11] Expedition Earth: discovering our planet's past and future through scientific drilling

convener:Junichiro Kuroda(Department of Ocean Floor Geoscience, Atmosphere and Ocean Research Institute, the University of Tokyo), Katsuyoshi Michibayashi(Department of Earth and Planetary Sciences, Nagoya University), Kohtaro Ujiie(Graduate School of Life and Environmental Sciences, University of Tsukuba), Clive Robert Neal(University of Notre Dame)

This multidisciplinary session encourages presentations of various scientific researches that uses samples and data obtained through scientific drilling projects such as the International Ocean Discovery Program (IODP) and the International Continental Scientific Drilling Project (ICDP). We organize several subsessions on the basis of scientific themes to effectively convey achievements and information to the audiences. These scientific themes include "Resilient and Dynamic Earth" (geohazard, climate change and natural resources), "Terrestrial to Extraterrestrial" (plate tectonics, planetary structure, asteroid impacts, and deep biosphere/astrobiology), and "Innovative Science and Technology" (subseafloor observatories, drilling technology development and data science). This session will invite lectures that summarize recent achievements and highlights in each field, and encourages presentations on recently implemented ICDP projects and IODP expeditions. We also aim to provide information on upcoming ICDP projects or IODP expeditions, and we welcome contributions on state-of-the art technological developments related to scientific drilling. The principal goal of this session is to provide a place where participants can efficiently acquire substantial information related to scientific drilling.
Also please visit the J-DESC event page for more details on this session;
J-DESC event page

[MIS11-01] Exploring the Arctic deep biosphere and its linkage to carbon cycling and climate variation with Chikyu

*Fumio Inagaki[1], Steffen L. Jørgensen[2], Yasuhiro Yamada[1], Rolf Birger Pedersen[2], ArcDB Project Team (1.Japan Agency for Marine-Earth Science and Technology (JAMSTEC), 2.University of Bergen, Norway)

[MIS11-02] Exploring the World’s Largest LIP: Testing the Ontong Java Nui hypothesis

*Takashi Sano[1], Maria Luisa Tejada[2], Clive R. Neal[3], Millard Coffin[4], Masao Nakanishi[5], Peter J. Michael[6], Jörg Geldmacher[7], Takeshi Hanyu[2], Seiichi Miura[2], Christian Timm[8], Anthony A. P. Koppers[9], Daisuke Suetsugu[2], Takashi Tonegawa[2], Akira Ishikawa[10], Kenji Shimizu[2], Paterno Castillo[11] (1.National Museum of Nature and Science, 2.Japan Agency for Marine-Earth Science and Technology, 3.University of Notre Dame, USA, 4.University of Tasmania, Australia, 5.Chiba University, 6.The University of Tulsa, USA, 7.GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany, 8.GNS Science, New Zealand, 9.Oregon State University, USA, 10.Tokyo Institute of Technology, 11.Scripps Institution of Oceanography, UCSD, USA)

[MIS11-03] Pre-prososal 951: The middle aged upper crust penetration on the North Arch off-Hawaii MoHole candidate site

*Susumu Umino[1,2], Tomoaki Morishita[1,2], Jun-Ichi Kimura[2], Mikiya Yamashita[3,2], Nobukazu Seama[4], Shigeaki Ono[2], Natsue Abe[2,1], Katsuyoshi Michibayashi[5,2] (1.Kanazawa University, 2.JAMSTEC, 3.Geological Survey of Japan, 4.Kobe University, 5.Nagoya University)

[MIS11-04] The crustal and upper mantle structure of the Hawaiian-Emperor Seamount Chain from marine seismic data

★Invited Papers

*Brian Boston[1], Philip Cilli[2], Robert Dunn[3], Donna J. Shillington[4], Anthony B. Watts[2], Ingo Grevemeyer[5], Laura Gómez de la Peña[5], Garrett Ito[3], Paul Wessel[3], Uri ten Brink[6], Nathan Miller[6] (1.Lamont-Doherty Earth Observatory, 2.University of Oxford, 3.University of Hawaii at Manoa, 4.Northern Arizona University, 5.GEOMAR, 6.USGS)

[MIS11-05] Drilling a Heterogeneous Lower Ocean Crust and Mantle
★Invited Papers

*Henry J Dick[1] (1.Woods Hole Oceanographic Institution)

[MIS11-06] Overview of IODP Exp. 376: hydrothermal systems and submarine eruption processes of Brothers volcano, Kermadec Arc

*Iona McIntosh[1], Cornel de Ronde[2], Susan Humphris[3], Tobias Höfig[4], Agnes Reyes[2], the IODP Expedition 376 Scientists (1.Japan Agency for Marine-Earth Science and Technology, 2.GNS Science, New Zealand, 3.Woods Hole Oceanographic Institution, USA, 4.International Ocean Discovery Program, Texas A&M University, USA)

Exploring the Arctic deep biosphere and its linkage to carbon cycling and climate variation with Chikyu

*Fumio Inagaki[1], Steffen L. Jørgensen[2], Yasuhiro Yamada[1], Rolf Birger Pedersen[2], ArcDB Project Team

1. Japan Agency for Marine-Earth Science and Technology (JAMSTEC), 2. University of Bergen, Norway

As the profound impacts and implications of the on-going climate change are becoming increasingly apparent, so too is the urgency to understand the complex feedback processes that regulate the Earth systems. Jointly, the scientific community agrees that the Arctic is a critically important region since it is responding to climate change more strongly than any other region in the world. Especially relevant is to understand the fluxes of carbon, from and within these remote regions. Great efforts are currently being made to advance our knowledge of carbon cycling in the Arctic –including terrestrial, marine, and cryospheric realms. However, one significant province is still left unexplored—the Arctic subseafloor. Knowledge of this environment is still comparatively poor, despite the Arctic subseafloor containing a significant proportion of the global carbon stock –its' short and long-term fate is tightly linked to both global climate change and the activity of microbial life inhabiting the deep marine biosphere. Further, the subsurface sedimentary sequence represents an invaluable archive of the past Arctic climatic variability, and has recorded some of the environmental consequences, and hence is key to understand and constrain future trajectories for our planet' s evolution. For example, during the early-to-middle Eocene, it has been discovered that fresh-to-brackish water conditions must have been strongly stratified, creating a freshwater lid and growth of freshwater algae for nearly a million years along the Arctic continental margin. However, as of today, the nature and extent of deep-biosphere microbial communities and their correlations to the past climate and environmental changes and carbon cycling are almost completely unexplored in the Arctic Ocean margin. As the subseafloor sediment contains invaluable information about the past oceanographic, climatic and depositional conditions, the scientific deep drilling expedition will allow us to look more detail millions of years back into previous global warming periods and learn how past variability in climate, ice-coverage, ocean water circulations, and continental input of organic matter have systematically influenced the past and current biospheres and carbon cycles in the Arctic Ocean margin. To address these issues, a scientific ocean drilling project to explore a 3,300 meter-deep, ~50 million-year-old subseafloor environment with riser drilling of the Chikyu at the Hinlopen Margin, southern Nansen Basin in the Arctic Ocean is proposed.

Keywords: Scientific Ocean Drilling, Arctic Ocean, Deep Biosphere, Nansen Basin, Biogeochemical Carbon Cycling, Chikyu

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Exploring the World’s Largest LIP: Testing the Ontong Java Nui hypothesis

*Takashi Sano[1], Maria Luisa Tejada[2], Clive R. Neal[3], Millard Coffin[4], Masao Nakanishi[5], Peter J. Michael[6], Jörg Geldmacher[7], Takeshi Hanyu[2], Seiichi Miura[2], Christian Timm[8], Anthony A. P. Koppers[9], Daisuke Suetsugu[2], Takashi Tonegawa[2], Akira Ishikawa[10], Kenji Shimizu[2], Paterno Castillo[11]

1. National Museum of Nature and Science, 2. Japan Agency for Marine-Earth Science and Technology, 3. University of Notre Dame, USA, 4. University of Tasmania, Australia, 5. Chiba University, 6. The University of Tulsa, USA, 7. GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany, 8. GNS Science, New Zealand, 9. Oregon State University, USA, 10. Tokyo Institute of Technology, 11. Scripps Institution of Oceanography, UCSD, USA

Large Igneous Provinces (LIPs) such as the Ontong Java Plateau in the western central Pacific (OJP) are important because they provide information on mantle processes and composition, and because their formation may have global environmental consequences. The OJP is the largest oceanic plateau and is probably the most voluminous igneous edifice on Earth. Despite its importance, the size, volume, and formation rate of the OJP are not well constrained yet. The maximum extent of OJP-related volcanism may be even greater, as volcanological studies indicate that long lava flows (or sills) from the OJP may have reached the adjacent Nauru, East Mariana, and possibly Pigafetta basins. Moreover, the similarity in age and geochemistry of lava flows from the Ontong Java, Hikurangi, and Manihiki plateaus suggests that they may have been once part of a single LIP (Ontong Java Nui). If true, the massive volcanism may have covered >1% of Earth’s surface. The lack of detailed knowledge of the size, age, and composition of the OJP has given rise to various models such as a surfacing mantle plume head, bolide impact, and fusible mantle melting, but no consensus model exists to explain its origin.
The OJP is divided into the High Plateau to the west and the Eastern Salient to the east and is presently the best sampled among Pacific oceanic plateaus. The basaltic basement of the OJP has been sampled by seven Deep Sea Drilling Project (DSDP Site 289) and Ocean Drilling Program (ODP Sites 289, 803, 807, 1183, 1185, 1186, and 1187) sites –but they are concentrated only in the High Plateau. In order to examine the true extent of the OJP (i.e., whether the flows or sills in the Nauru, East Mariana, and Pigafetta basins, as well as those from the Manihiki, and Hikurangi plateaus are parts of the Ontong Java Nui volcanism), we propose drilling at five sites on the Eastern Salient and adjacent basins to recover basement samples. We also propose drilling through the sedimentary section on the Magellan Rise, a small plateau that formed >20 Myr before the proposed Ontong Java Nui emplacement. Because of its older age, the sedimentary sequence on Magellan Plateau may preserve ash layers that cover all Ontong Java related eruption events.

Keywords: LIPs, magma, basalt

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Pre-prososal 951: The middle aged upper crust penetration on the North Arch off-Hawaii MoHole candidate site

*Susumu Umino[1,2], Tomoaki Morishita[1,2], Jun-Ichi Kimura[2], Mikiya Yamashita[3,2], Nobukazu Seama[4], Shigeaki Ono[2], Natsue Abe[2,1], Katsuyoshi Michibayashi[5,2]

1. Kanazawa University, 2. JAMSTEC, 3. Geological Survey of Japan, 4. Kobe University, 5. Nagoya University

We propose to drill a complete upper crustal section and into the uppermost gabbros in ~80 Ma crust spread at 8 cm/a on the North Arch off-Hawaii (Fig. 1). The goals are to better understand the physical, chemical, and biological architecture and evolution of the oceanic crust, with special reference to the relationship between the diversity of Moho and aging of oceanic lithosphere including the effect of North Arch volcanism, as well as the history of hazardous giant landslides from the Hawaiian volcanoes.

Previous drilling into tectonically undisturbed oceanic crust is limited and skewed to young and slow-spread crust <4 cm/a, with a wide gap of crustal age between 20 and 110 Ma, including the world average age of 63 Ma and spreading rate of 8 cm/a (Fig. 2). Thus, previous drilling of oceanic crust has not sampled representative oceanic crust. The oceanic crust on the North Arch off-Hawaii meets the average spreading rate and the age gap and is ideal to understand the physical and chemical evolution of aged oceanic lithosphere and the diversity of Moho.

The overarching goals to be addressed by drilling are to better constrain

1) the nature of layer 2/3 transition and its relations with the dike-plutonic transition,

2) the relationships between the style of crustal extension and the architecture of the upper crust,

3) the styles and vigor of hydrothermal circulation and alteration with declining temperature in the aged oceanic crust,

4) the physical and chemical evolution of oceanic lithosphere with special reference to the Moho diversity and the North Arch volcanism,

5) the frequency, size and possible failure mechanics of hazardous giant landslides caused by the periodic collapse of Hawaiian shield volcanoes, and

6) the depth limits of microbial life in ~85 Ma aged, hydrated, and cold crust where metabolic strategies have remained completely unexplored.

We have yet to penetrate through the dike-plutonic transition and recover the lower crustal cumulates, which are critical to understand the relationships between lithology and physical property through the

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Layer 2/3 transition, and the magmatic accretion and hydrothermal cooling at depth.

The style of crustal extension differs in fast and intermediate spreading ridges, which makes the distinct density structures of the upper crust. Fast-spread oceanic crust comprises dense sheet flows underlain by thin sheeted dikes. This density structure enhances more magma to extrude, allowing the crust to extend solely by magmatic accretion. In contrast, the intermediate-spread crust consists of less dense, pillow-dominant extrusive rocks, yielding an apparent level of neutral buoyancy that traps magma to develop the sheeted dikes below. The crust consequently extends by dike intrusions in the lower levels and by faults in the shallow levels to form axial troughs. The style of crustal extension from magmatic accretion to stretching changes in a spreading rate interval of 7–10 cm/a. The relationship between the plate spreading mode and the resulting oceanic crustal architecture is a key issue for this drilling program.

Aged lithosphere upon subduction is important in generating arc magmas and large earthquakes through dehydration, and ultimately the geochemical evolution of the mantle. Aging of lithosphere also causes the diversity of Moho in the Pacific Plate. Correlation of magma geochemistry, alteration, stress conditions and seismic structures investigated by drilling enables us to understand the relationship between the Moho diversity and the aging of oceanic lithosphere.

The enormous size and rapid growth of Hawaiian volcanoes causes them to become gravitationally unstable and collapse, which have generated some of the largest landslides on Earth and undoubtedly produced colossal tsunami waves.

Drilling into the deep crust would provide the limit of extremophilic biological communities that could survive or once survived at extremely high temperatures or with low nutrient and energy supplies.

Keywords: Oceanfloor Drilling, MoHole, Upper crust penetration off Hawaii, Crustal architecture, North Arch volcanism, Giant landslides

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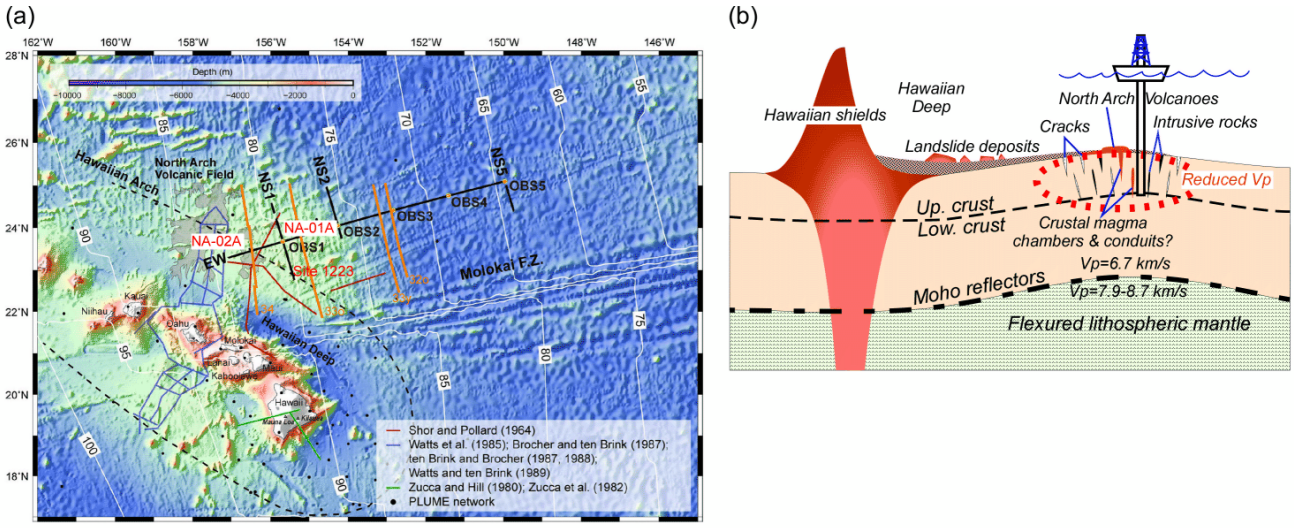

Fig. 1. (a) Proposed drill sites (stars) and the bathymetry of the North Arch volcanic field [after Ohira et al., 2018]. Magnetic anomalies (orange lines) are based on NOAA Marine Trackline Geophysical Data (https://www.ngdc.noaa.gov/mgg/geodas/trackline.html). (b) Flexured lithosphere by the load of Hawaiian volcanoes formed exensional cracks in the shallow levels on the North Arch, which reduces crustal Vps[Ohira et al., 2008]. In contrast, Vp structures in the uppermost mantle are comparable to those in other lithospheric mantle formed at fast-spreading ridges, indicating preservation of the original structures.

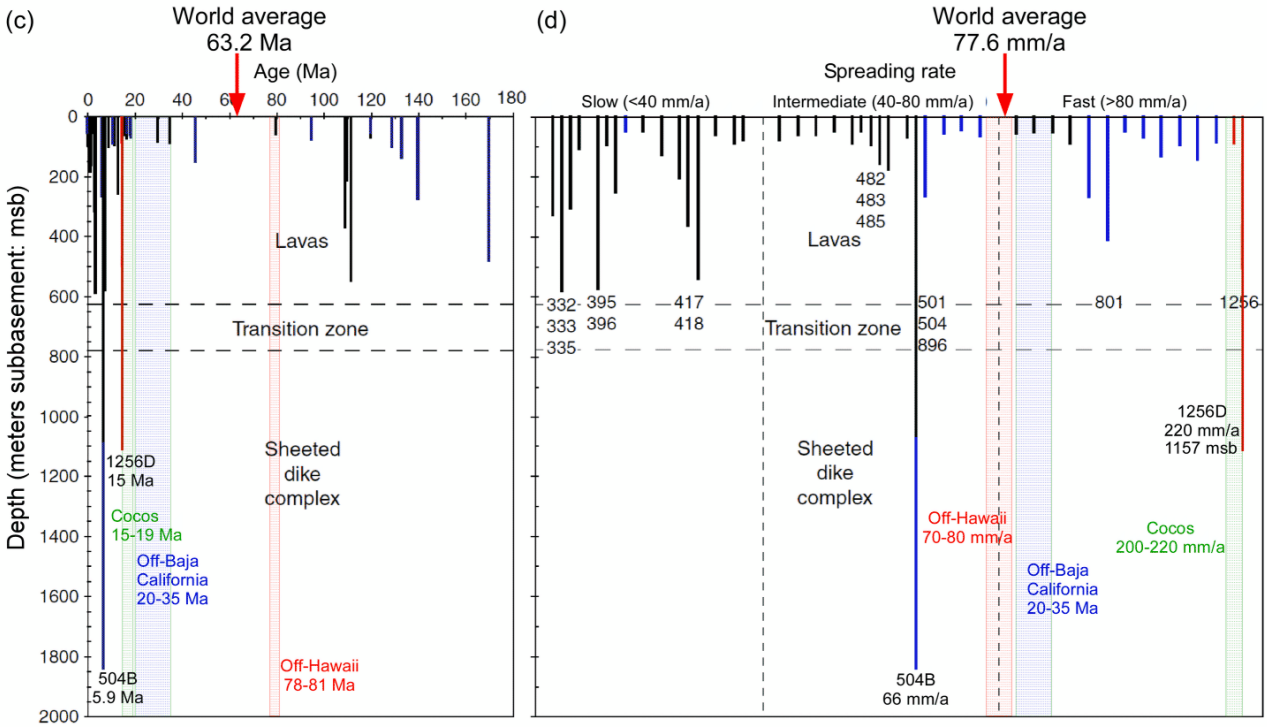

Fig. 2. Ocean drill holes deeper than 50 m into the oceanic basement plotted against the basement age (c) and categorized on the basis of spreading rate that formed the basement crust (d) [modified after Teagle et al., 2006]. World average age and spreading rate are based on the 3.6 min grid data from EarthByte agegrid 2008 [Muller et al., 2008].

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The crustal and upper mantle structure of the Hawaiian-Emperor Seamount Chain from marine seismic data

*Brian Boston[1], Philip Cilli[2], Robert Dunn[3], Donna J. Shillington[4], Anthony B. Watts[2], Ingo Grevemeyer[5], Laura Gómez de la Peña[5], Garrett Ito[3], Paul Wessel[3], Uri ten Brink[6], Nathan Miller[6]

1. Lamont-Doherty Earth Observatory, 2. University of Oxford, 3. University of Hawaii at Manoa, 4. Northern Arizona University, 5. GEOMAR, 6. USGS

The northeast Hawaiian Arch is one of the site locations considered for scientific drilling of Cretaceous oceanic crust and Moho. We used R/V *Marcus G. Langseth* to acquire deep-penetration, multichannel seismic reflection data and wide-angle seismic data across and along the Hawaiian Island Chain to examine the crustal structure resulting from recent (>5 Ma) volcano construction and the structure of the Cretaceous oceanic lithosphere on which the volcanic chain was built. For acquisition of the seismic reflection data, we used a nominal 6600-cu-in tuned air gun array and a 15-km-long hydrophone streamer cable. For wide-angle seismic data, we used the same source with ocean-bottom seismometers spaced at ~15 km. Additionally, legacy data from common depth point and constant offset profile data acquired on R/V *Robert D. Conrad* and R/V *Kana Keoki* during August-September 1982 have been reprocessed from the original field data. The reprocessed profiles show significant improvement in image quality allowing for additional constraints on the Moho and deformation from volcanic loading of the plate. Analyses of the data have allowed imaging of the contact between the pre-existing oceanic crust and the volcanic seamounts, the structure of the surrounding Pacific Plate, and the effects of volcanic loading on the oceanic plate.

Keywords: Hawaii, Ocean Drilling, Seismic Data

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Drilling a Heterogeneous Lower Ocean Crust and Mantle

*Henry J Dick[1]

1. Woods Hole Oceanographic Institution

Deep drilling in the lower ocean crust and mantle has provided enormous scientific return from remarkably few expeditions. Deep drilling has penetrated through the lavas and dikes to the dike-gabbro transition in fast spread East Pacific Rise Crust, down through the seismic layer 2-3 boundary in sheeted dikes in slow-spread Costa Rica rift crust, a 1400 m section of slow-spreading Mid-Atlantic Ridge lower crust, another 1508-m section of lower crust at the ultraslow spreading SW Indian Ridge, and short sections of the lowermost and uppermost East Pacific Rise crust at Hess Deep. Viewed from the perspective of the Penrose Model of a uniform layered ocean crust and mantle, then, the composition and architecture of the ocean crust should be well determined. These various pieces of crust, however, formed over a wide range of magma flux and spreading rates from 60 to 14 mm/yr. The long section of MAR crust formed at low melt flux, and bears only modest resemblance to the long section of ultraslow spread SW Indian Ridge crust formed at moderate melt flux. The latter has as much in common with East Pacific Rise crust as it does with the former. On the Gakkel and SW Indian Ridges, there are large regions with little or no crust at all, and at slow spreading ridges, both seismology and sampling and mapping show that large portions of the crust is composed only of lavas and dikes overlying the mantle. Thus, the composition and architecture of the ocean crust is highly variable and remains poorly constrained. The diversity of what has been found to date, however, provides the basis for planning a systematic program of seafloor drilling that will provide a realistic image of how the lower ocean crust forms, and how extension at accretionary ocean ridge plate boundaries is accommodated, and how that relates to evolution of the underlying mantle.

Keywords: Lower Ocean Crust, Mantle, Crustal architecture

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Overview of IODP Exp. 376: hydrothermal systems and submarine eruption processes of Brothers volcano, Kermadec Arc

*Iona McIntosh[1], Cornel de Ronde[2], Susan Humphris[3], Tobias Höfig[4], Agnes Reyes[2], the IODP Expedition 376 Scientists

1. Japan Agency for Marine-Earth Science and Technology, 2. GNS Science, New Zealand, 3. Woods Hole Oceanographic Institution, USA, 4. International Ocean Discovery Program, Texas A&M University, USA

The recent International Ocean Discovery Program (IODP) Expedition 376 to Brothers volcano in the Kermadec Arc in May-July 2018 is an example of the ambitious science that can be achieved through scientific drilling. Brothers volcano is a submarine caldera volcano that hosts two distinct, active hydrothermal systems –one dominated by seawater-rock interactions, and the other dominated by magmatic fluids and gases. As such, it is an exciting target for research related to geohazards (what are the eruption processes and related hazards of submarine caldera volcanoes?), hydrothermal mineralisation (what controls these processes and how do they relate to ore deposits now exposed on land?) and geobiology (what life may exist in this extreme range of temperature and pH conditions?). Despite challenging drilling conditions (including temperatures as high as 236 ˚C and pH as low as 1.8), with D/V JOIDES Resolution we recovered 222.4 m of core from five sites across the volcano as well as three borehole fluid samples. Here we present an overview of the drilling operations, the preliminary findings of the Expedition, and future plans to investigate its submarine eruption dynamics.

Recovered core material consists primarily of dacitic volcaniclastics (breccia) and lavas, affected by pervasive and complex alteration. We show that the extent of alteration reflects primary lithological porosity and the contrasting spatial and temporal contributions of seawater, hydrothermal fluid and magmatic fluid. Our findings suggest a two-step model for the origins of metal-rich volcanogenic massive sulphide deposits that is linked to caldera formation (de Ronde et al, 2019). In this model, initial hydrothermal activity of the pre-caldera volcano is dominated by magmatic gases and hypersaline brines. The gases mix with seawater as they ascend to the seafloor, while the dense hypersaline brines remain in the subsurface. Following caldera collapse, seawater is able to infiltrate the volcano through fault-controlled permeability, where it interacts with wall rock and the sequestered hypersaline brines before finally transporting their associated metals back to the seafloor where it forms Cu-Zn-Au-rich chimneys at the caldera rim. This two-step process may be common at submarine arc volcanoes that host volcanogenic massive sulphide deposits, and provides a mechanism for efficiently concentrating mineralisation at or near the seafloor. Future work will focus on identifying the volcanic eruption processes that are able to produce a submarine caldera at water depths of more than 1300 m, where hydrostatic pressure may modify eruption styles by limiting the amount of degassing and bubble growth that is possible during magma ascent.

de Ronde, Humphris, Höfig, Reyes, and the IODP Expedition 376 Scientists (2019) Critical role of caldera collapse in the formation of seafloor mineralization: The case of Brothers volcano. Geology, v.47, p.762-766

Keywords: IODP, submarine volcanism, hydrothermal

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[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS11] Expedition Earth: discovering our planet's past and future through scientific drilling

convener:Junichiro Kuroda(Department of Ocean Floor Geoscience, Atmosphere and Ocean Research Institute, the University of Tokyo), Katsuyoshi Michibayashi(Department of Earth and Planetary Sciences, Nagoya University), Kohtaro Ujiie(Graduate School of Life and Environmental Sciences, University of Tsukuba), Clive Robert Neal(University of Notre Dame)

This multidisciplinary session encourages presentations of various scientific researches that uses samples and data obtained through scientific drilling projects such as the International Ocean Discovery Program (IODP) and the International Continental Scientific Drilling Project (ICDP). We organize several subsessions on the basis of scientific themes to effectively convey achievements and information to the audiences. These scientific themes include "Resilient and Dynamic Earth" (geohazard, climate change and natural resources), "Terrestrial to Extraterrestrial" (plate tectonics, planetary structure, asteroid impacts, and deep biosphere/astrobiology), and "Innovative Science and Technology" (subseafloor observatories, drilling technology development and data science). This session will invite lectures that summarize recent achievements and highlights in each field, and encourages presentations on recently implemented ICDP projects and IODP expeditions. We also aim to provide information on upcoming ICDP projects or IODP expeditions, and we welcome contributions on state-of-the art technological developments related to scientific drilling. The principal goal of this session is to provide a place where participants can efficiently acquire substantial information related to scientific drilling.
Also please visit the J-DESC event page for more details on this session;
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[MIS11-07] IODP/ICDP Expedition 364: Using Geophysical Data to Map Suevite and Impact Melt in the Chicxulub Impact Crater

★Invited Papers

*Gail Lynn Christeson[1], Joanna Morgan[2], Sean Gulick[1] (1.University of Texas at Austin, 2.Imperial College London)

[MIS11-08] Cretaceous paleoceanographic events recorded in sedimentary sequences from IODP Exp. 369 at southern high latitude: Oxygen and carbon isotope stratigraphy and implications from biomarkers

*Takashi Hasegawa[1], Akiko S. Goto[1], Scientists of IODP Exp. 369 (1.Faculty of Geoscience and Civil Engineering, Institute of Science and Engineering, Kanazawa University)

[MIS11-09] **Preliminary results of IODP Expedition 379 (Amundsen Sea West Antarctic Ice Sheet History)**

*Keiji Horikawa[1], Masahiro Noda[2], Masao Iwai[3], Masako Yamane[4], Karsten Gohl[6], Julia S Wellner[7], Scientists IODP Expedition 379[5] (1.Graduate School of Engineer and Science for Research, University of Toyama, 2.Graduate School of Engineer and Science for Education, University of Toyama, 3.Center for Advanced Marine Core Research, Kochi University, 4.Institute for Space-Earth Environmental Research, Nagoya University, 5.IODP Expedition 379 Scientists, 6.Alfred Wegener Institute Helmholtz—Center for Polar and Marine Research, Germany, 7.Earth & Atmospheric Sciences, University of Houston)

[MIS11-10] **Foraminiferal Na/Ca suggests decreased seawater Ca concentration over the past 40 Myr.**

★Invited Papers

*Yair Rosenthal[1], Xiaoli Zhou[1], Weimin Si[2] (1.Rutgers University, 2.Brown University)

[MIS11-11] **Deep microbial proliferation at the basalt interface in aged oceanic crust**

*Yohey Suzuki[1] (1.Graduate School of Science, The University of Tokyo)

[MIS11-12] IODP Expedition 385: Guaymas Basin Tectonics and Biosphere

*Yuki Morono[1], Andreas Teske[2], Daniel Lizarralde[3], Tobias W Höfig[4], IODP EXPEDITION 385 SCIENTISTS[5]
(1.Kochi Institute for Core Sample Research, Japan Agency for Marine-Earth Science and Technology, 2.Department of Marine Sciences, University of North Carolina at Chapel Hill, 3.Department of Geology and Geophysics, Woods Hole Oceanographic Institution, 4.International Ocean Discovery Program, Texas A&M University, 5.Full list of Exp. 385 Scientific Participants: http://iodp.tamu.edu/scienceops/precruise/guaymas/participants.html)

IODP/ICDP Expedition 364: Using Geophysical Data to Map Suevite and Impact Melt in the Chicxulub Impact Crater

*Gail Lynn Christeson[1], Joanna Morgan[2], Sean Gulick[1]

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IODP/ICDP Expedition 364 drilled one hole (M0077A) into the Chicxulub peak ring, recovering core from depths 505.7-1334.7 m below the seafloor. From bottom to top, the core consisted of ~587 m of shocked granitic target rocks, ~25 m of impact melt rock, ~104 m of suevite, and ~112 m of post-impact sedimentary rock. Analyses of core material, combined with numerical modeling, reveal details of impact and post-impact processes including: 1) The shocked granitic target rocks originated from 8-11 km depth and traveled both outwards and inwards during crater excavation and collapse; during this time these rocks experiences pervasive fracturing. 2) The impact melt rock and lowermost suevite were deposited rapidly by outward flowing melt with possible melt-water interaction (MWI). 3) The majority of the suevite, the uppermost 90 m, was deposited as a resurge deposit formed through settling and seiches in the flooded crater. 4) The lowermost sedimentary rock records the first day of the Cenozoic, and includes evidence for tsunami transporting material from distant shorelines and for impact-generated fires.

We can use geophysical data to map units with distinct physical properties from hole M0077A throughout the Chicxulub impact crater. We utilized the full-waveform inversion (FWI) method to produce high-resolution velocity models of the upper 1.5-2 km on a grid of two-dimensional seismic reflection profiles. A prominent feature in the FWI velocity images is a layer of low-velocity rocks at a depth just below the K-Pg boundary that is associated with the suevite resurge deposit at hole M0077A. The resurge deposit is fairly uniform in thickness (175-190 m) in the annular trough, peak ring, and central basin. The peak ring is identified by elevated topography and low seismic velocities associated with the shocked and fractured granitic target rock. The peak ring is narrower and more elevated in the west near hole M0077A, and is wider and deeper in the east. These differences may be related to pre-impact heterogeneity, as water depth and sediment thickness (deeper water and thicker sediment to northeast) varied with azimuth around the impact site. The top of impact melt is identified in the annular trough and central basin by a low frequency reflector and high seismic velocities. The thickness of material between the base of the suevite resurge deposit and the top of melt is much greater in the central basin than in the annular trough; upwarped features above the melt sheet in the central basin may be possible hydrothermal upflow zones.

Keywords: impact crater, Chicxulub, IODP

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Cretaceous paleoceanographic events recorded in sedimentary sequences from IODP Exp. 369 at southern high latitude: Oxygen and carbon isotope stratigraphy and implications from biomarkers

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Paleoceanographic perturbation at southern high latitudes during the Cretaceous greenhouse is one of the primary targets of IODP Exp. 369. Carbon and oxygen isotope stratigraphy of the important intervals including Oceanic Anoxic Event (OAE)1d, Mid-Cenomanian Event (MCE) and OAE2 recovered by the cruise indicates that global correlations of the events are not straightforward with the isotope stratigraphy. Short-term fluctuations of carbon isotope values larger than 0.5 permil presumably derived from orbital forcing, potenitally masking the global signal near the MCE interval. Carbonate carbon isotope chemostratigraphy reveals the horizons of “onset” and “recovery” of the carbon isotope excursion (CIE) across OAE2 although the main part of the event could not be analyzed because of a “carbonate-free interval (CFI)”. A characteristic biomarker derived from haptophytes, tetracontadienone (C40:2 Et alkenone), was found in the CFI and provided an important target for carbon isotope analysis. The stratigraphic pattern of carbon isotope values of the alkenone filled one interval of the gap and showed a +2.5 to +3.0 permil positive excursion in addition to the magnitude of CIE observed with the carbonate (~4 permil CIE is suggested in total). It also showed that black organic-rich layers were stratigraphically located below the first peak of the globally known CIE of OAE2. Lycopane, a biomarker known from various anoxic sediments, and n-alkanes longer than C40 that characterized the black layers of the OAE2 interval were also found from the interval correlative to OAE1d from U1516, suggesting comparable paleoceanographic conditions during OAE1d and OAE2 in this region.

Keywords: IODP, Cretaceous, biomarkers, OAE

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Preliminary results of IODP Expedition 379 (Amundsen Sea West Antarctic Ice Sheet History)

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The Amundsen Sea sector of Antarctica is the most vulnerable part of the West Antarctic Ice Sheet (WAIS) because of the great water depth at the grounding line, the absence of substantial ice shelves, and potential intrusion of relatively warmer Circumpolar Deep Water (CDW) onto the Amundsen Sea continental shelf (e.g., Hillenbrand et al., 2017, Holland et al., 2019). The WAIS has been losing ice throughout the satellite record, currently at a rate equivalent to global sea-level rise of ~4.5 cm/100 yr (2012–2017 average) (Shepherd et al., 2018). Recent models suggest that much of the Antarctic Ice Sheet could be lost even under relatively moderate greenhouse gas emission scenarios (RCP4.5) (DeConto and Pollard, 2016). Given these situations, the IODP Expedition 379 aimed to reconstruct the WAIS history during the Neogene and Quaternary to unravel driving forces of the retreat and advances of the WAIS.

During the IODP Expedition 379 in January–March 2019, persistent sea ice prevented access to all proposed continental shelf sites and abundant mobile icebergs forced loss of ~50% drilling time, however the expedition accomplished two successful drill sites (U1532 and U1533) on the continental rise of the Amundsen Sea (Gohl et al., 2019). Site U1532 drilled to a depth of 794 m below seafloor (90% recovery) and obtained a nearly continuous record from the upper Miocene to the Pleistocene (< 6.033 Ma), while site U1533 reached 383 m below seafloor with 70% recovery. These sites are located on a large sediment drift, and high sedimentation rates (10–61 cm/kyr) in the Pliocene–Miocene sequence allow us to analyze high-resolution paleoceanographic changes in this region. Both cores are characterized by cyclic lithofacies of massive muddy sediments, including higher microfossil abundance and ice-rafted debris (IRD), and laminated terrigenous muddy sediments, suggesting a possibility of repetitive cycles corresponding to interglacial and glacial cycles (Gohl et al., 2019).
Pb is mainly supplied to the ocean by continental weathering, and its particle reactive nature results in shorter residence time (20–400 yrs) in the ocean. These geochemical characteristics make it useful for investigating region-specific continental weathering, and paleo-seawater records of Pb isotope compositions can be obtained from Fe-Mn oxide leaching of marine sediments. Preliminary data on Fe-Mn oxide Pb isotopes ($^{206,207,208}Pb/^{204}Pb$) of massive muddy sediments from U1532 showed systematically lower values compared to those of laminated terrigenous muddy sediments, suggesting that weathering intensity in western Antarctica with relatively unradiogenic Pb were increased during the intervals with higher abundance of microfossil and IRD. Post-expedition studies on mineralogical and geochemical analyses of IRD, microfossil analyses, organic geochemical analyses done by exp. 379 scientists will further improve our understanding of the WAIS history over the glacial–interglacial and longer timescales in the Pliocene.

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Keywords: IODP, Amundsen Sea, West Antarctic Ice Sheet, Pliocene

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Foraminiferal Na/Ca suggests decreased seawater Ca concentration over the past 40 Myr.

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The reconstruction of seawater calcium concentration ($[Ca^{2+}]_{SW}$) in the geologic past is crucial to our understanding of long-term changes in the carbon cycle as related to climate and tectonics. Here we propose that because of the long oceanic residence time of Na^{+} (>>50 Myr), variations in foraminifera Na/Ca potentially offer a new proxy of seawater calcium concentration in the past. We combined evidence from culture experiments on live foraminifers, core tops calibration and down-core measurements of benthic foraminifera to show that seawater $[Ca^{2+}]_{SW}$ concentration was substantially lower between ~20-40 Ma, and increased to the modern level through the past 15 Myr. Combining the Neogene $[Ca^{2+}]_{SW}$ record with our global reconstructions of Mass Accumulation Rates of the main marine calcifying groups for the past 15 Myr, used to assess variations in alkalinity fluxes from continental weathering and changes in the oceanic calcite compensation depth (CCD), we explore possible causes for the observed changes in seawater chemistry.

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Deep microbial proliferation at the basalt interface in aged oceanic crust

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The upper oceanic crust is mainly composed of basaltic lava that constitutes one of the largest habitable zones on Earth. However, the nature of deep microbial life in oceanic crust remains poorly understood, especially where old cold basaltic rock interacts with seawater beneath sediment. It is shown that microbial cells are densely concentrated in Fe-rich smectite on fracture surfaces and veins in 33.5- and 104-million-year-old (Ma) subseafloor basaltic rock drilled during the IODP Expedition 329. The Fe-rich smectite is locally enriched in organic carbon. Nanoscale solid characterizations reveal the organic carbon to be microbial cells within the Fe-rich smectite, with cell densities locally exceeding 10^{10} cells/cm^3. Dominance of heterotrophic bacteria indicated by analyses of DNA sequences and lipids supports the importance of organic matter as carbon and energy sources in subseafloor basalt. Given the prominence of basaltic lava on Earth and Mars, microbial life could be habitable where subsurface basaltic rocks interact with liquid water.

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IODP Expedition 385: Guaymas Basin Tectonics and Biosphere

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Guaymas Basin is a young marginal rift basin in the Gulf of California characterized by active seafloor spreading and rapid sediment deposition, including organic-rich sediments derived from highly productive overlying waters and terrigenous sediments from nearby continental margins. The combination of active seafloor spreading and rapid sedimentation within a narrow basin results in a dynamic environment where linked physical, chemical, and biological processes regulate the cycling of sedimentary carbon and other elements. This continuum of interrelating processes from magma to microbe motivated International Ocean Discovery Program Expedition 385 and is reflected in its title, “Guaymas Basin Tectonics and Biosphere.”

During IODP Expedition 385, organic-rich sediments with sill intrusions on the flanking regions and in the northern axial graben of Guaymas Basin were drilled. Numerous technical innovations (for example, the sophisticated advanced piston corer [APC] and half-length APC) have greatly improved sample recovery and a total of 4176.2 m core (755 total cores with a recovery rate of 87.9%) in eight sites and 26 holes were recovered. Drill sites extend from the northwestern to the southeastern flanking regions of Guaymas Basin, covering an ~81 km long transect. Adjacent Sites U1545 and U1546 recovered the oldest and thickest sediment successions (to ~540 meters below seafloor [mbsf]), one without sill emplacement (Site U1545), and one with a deeply buried sill (~356-430 mbsf) that impacted the sediment column (Site U1546). Because the two sites are adjacent to each other (~1 km apart) and differ primarily because of the presence or absence of this large sill, they provide a model area for studying the consequences of sill emplacement into an older sediment column. A surprising feature of both sites was the strong thermal gradient that allowed us to recover continuous sample sets with in situ temperatures as high as 70˚-80˚C. Sites U1547 and U1548 are located in the central sedimented bowl and on the outer periphery of a circular hydrothermal mound called Ringvent, where a shallow, slowly cooling sill is driving steep hydrothermal gradients, which in turn shift the zones of authigenic mineral precipitation and compress the microbial abundance profile toward shallower depths. The thermal, lithologic, geochemical, and microbiological contrasts between the two deep northwestern sites and the Ringvent sites form the scientific centerpiece of the expedition. These observations are supplemented by results from sites that represent attenuated cold seepage conditions in the central basin (Site U1549), hydrate occurrence near the Sonora margin (Site U1552), complex sediments and sills in the northern axial trough (Site U1550), and terrigenous sedimentation events on the southeastern flanking regions (Site U1551).
The scientific outcomes of Expedition 385 will (1) revise long-held assumptions about the role of sill emplacement in subsurface carbon mobilization versus carbon retention, (2) comprehensively examine the subsurface biosphere of Guaymas Basin and its responses and adaptations to hydrothermal conditions, (3) redefine hydrothermal controls of authigenic mineral formation in sediments, and (4) yield new insights into many geochemical and geophysical aspects of both architecture and sill-sediment interaction in a nascent spreading center. The generally high quality and a high degree of completeness of the shipboard datasets presents opportunities for interdisciplinary and multidisciplinary collaborations during shore-based studies.

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Keywords: Guaymas Basin, Deep biosphere

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[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS11] Expedition Earth: discovering our planet's past and future through scientific drilling

convener:Junichiro Kuroda(Department of Ocean Floor Geoscience, Atmosphere and Ocean Research Institute, the University of Tokyo), Katsuyoshi Michibayashi(Department of Earth and Planetary Sciences, Nagoya University), Kohtaro Ujiie(Graduate School of Life and Environmental Sciences, University of Tsukuba), Clive Robert Neal(University of Notre Dame)

This multidisciplinary session encourages presentations of various scientific researches that uses samples and data obtained through scientific drilling projects such as the International Ocean Discovery Program (IODP) and the International Continental Scientific Drilling Project (ICDP). We organize several subsessions on the basis of scientific themes to effectively convey achievements and information to the audiences. These scientific themes include "Resilient and Dynamic Earth" (geohazard, climate change and natural resources), "Terrestrial to Extraterrestrial" (plate tectonics, planetary structure, asteroid impacts, and deep biosphere/astrobiology), and "Innovative Science and Technology" (subseafloor observatories, drilling technology development and data science). This session will invite lectures that summarize recent achievements and highlights in each field, and encourages presentations on recently implemented ICDP projects and IODP expeditions. We also aim to provide information on upcoming ICDP projects or IODP expeditions, and we welcome contributions on state-of-the art technological developments related to scientific drilling. The principal goal of this session is to provide a place where participants can efficiently acquire substantial information related to scientific drilling.
Also please visit the J-DESC event page for more details on this session;
J-DESC event page

[MIS11-13] The next step following the accomplished drilling into seismogenic zones of M2.0-5.5 earthquakes in South African gold mines (ICDP DSeis)

★Invited Papers

*Hiroshi Ogasawara[1], Bennie Liebenberg[2], Yasuo Yabe[3], Takatoshi Ito[3], Jim Mori[4], Tetsuro Hirono[5], Yuhji Yamamoto[6], Tullis C Onstott[7], Tom L. Kieft[8], Ray J. Durrheim[9], Musa S.D. Manzi[9], Martin Ziegler[10], Thomas Wieresberg[11], Serge Shapiro[12], Surendra N. Samala[13], Esta van Heerden[14], Julio Castillo[15], Phil Dight[16] (1.Faculty of Science and Engineering, Ritsumeikan University, 2.Moab Khotsong mine, 3.Tohoku Univ., 4.Kyoto Univ., 5.Osaka Univ., 6.Kochi Core Center, Kochi Univ., 7.Princeton Univ., 8.New Mexico Inst., 9.Univ. Witwatersrand, 10.ETH, Zurich, 11.GFZ, Potsdam, 12.Berlin Free Univ., 13.Indian Inst. Tech., Hyderabad, 14.iWater, 15.Free State Univ., 16.W. Australia Univ.)

[MIS11-15] **Constraints on paleo-stress magnitude in Hikurangi Margin, New Zealand, at Site U1518, Expedition 375**

*Yoshitaka Hashimoto[1], Ryo Nishimori[1], Annika Greve[2], Julia Morgan[3] (1.Kochi University, 2.Utrecht University,, 3.Rice University)

[MIS11-16] Can subducting Kyushu-Palau Ridge weaken Hyuga-nada subduction interface, western Nankai Trough: A Proposal to IODP

*Rie Nakata[1], Masataka Kinoshita[1], Yoshitaka Hashimoto[2], Yusuke Yamashita[3] (1.University of Tokyo, 2.Kochi University, 3.Kyoto University)

[MIS11-17] Overview of drilling active backarc basin, Okinawa Trough: ongoing rifting of Eurasian continental margin

*Makoto Otsubo[1] (1.Geological Survey of Japan, Research Institute of Earthquake and Volcano Geology)

[MIS11-18] Outline of JBBP (Japan Beyond-Brittle Project) to drill into supercritical geothermal systems

★Invited Papers

*Hiroshi Asanuma[1] (1.AIST)

The next step following the accomplished drilling into seismogenic zones of M2.0-5.5 earthquakes in South African gold mines (ICDP DSeis)

*Hiroshi Ogasawara[1], Bennie Liebenberg[2], Yasuo Yabe[3], Takatoshi Ito[3], Jim Mori[4], Tetsuro Hirono[5], Yuhji Yamamoto[6], Tullis C Onstott[7], Tom L. Kieft[8], Ray J. Durrheim[9], Musa S.D. Manzi[9], Martin Ziegler[10], Thomas Wieresberg[11], Serge Shapiro[12], Surendra N. Samala[13], Esta van Heerden[14], Julio Castillo[15], Phil Dight[16]

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The DSeis project successfully accomplished drilling into a seismogenic zone in Archean metasedimentary and volcanic rock formations to recover samples from a structure that hosted an M5.5 earthquake (ICDP Annual Report 2018). Here, we summarize our activity in 2019 and plans for 2020, which include a proposed ICDP post-drilling workshop at Kochi Core Center (KCC), Japan, where DSeis imported the most critical drilled core.

Previous projects of deep fault drilling from the Earth's surface or the ocean bottom include the North Anatolian, Alpine, Chelungpu, Nojima, and San Andreas, Wenchuan Faults, Eger Rift, as well as the JFAST and NanTroSEIZE drilling projects offshore Japan, respectively. The unprecedented outcomes from these investigations have enhanced the understanding of fault behavior significantly, yet nobody has yet elucidated seismogenic zones. Therefore, the ICDP Science Plan 2014-2019 raised several open fundamental questions to deepen our understanding of seismogenic processes and associated deep life. To address them, DSeis accomplished wire-line full-core drilling of three holes with a total length of 1.6 km. This approach was fundamentally different from the previous fault drilling projects which mainly used rotary or other non-coring drilling methods using drilling mud and with limited spot coring. The target of DSeis was the aftershock zone of an M5.5 earthquake below a deep gold mine in South Africa that several tens of near-field seismic sensors identified. Although seismicity of the DSeis's drilling target was more than two to four orders of magnitude lower than that of the projects mentioned above, the previous projects were challenged by identifying the location of the seismogenic zone accurately enough for detailed coring. In the DSeis project, the important differences included: (1) drilling from 2.9 km depth at the mine allowed design of the drilling directions with minimal risk of borehole breakouts or core discing; (2) a 3 m double and a 1.5 m triple-tubes were used for the critical sections, resulting in successfully recovering samples of not only intact core but also fragile lithologies in the fault zone; (3) drilling without mud resulted in better core recovery, e.g. not losing tiny rock fragments to be washed away. Petrological and geochemical analyses revealed an altered lamprophyre dike with talc hosted the M5.5 earthquake (Hirono et al. 2020 JpGU). The structure exhibited distinctively large density and magnetic susceptibility.

Funato and Ito (2017) developed a new non-destructive method that needs only a drilled core to measure stress, by Diametrical Core Deformation Analysis (DCDA), allowing us more than 200 measurements of differential stress. We supplement 3D core stress measurement at three depths in Hole A with Deformation Rate Analysis.

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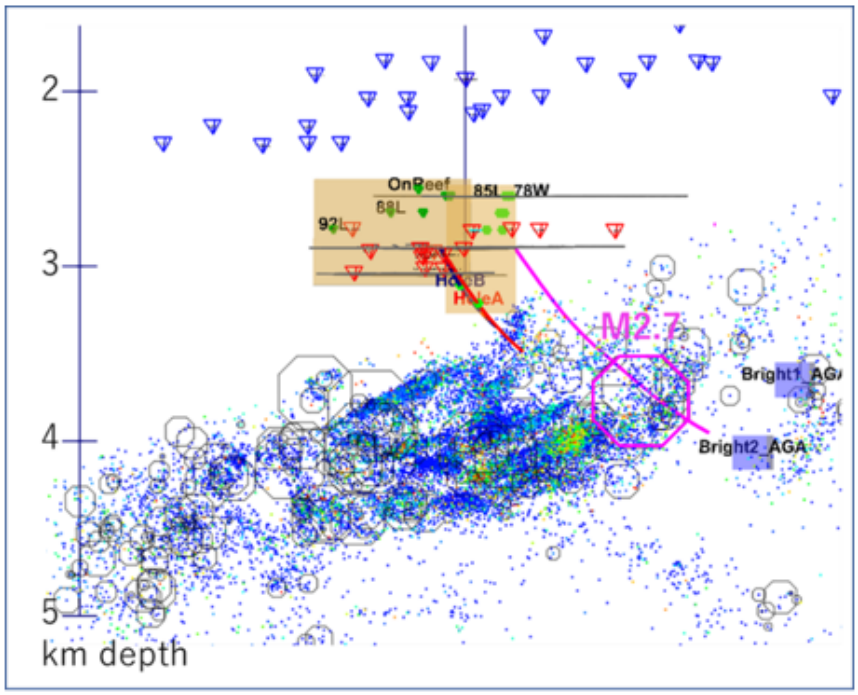
Ogasawara et al. (2020 JpGU) analyzed the 3D seismic reflection data, revealing a nearly vertical geological structure that crosscuts all the older formations and structures up to Karoo-age sediments near the Earth's surface. This structure is interpreted as a Karoo-age dike that was emplaced when the Gondwana supercontinent broke up at ca. 180 Ma.

Hole A intersected a hypersaline brine fissure rich in abiogenic volatile hydrocarbons (Rusley et al. 2018 AGU; Wiersberg et al. 2018 AGU; Nisson et al. 2019 AGU). These new findings will allow us to discuss how deep life can be fueled.

Additional effort to analyze the existing critical sections of the core at Kochi Core Center is crucial. As Holes A and B/C are still kept uncased and open except near the M5.5 structure, additional down-hole investigation increases critical data. We can plan an additional drilling campaign to traverse or reach an M2.7 aftershock source zone and the M5.5 strong-motion sources. To make the best plan, we have proposed ICDP a workshop at KCC.

ICDP, JSPS Core-to-Core Program, US NSF, German DFG, South African NRF, MEXT, KCC, and Ritsumeikan Univ. financially support the project.

Keywords: altered lamprophyre dike, fault material recovered, stress measured, hypersaline brine and gas, deep life



A provisional plan to drill Hole D (in pink) from the existing DSeis Site 2 to probe a M2.7 aftershock of the 2014 Orkney earthquake and the strong motion sources of the mainshock (Bright 1 and 2 in the figure) located by in-mine seismic networks (blue and red triangles). Red and blue lines: Holes A and B (817 and 700m respectively) DSeis collared at 2.9 km depth. Seismic data courtesy of AngloGold Ashanti. Brown squares with small green triangles: a non-meteoric hypersaline brine dike with 1-2 m thickness.

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Constraints on paleo-stress magnitude in Hikurangi Margin, New Zealand, at Site U1518, Expedition 375

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Understanding stress and strain in subduction zones is essential to understand earthquake-slip behaviours. After the 2011 Tohoku earthquake, a horizontal compressional stress changed to a horizontal extensional stress at a regional scale (e.g., Asano et al., 2011). Paleo-stress analyses using micro-fault inversion has been used to demonstrate temporal changes in stress in on-land accretionary complexes such as the Shimanto Belt (Japan) and near the Chelung-pu fault in Taiwan (Hashimoto et al., 2014; Hashimoto et al., 2015). In the latter study the paleo-stress magnitude was also constrained using stress polygons. The results found an increase in magnitude of the horizontal compressional stress. The change in stress could be caused by a decrease in shear stress on the plate boundary, which contributes to the horizontal compressional stress.

Site U1518 of International Ocean Discovery Program (IODP) Expedition 375 is located at the toe of the Hikurangi subduction margin (North Island, New Zealand). In cores from this site, normal faults, fractures and a small number of thrust faults coexist. This is indicative of stress changes in the past. We conducted paleo-stress analysis to examine the stress changes in the shallow portion of Hikurangi margin, New Zealand.

We conducted paleo-stress analysis on normal faults, and open and filled fractures. The deformation structures are distributed mainly below around 300 m where two fractured fault zones were identified (Fagereng et al., 2019). Although the cross-cutting relationship is not clear based on the limited core-observations, the distributions of the structures overlap. Paleomagnetic declinations were used to reorient the faults into a geographic reference frame. Because open and filled fractures show no visible displacement, paleo-stress analysis was conducted using the dike method. Many normal faults have no striations, therefore, we used them as sense data only, using a micro-fault inversion method. Both methods were modified to subdivide the stress history into multiple stages using computed statistics.

The estimated orientation of σ_1 is NW-SE or WNW-ESE and σ_3 is vertical for open and filled fractures, which indicates thrust-type stress. The stress ratio, $(\sigma_1 - \sigma_2) / (\sigma_1 - \sigma_3)$, is about0.5. The σ_1 direction is consistent with a NE-SW lineation of K_{max} in the upper strand of the fault zone as was determined using the Anisotropy of Magnetic Susceptibility (AMS) method (Greve et al., in revision). For the normal faults, σ_1 is vertical and the stress ratio is 0.5. Because the normal faults have only sense without a defined slip direction, the orientations for σ_2 and σ_3 are not well constrained.

Both thrust- and normal-fault stress states were observed in the cores at U1518 for the brittle faults or fractures, which suggests that both compressional and extensional critical states were achieved during the evolution of this system. Using stress polygons with the stress orientations and the stress ratio (Hashimoto et al., 2015), the stress magnitudes were constrained for each stress state, allowing us to estimate variations in pore pressure ratio. The differential stresses for horizontal compression and horizontal extension are about 2-4 MPa and about 1 MPa, respectively. The range for maximum shear stress is about 1-3 MPa. Additionally, applying dynamic Coulomb wedge theory (Wang and Hu, 2006) to the high angle slope at the toe of Hikurangi margin, the basal effective friction coefficient and shear stress

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around 300 m depth for each state can be calculated. Accordingly, the shear stress difference between the compressional and extensional critical state was about 1-2 MPa. The shear stress change determined from both methods (stress polygons and dynamic critical taper model) are mostly consistent. The stress drop is larger than expected for slow earthquakes but probably consistent with a large tsunami earthquake near the trench.

Keywords: Paleo-stress, Hikurangi margin, IODP Expedition 375

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Can subducting Kyushu-Palau Ridge weaken Hyuga-nada subduction interface, western Nankai Trough: A Proposal to IODP

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Hyuga-Nada is located at the southwestern end of the Nankai trough, and a transition zone to the Ryukyu trench. Here, Kyushu-Palau Ridge (KPR), an aseismic remnant arc of the Izu-Bonin-Mariana arc, obliquely subducts beneath the Amurian plate, and separates the newer Shikoku and older West Philippine basins. Comparing to the rest of the Nankai subduction zone, the plate interface at Hyuga-Nada is known to be weakly coupled, represented by frequent regular earthquakes of M7 or smaller and a lack of earthquakes of M8 or larger. Recursive swarms of very low-frequency earthquakes and tremors are observed near the trench, and clearly coincide with the seamount of KPR inferred from magnetic anomalies. Based on previous understanding in other subducted seamounts (e.g. Hikurangi), we hypothesize that the unique earthquake signatures are related to the KPR subduction and/or the transition of the two subduction systems. First, basic stress and frictional properties of the subducting interface is controlled by input sediments, topography and temperature of the incoming plate, of which the KPR, Shikoku and West Philippine Basins differ significantly. Second, the rough plate interface associated with KPR creates tectonic erosion, and modulates geomechanical and hydraulic conditions of the plate interface and the upper plate. This creates a favorable condition for slow earthquakes to occur (i.e., high pore-pressure). We propose to conduct scientific drilling and place observatories, in order to i) characterize age, lithologies, fluid properties of the incoming sediments, ii) estimate past and current deformation and stress conditions above and near KPR, and iii) monitor their evolution over earthquake cycles, as well as iv) explore slow earthquake events. We combine the results with modeling, seismic/structural, geodetic observations to validate, refine and deepen the understanding of the ridge subduction and the associated phenomena.

Keywords: IODP, slow earthquakes, ridge subduction

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Overview of drilling active backarc basin, Okinawa Trough: ongoing rifting of Eurasian continental margin

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We introduce the outline of scientific drilling for the Okinawa Trough. The Ryukyu arc fringes Eurasian continental margin, and is subducted by the Philippine Sea plate at Ryukyu trench. The arc has an active backarc basin, called the Okinawa Trough. Although the Okinawa Trough has a thin crust (~10 km), no exposed oceanic basalts in axis of the Trough have been reported and the continental crust is thinning with the normal faulting (Arai et al. 2017, JGR, 122, 622–641; Nishizawa et al., 2019, EPS, 71:21). The backarc basin like the Okinawa Trough is rare in the world (another is the Bransfield Strait near Antarctica), and normal faulting in this region are key to understand the evolution of backarc basins. And, the Kuroshio warm current flows into the East China Sea from between the Taiwan and Ryukyu Arc, but it is unknown when it started. We are considering the ocean scientific drilling for the Okinawa Trough with three scientific targets: Q1. What are factors controlling opening of back-arc basins? Q2. How are fault-fluid-heat related in active rift zone before exposure of oceanic basalt? Q3. When did Kuroshio (warm current) flow into East China Sea?

Keywords: Normal fault, Volcanics, Fluid, Ryukyu arc, Island arc, IODP

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Outline of JBBP (Japan Beyond-Brittle Project) to drill into supercritical geothermal systems

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Target of the JBBP (Japan Beyond-Brittle Project) is to demonstrate presence of ultra-high temperature geothermal resources inside shallow magma chambers. It has been inferred that the geothermal resources is under supercritical condition and nationalwide potential of “Supercritical Geothermal Power Generation” reaches to hundreds GW, although there are a lot of scientific unknowns and necessary technological breakthroughs. NEDO has funded to survey the most promising location of the proof-of-concept drilling and to investigate detailed feasibility of the Supercritical Geothermal Power Generation from FY2018, and 6 related projects are on-going. Outline of the studies in the NEDO Supercritical Geothermal Project and scientific challenges will be presented in the session.

Keywords: scientific drilling, supercritical geothermal

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[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS12] Developments and applications of XRF-core scanning techniques in natural archives

convener:Huang Jyh-Jaan Steven(Institute of Geology, University of Innsbruck), Atsuko Amano(National institute of Advanced Industrial Science and Technology), Masafumi MURAYAMA(Faculty of Agriculture and Marine Science, Kochi University), Liang-Chi Wang(National Chung Cheng University)

X-ray fluorescence (XRF) core scanning techniques have revolutionized element proxy-based paleo-researches over the last decade and now becomes an indispensable tool for many research area. However, despite being fast, non-destructive and providing records of elemental variations at submillimeter resolution, science applications of XRF-core scanning results also encounter numerous challenges due to its intrinsically semi-quantitative and ultra-high resolution nature, such as the influences of down-core physical and organic variations, parameter optimizations of machinery, as well as quantitative calibrations and evaluations of the voluminous and complex scanning data. Therefore, the implications of shifts and trends in the elemental data remain difficult to interpret in many settings.
It is therefore considered timely to bring together international specialists using high-resolution XRF-core scanners in all fields of science to present new research, to stimulate new collaborations and discussions, as well as to propose new technological developments.

[MIS12-01] Bromine (Br) counts measured by XRF core scanner (ITRAX) as a proxy of marine organic carbon content in the hemiperagic sediments of the Japan Sea

★Invited Papers

*Arisa Seki[1], Ryuji Tada[2,3,4], Shunsuke Kurokawa[4], Masafumi Murayama[5] (1.Faculty of Science, Shinshu University, 2.Chiba Institute of Technology, 3.Yunnan University, 4.Graduate School of Science, The University of Tokyo, 5.Faculty of Agriculture and Marine Science, Kochi University)

[MIS12-02] The advantages and limits of ITRAX core scanner: Learning by comparison with destructive element and isotope data from the Gulf of Alaska sediment core

★Invited Papers

*Keiji Horikawa[1], Nurunnabi MD Mondal[2], Masafumi MURAYAMA[3], Katsuya Nejigaki[4], Osamu Seki[5], Yusuke Okazaki[6] (1.Graduate School of Engineer and Science for Research, University of Toyama, 2.Graduate School of Engineer and Science for Education, University of Toyama, 3.Faculty of Agriculture and Marine Science, Kochi University, 4.Graduate School of Integrated Arts and Sciences, Kochi University , 5.Institute of Low Temperature Science, Hokkaido University, 6.Graduate School of Science, Kyushu University)

[MIS12-03] Quantitative micro-XRF scanning spectroscopy of freshwater lake sedimentary sequences based on the X-ray absorption and emission theories

★Invited Papers

*Nagayoshi Katsuta[1] (1.Faculty of Education, Gifu University)

[MIS12-04] The characteristics of turbidites beds of southwestern Ryukyu Trench floor: A new approach from the X-ray fluorescence core scanning analysis

*KanHsi Hsiung[1], Kiichiro Kawamura[2], Toshiya Kanamatsu[1], Ken Ikehara[3], Kazuko Usami[4], Chorng-Shern Horng[5], Naohiko Ohkouchi[1], Nanako O. Ogawa[1], Saneatsu Saito[1], Masafumi MURAYAMA[6] (1.Japan Agency for Marine-Earth Science and Technology, 2.Yamaguchi University, 3.Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology, 4.Japan NUS Co., Ltd., 5.Institute of Earth Sciences, Academia Sinica, 6.Faculty of Agriculture and Marine Science, Kochi University)

Discussion

Bromine (Br) counts measured by XRF core scanner (ITRAX) as a proxy of marine organic carbon content in the hemiperagic sediments of the Japan Sea

*Arisa Seki[1], Ryuji Tada[2,3,4], Shunsuke Kurokawa[4], Masafumi Murayama[5]

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The marine organic carbon content in sediments is a useful tool for reconstructing past productivity in the ocean. Bromine (Br) has been proposed as a useful proxy for marine organic carbon (Ziegler et al., 2008), since bromine is more concentrated in marine organic matter compared to terrestrial organic matter (Berg and Solomon, 2016).

In this study, we estimate the marine organic carbon content from the Br counts measured by the XRF core scanner. The hemipelagic sediments of the Japan Sea obtained during Integrated Ocean Drilling Program (IODP) Expedition 346 were used because they have distinct alternation of dark colored (organic rich) and light colored (organic poor) layer (Tada et al., 2015).

We measured the bromine content in the sediments using an XRF core scanner (ITRAX) in the Kochi University, Japan. The total organic carbon (TOC) content, total nitrogen (TN) content, and stable carbon isotope ($\delta^{13}C$) values were also measured for discrete samples from the same sediments. The stable carbon isotope ratio of the total organic carbon is used to estimate the marine organic carbon content within the total organic carbon.

The Br counts and marine organic carbon content show a high correlation, which we used to construct a calibration equation of the marine organic carbon content from the Br counts. Using the calibration equation, we reconstructed high-resolution record of marine organic carbon content in the hemiperagic sediments of the Japan Sea during the Quaternary with a time resolution of ~ 50 years.

The method to estimate the marine organic carbon content from the Br counts measured by the XRF core scanner proposed in this study will be a useful tool to reconstruct the organic carbon content with high resolution and high speed.

Keywords: XRF core scanner, ITRAX, Marine organic carbon, Japan Sea, IODP

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The advantages and limits of ITRAX core scanner: Learning by comparison with destructive element and isotope data from the Gulf of Alaska sediment core

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ITRAX is a new non-destructive, rapid, automated multi-function core scanner, developed by the Southampton Oceanography Centre (now National Oceanography Centre, Southampton, UK) and the Cox Analytical Systems of Gothenburg, Sweden. The instrument incorporates an intense micro-X-ray beam being designed to gather optical and micro-radiographic images and X-ray fluorescence (XRF) spectrometry elemental profile that provides high-resolution geochemical records from terrestrial and marine sediment cores. Rothwell and Croudace (2015) showed that 60 elements or ratios measured by XRF core scanner have been used for core characterization, determination of climate changes, recognition of sedimentological events like ash layers, turbidites, ice-rafted debris, and aeolian dust, provenance studies, facies interpretation, diagenetic studies, and core correlation studies.

However, despite its rapid acquisition of high-resolution multi-elemental data, there are some limitations and cautions. That is ITRAX core scanner measures element intensities in total counts or count per second, and intensities may be affected by the X-ray source, measurement time, other elements, physical properties of the sediment and protection foil, potentially leading to large uncertainties for paleoenvironmental interpretation. Thus, to correctly interpret ITRAX data, destructive element data measured by ICP-MS, ICP-OES, and WD-XRF are also still needed.

Recently, we had the experience to use the ITRAX XRF core scanner for our sediment core CL14PC (Gulf of Alaska, 59° 33.35´N, 144° 09.35´W, water depth 690 m) at the CMCR, Kochi University, Japan. Our sediment slab sample was 5 cm wide, 100 cm long, and 1 cm thick, and we operated with a molybdenum (Mo) anode tube at 20 seconds, with 30 kV (voltage) and 55 mA (current) and with 0.4 mm and 1 cm resolution. We also measured element concentration with WD-XRF and ICP-MS, and Sr-Nd-Pb isotopes of bulk sediments. We found that ITRAX XRF counts for the element K, Ca, Ti, Mn, Fe, and Sr represented lower correlation (R^2) with WD-XRF concentration data (wt%). Especially, the deviation was higher in the core-top for K and Ti. We discussed that high Cl content in the soupy core-top sediments reduces K count by absorption of the Kα fluorescence of K and Ti intensities may be decreased towards core tops due to lower compaction and high dilution by high porewater content. We also found very low counts in the case of Al and no signal (counts) for Mg, indicating that molybdenum (Mo) X-ray tube in the ITRAX system cannot detect these elements, although detection of Al in the currently available model using Cr tube is good. Further, in the presentation we will also present XRF-based provenance proxy data and Sr-Nd-Pb isotopes of bulk sediments of geochemical tracers.

Keywords: ITRAX, WD-XRF, bromine, Sr-Nd-Pb isotope, provenance analysis

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Quantitative micro-XRF scanning spectroscopy of freshwater lake sedimentary sequences based on the X-ray absorption and emission theories

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Nondestructive micro-XRF scanning spectroscopy of marine and lake sedimentary sequences has been provided detailed paleoenvironmental records through element intensity proxy data. However, there are problems with the effects of interstitial pore water on micro-XRF intensities because the XRF intensities are measured directly at the surface of split wet sediment core samples. Several methods for solving this problem have been proposed, but these were limited to mathematical, statistical and empirical approaches except for Kido et al. (2006). Then, Katsuta et al. (2019) developed a new method for correcting XRF data to compensate for the effects of pore water using resin-embedded sediment samples with a scanning X-ray analytical microscope which allows to simultaneously measure the XRF and transmitted X-ray intensities. Simple linear regression between the linear absorption coefficients of the samples and their porosity, based on the Lambert-Beer law, allows calculation of the interstitial pore space and the amount of the pore water with high reproducibility. On the other hand, the micro-XRF intensities of resin-embedded samples were reduced compared with the dry samples. This is because (1) the XRF absorption of resin within sediment and (2) the sediment dilution effect by resin. A micro-XRF correction equation based on the XRF emission theory, which were improved from method of Kido et al. (2006), provides a reasonable explanation for two effects. This poster presentation shows the theory and methods, and its application to sedimentary sequence from freshwater lakes such as Lake Baikal, Lake Ohnuma, etc.

Keywords: Transmitted X-ray intensities, Water content calibration, Micro-XRF intensity correction, Element concentration

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The characteristics of turbidites beds of southwestern Ryukyu Trench floor: A new approach from the X-ray fluorescence core scanning analysis

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The southwestern Ryukyu Trench terminates on the eastern margin of the indenting northern Gagua Ridge and is characterized by a curved fan-shaped trench floor. This study area is an ideal place to study the sediment transport of oceanic trenches in terms of source-to-sink. Therefore, the characteristics and related geochemical characterization of trench turbidites were analyzed. We collected one piston core and related pilot core from the cruise KR1518 in 2015. Two pushed cores also were collected by SHINKAI6500 from the cruise YK1611 in 2016. These sites are deeper than 6,000 m water depth of the southwestern Ryukyu Trench floor. The sedimentary succession of Ryukyu Trench cores is dominated by gray silt interbedded with numerous silt-fine sand. These silt-fine sand layers can be considered as turbidite beds. Most of the turbidite beds show very thin lamination less than 2 cm thick. Based on visual core descriptions and XRF results, the elemental ratios of XRF can help determine the contact between turbidite and hemipelagic sediments, particularly for the thin turbidite beds. The depths of turbidite beds were highly correlated with the intensities of several elements. The intensities of calcium and iron are considered the most sensitive geochemical indicators. The elemental ratios Zr/Rb and Ca/Fe of most turbidite beds correspond to fining-upward sequences that were used to identify each thin turbidite. Based on the results of magnetic measurements, the presence of pyrrhotite signatures indicates that the Taiwan-sourced turbidites are interbedded with hemipelagic sediments. Radiocarbon dating and organic geochemical measurements from some specific layers were also conducted. To sum up, these results can increase the insight of turbidites in distal and deep-water environments.

Keywords: deep-sea turbidite, X-ray fluorescence, Pyrrhotite, Ryukyu Trench

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[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS13] Integrated Analysis of Geoscience Observations from the Floor to Surface of the Ocean

convener:Keisuke Ariyoshi(Japan Agency for Marine-Earth Science and Technology), Joan S Gomberg(USGS Earthquake Science Center), Narumi Takahashi(National Research Institute for Earth Science and Disaster Resilience), Motoyuki Kido(International Research Institute for Disaster Science, Tohoku University)

Sea bottom pressure data contains various components such as crustal deformation, ocean oscillation, tidal variability, atmospheric change, and instrumental drift. So far, seismologists have treated the ocean oscillation as noise, and ocean physicists have done vice versa (considering crustal deformation as noise). Such problems apply to ongoing undersea acoustic distance measuring and other types of ocean observations. In this session, wewelcome contribution on various topics focusing on the complementary relationship between seismology, ocean physics, meteorology, tsunami technology, and other related fields.

[MIS13-01] **Relationship between Kuroshio's meander and crustal deformation around Nankai Trough**

*Keisuke Ariyoshi[1], Akira Nagano[1], Takuya Hasegawa[1,2], Hiroyuki Matsumoto[1] (1.Japan Agency for Marine-Earth Science and Technology, 2.Graduate School of Science and Faculty of Science, Tohoku University)

[MIS13-02] **An integrated observation system from the ocean bottom to the atmosphere to study air-sea interaction in the Kuroshio region south of Shionomisaki**

★Invited Papers

*Kosei Komatsu[1,2], Akira Kuwano-Yoshida[3], Keisuke Ariyoshi[4] (1.GSFS, Univ. Tokyo, 2.AORI, Univ. Tokyo, 3.DPRI, Kyoto Univ., 4.Japan Agency for Marine-Earth Science and Technology)

[MIS13-03] Isolating oceanic contributions to ocean bottom pressure observations by using numerical ocean models to detect transient seafloor displacements

★Invited Papers

*Yoichiro Dobashi[1], Daisuke Inazu[1] (1.Tokyo University of Marine Science and Technology)

[MIS13-04] Continuous buoy observation of ocean bottom pressure and sea surface height and the system revision

*Narumi Takahashi[1,2], Kentaro Imai[2], Motoyuki Kido[3], Yusaku Ohta[3], Tatsuya Fukuda[2], Yasuhisa Ishihara[2], Hiroshi OCHI[2], Ryota Hino[3] (1.National Research Institute for Earth Science and Disaster Resilience, 2.Japan Agency for Marine Earth Science and Technology, 3.Tohoku University)

[MIS13-05] Improvement in estimation of seafloor crustal deformation from ocean bottom pressure observations at the Hikurangi subduction zone offshore New Zealand

*Tomohiro Inoue[1], Tomoya Muramoto[2], Daisuke Inazu[3], Yoshihiro Ito[4], Ryota Hino[5], Kazuaki Ohta[6], Syuichi Suzuki[5] (1.Kyoto University, 2.National Institute of Advanced Industrial Science and Technology, 3.Tokyo University of Marine Science and Technology, 4.Disaster Prevention Research Institute, 5.Tohoku University, 6.National Research Institute for Earth Science and Disaster Resilience)

[MIS13-06] Earthquake-triggered Submarine Sediment Gravity Flows in Action

★Invited Papers

*Joan S Gomberg[1], Keisuke Ariyoshi[2], Paul Johnson[3], Susan Hautala[3] (1.USGS Earthquake Science Center, USA, 2.JAMSTEC, Japan, 3.University of Washington, USA)

Relationship between Kuroshio’s meander and crustal deformation around Nankai Trough

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DONET (Dense Oceanfloor Network system for Earthquakes and Tsunamis) has been developed and installed around Nankai Trough, which was motivated by the 2004 Sumatra-Andaman Earthquake. DONET contains pressure gauges as well as seismometers, which is expected to detect crustal deformations around the source regions of megathrust earthquakes. From previous studies (e.g., Ariyoshi et al., 2014 Marine Geophysical Research) show that levelling changes due to slow earthquakes in the preseismic stage of megathrust earthquake are different sense at the DONET points even in the same science node. On the other hand, oceanic fluctuations has so large spatio-temporal scale as to be coherent for all of DONET points. This difference suggests the possibility of extracting crustal deformations component from ocean bottom pressure data by differential of stacking data. However, this operation could not be applied to local-scale fluctuations related to ocean mesoscale eddies and current fluctuations, which affects ocean bottom pressure through water density changes in the water column (from the sea surface to the bottom). In this presentation, we investigate the time series of ocean bottom pressure change from both oceanic fluctuation and crustal deformation especially during Kuroshio’s meander.

Keywords: Megathrust earthquakes in subduction zones, meso-scale eddies

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An integrated observation system from the ocean bottom to the atmosphere to study air-sea interaction in the Kuroshio region south of Shionomisaki

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The Kuroshio, the western boundary current in the North Pacific, transports huge amounts of water volume and heat from the subtropical region to the downstream south of Japan, where active interaction occurs perpetually between the atmosphere and the ocean. Massive water vapor is supplied from the ocean to the atmosphere, which drives energetic disturbances to cause disasters such as typhoons and explosive cyclones. On the other hand, the atmospheric disturbances promote development of wind waves and storm surges at the sea surface and intensify vertical mixing due to enhanced turbulence inside the ocean. In the Kuroshio region, conventional ship-based measurements can hardly approach the actual condition of the air-sea interaction mainly because of ordinarily strong currents and frequent attacks of severe storms. However, recent studies present probability of detecting the oceanic and atmospheric events by using bottom pressure gauges distributed at the sea floor originally for monitoring the hydraulic pressure fluctuations due to submarine earthquakes. This study aims to construct an integrated observation system from the ocean bottom to the atmosphere in order to elucidate processes of the air-sea interaction in the Kuroshio region, which generate frequently several disturbances in the atmosphere and ocean. This observation system is expected to contribute to realization of more accurate monitoring or forecasting of severe natural disasters.

Our new observation system focuses on the region south of Shionomisaki, the southern tip of Kii Peninsula, where several atmospheric and oceanic events frequently occur under influences of the Kuroshio and the Dense Ocean floor Network system for Earthquakes and Tsunamis (DONET) has been arranged widely by JAMSTEC at the sea floor since 2006 for monitoring precisely the hypocentral region of Tonankai earthquake that are very likely to occur around Nankai trough. DONET/DONET2 (the second phase of DONET) consists of a 300/450 km length of a backbone cable system with 20/29 observatories, each of which is equipped with a high-precision quartz pressure gauge and seismometer. The pressure gauge can measure fine fluctuations of water pressure at the bottom with an accuracy of 0.01 db, hence in some cases it has a potential to detect signals attributed to disturbances generated in the ocean interior, at the sea surface, and even in the atmosphere, in addition to its intended purposes. Our new observation system is mainly composed of three platforms: (1) a network of water pressure gauges at the ocean bottom by DONET and DONET2, (2) an atmospheric observatory located at Shionomisaki wind effect laboratory of DPRI, Kyoto Univ., and (3) a cooperated ship-observatory among the R/V Shinsei-maru, JAMSTEC, the T/S Seisui-maru, Mie Univ. and the D/V Chikyu, JAMSTEC.

The first trial of our new system was conducted in autumn 2018 mainly to validate the accuracy of detecting sub-mesoscale oceanic frontal disturbances linked with fluctuation of the Kuroshio current-path by the bottom pressure gauges of DONET/DONET2, as part of the observational campaigns. In the cruise period, the Kuroshio has taken a large meander path; therefore, the Kuroshio flowed far away from Kii Peninsula and all the DONET/DONET2 points were covered with the slope waters. Timeseries of the bottom pressure at 0.1 s intervals presented temporal variation identical within the range of 0.16 db to

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the barotropic fluctuation of the external tide estimated from an astronomical tide model. Cross-spectral analysis of the bottom pressure fluctuations suggested that oceanic disturbances with the period of one hour propagated northeastward from the front of the Kuroshio located southwest of Kii P. to the slope water region southeast of Kii P. The first trial of this new system presented a capability of the sea floor observatory to detect oceanic disturbances originated from the Kuroshio front even under the calm conditions in autumn 2018.

Keywords: integrated observation system, DONET, ocean bottom to atmosphere, Kuroshio

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Isolating oceanic contributions to ocean bottom pressure observations by using numerical ocean models to detect transient seafloor displacements

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The purposes of Ocean Bottom Pressure (OBP) observations are diverse, mainly physical oceanography and marine geodesy. OBP gauges record phenomena on various temporal variations by long-term continuous and detectability of sub-centimeter changes of water column height just above them. Focusing on seafloor deformations, there are expectations for detecting cm-scale vertical seafloor displacements associated with slow earthquakes because slow earthquake events are highlighted as clues to understand huge earthquakes (Mw8+). 1hPa pressure change is almost equivalent to 1cm seafloor displacement under the hydrostatic condition, so 1hPa pressure decreasing can be interpreted 1cm seafloor uplift. Although OBP gauges have potential to resolve cm-level seafloor displacement, it isn't easy task to detect signals precisely because OBP time-series contain overlying lots of components, so we should isolate some signals as noise. Especially, non-tidal oceanic variation and mechanical drift are definitive contributions to mask earthquake signals from the point of amplitude and temporal scale (days to tens of days).

In this research, We focused on isolating non-tidal oceanic contributions by using several numerical ocean models. Ocean modeling has hardly ever been used to calculate OBP, however comparison has begun with expanding of OBP observation (e.g. Muramoto et al., 2018; Fredrickson et al., 2019). We show the applied models in this research as follows; #1 HYCOM (Cummings et al., 2013), #2 GLORYS (Ferry et al., 2010), #3 JCOPE2M (Miyazawa et al.,2017), #4 ECCO2 (Menemenlis et al., 2011), #5 Single-layer Ocean Model (SOM) (Inazu et al., 2012). Each model except #5 has tens of vertical layers to explain pycnocline. Horizontal resolution of model #1, #2, #3, #4 is $1/12^{\circ}$ (about 10 km), though $1/4^{\circ}$ is employed for model #4, also output from #3 is available only in Northwest Pacific. Model skills of each models were compared by amplitude after subtracting modeled ocean variations from observed OBP time series. We employed RMS noise level (3σ) and power spectrum of the observed OBP for evaluating the model skills. We compiled OBP datasets (10~12months) from several subduction zones around Pacific rim (Japan Trench (JT) 19 sites, Nankai Trough (NT) 51sites, Hikurangi Trough (HT) 7sites, Cascadia subduction zone (CSZ) 27sites, Chile trench (CT) 5sites).

We report that there were different characteristics of noise correction ability within 5 models for each region. Especially in HT, we can see the high predictability of SOM driven by wind stress and sea level pressure in short periodic band (shorter than 20 days) than other models driven by wind stress and heat/freshwater flux (e.g. 3σ comparison; before model correction 6.24cm; after SOM correction 3.57cm; after HYCOM correction 4.65cm). This result implied that OBP variations of HT is significantly affected by sea level pressure, actually HT is located under the effect of low-pressure zone around Antarctica which causes strong synoptic scale atmospheric disturbance. Based on this result, We calculated wind stress and sea level pressure driven OBP variations separately using the SOM framework. After confirming the linearity of wind stress and sea level pressure to OBP variation, we combined multi-layer model output and sea level pressure driven OBP from SOM, then compared with observations. As a result, We got better noise correction ability from all multi-layer models combined with sea level

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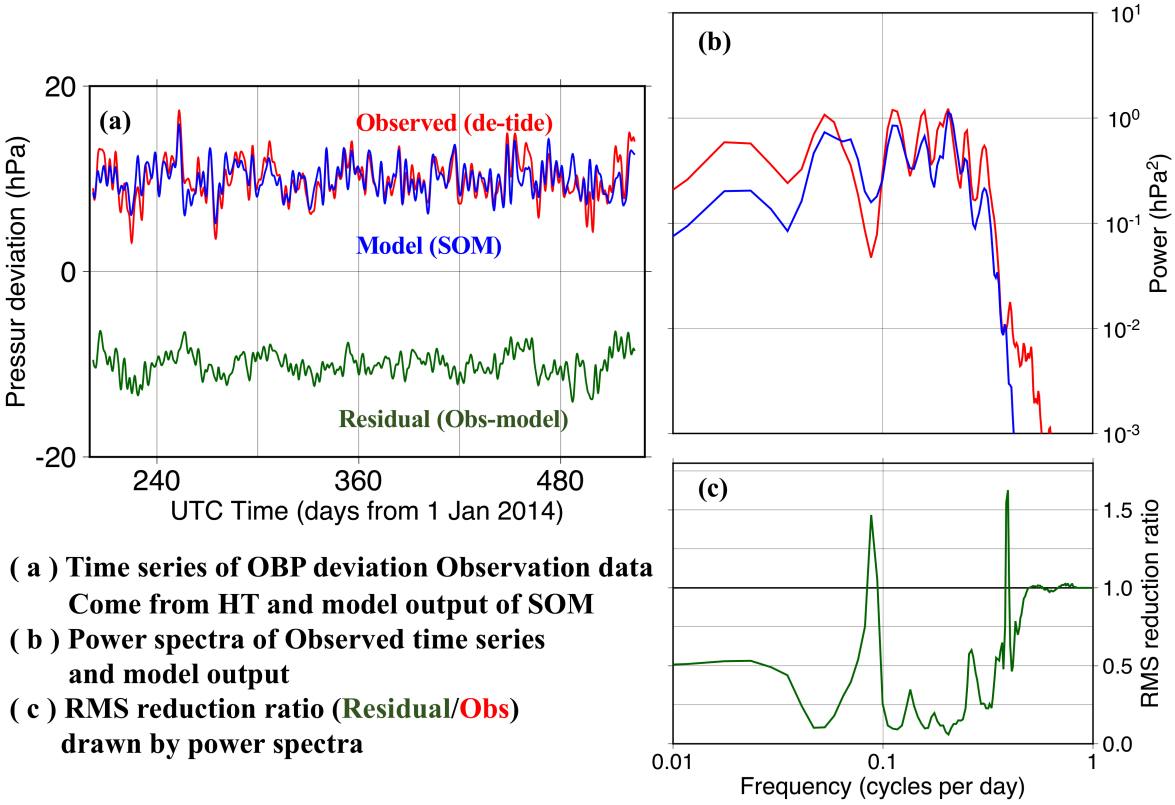
pressure component in HT (e.g. GLORYS wind 4.88cm; wind + prs 4.02 cm). In addition to the HT case, comparison in NT also showed large contributions of sea level pressure to OBP variations because all models became to be improved by combining sea level pressure component. From this result, We concluded sea level pressure contribution as well as wind stress should be considered in order to predict consistent OBP variations and contribute to detect centimeter-scale vertical seafloor displacements.

Keywords: Crustal deformation, Ocean Bottom Pressure , Numerical Ocean Modeling



(a) Time series of OBP deviation Observation data Come from HT and model output of SOM
(b) Power spectra of Observed time series and model output
(c) RMS reduction ratio (Residual/Obs) drawn by power spectra

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Continuous buoy observation of ocean bottom pressure and sea surface height and the system revision

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We have developed buoy system for tsunami and crustal displacement (Takahashi et al., 2014; 2015; Imano et al., 2015). This system has pressure sensor on the sea bottom, and logger for precise point positioning plus various meteorological sensors and sea current meter on the buoy. We carried out sea trial around the Nankai Trough area for approximately one year and introduce the comparison among these data recorded by various sensors on the sea bottom and sea surface here.

Bottom pressure sensor data is sent to the buoy using acoustic data transmission. Observed pressure data is converted time length of double pulses on the sea bottom, and these are converted again to digital data after the acoustic transmission. The time is needed to keep dynamic range with high resolution for the bottom pressure data, and we set eight meters and 1 centimeter as these parameters. Therefore, data sampling of the bottom pressure is 15 seconds.

The bottom pressure was various signals, which were tsunami signals by off the southeastern coast of Mie-prefecture (M6.5), disturbance of sea surface height by typhoon, and so on. Some very low frequency earthquakes were also recorded, which have time duration of approximately 500 seconds and frequency component of a few minutes. In addition, characteristic signals with long time duration of over three days and frequency component less than 16 minutes were also observed approximately every month. We interpret them to be possible tubidite flows along near major canyons.

We consider revision of the buoy system. Sea bottom pressure we collected are transmitted to the wire-end station set at 1,000 m below sea level using acoustic transmission. And the data collected by the wire-end station are sent to the buoy station through a wire-line. Current issues to be resolved are transmission error due to acoustic noises and damages on the wire-line due to rotation of the buoy during long period implementation. In addition, we consider to improve electrical consumption for acoustic data transmission and the successful ratio.

Keywords: buoy system, Bottom pressure observation

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Improvement in estimation of seafloor crustal deformation from ocean bottom pressure observations at the Hikurangi subduction zone offshore New Zealand

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Over the last decades, ocean bottom pressure gauges (OBPG) have been widely deployed in the world to measure seafloor crustal deformation from tectonic events, such as large earthquakes and slow slip events (SSE). However, any adequate technique, especially to detect SSE from OBPG data, has not been established, because oceanographic effects appeared on the OBPG data have not been fully understood and evaluated yet. One of the largest oceanographic components is an ocean tide. The ocean tide is composed of some periods. Long-period components with fortnightly and monthly periods have to be carefully evaluated and removed to detect SSE, because amplitudes and durations of them are similar to those from SSEs. In previous researches (e.g., Muramoto et al., 2019; Hino et al., 2014), however, the long-period tidal components have not been regarded. Here, we develop a novel approach to remove the long-period tidal components(fortnightly, monthly), and apply to detect SSE on the OBPG data in the Hikurangi subduction margin.

We apply BAYTAP-L (Tamura et al., 1991) to each of the OBPG records, in which make statistical estimation of long-period tidal component; all of tidal components are calculated by solving the penalty least square problems with Akaike’ s Bayesian information criterion (Akaike 1980), assuming smoothness of the component other than long tide on OBPG. Before applying the tide analysis, instrumental drift, non-tidal components calculated from a barotropic model (Inazu et al., 2012), and air pressure at the sea surface from atmospheric disturbances, are removed.

By removing tidal components less than monthly periods, the root mean square (RMS) of time series of the pressure decrease by about 10% of RMS from previous method, equivalent to 0.1hPa. We will estimate the uplift of the seafloor with fitting the linear and step function to the obtained time series and compare the results with the previously estimated values (e.g., Muramoto et al., 2019; Wallace et al., 2016). We will also discuss RMS of time series data with comparing multiple layer models, such as HYCOM(Bleck & Boudra, 1981) and ECCO2(Menemenis et al., 2008).

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Earthquake-triggered Submarine Sediment Gravity Flows in Action

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Submarine sediment gravity flows are significant and far-reaching hazards that link the seemingly disparate processes of earthquakes and episodic sediment redistribution. These flows develop when sediments derived from river bottoms, ocean floors, or failed submarine sedimentary slopes become suspended in the water column. Once the water column becomes sufficiently dense, rapidly traveling flows may develop that scour the seabed and entrain even more sediment. The flows then accelerate and become turbulent currents that can travel hundreds of kilometers. This phenomenon transports a major fraction of global sediments from land to sea, and threatens the millions of km of seafloor cables that enable global communications. Earthquake-generated seismic shaking is a well-documented trigger of sediment gravity flows. When preserved, the sedimentary deposits left behind when the flows stop (called 'turbidites'), serve as geologic recorders of past earthquakes. Much of our understanding of the conditions and mechanisms that generate sediment gravity flows comes from sparse and remote observations only of their impacts, hampering useful inferences from the turbidited record about earthquake recurrence and assessments of the hazards flows pose.

Data provided by the seafloor cabled Dense Oceanfloor Network system for earthquakes and tsunamis (DONET), located atop the Nankai subduction zone. This region has previously documented turbidites and sediment flows, all offering a novel opportunity to eliminate the non-uniqueness inherent in existing flow models derived only from end-product observations. DONET provides direct records of seismic shaking within a few km of where flows originate and travel, from numerous types of earthquakes with varied seismic wave characteristics. DONET was developed and is operated by the Japan Agency for Marine-Earth Science and Technology and the National Institute for Earth Science and Disaster Prevention, and now includes 49 seafloor stations where pressures, temperatures, and three component ground velocities and accelerations are recorded continuously. These numerous types of continuous measurements permit the detection of flows as they develop and their impacts, in addition to measuring those conditions that fail to produce flows. We analyze the shaking characteristics from multiple earthquakes, particularly from a M6.0 event that occurred <20 km of a DONET station on April 1, 2016 and from the M6.1 and M7.1 Kumamoto, Japan earthquakes on April 14 and 16, 2017. The April 1st event generated peak ground accelerations in excess of 0.6 g at multiple sites, and was likely capable of causing slope failures in most comparable environments. We analyze bathymetric data to identify likely flow paths and unstable slopes for these events. We examine seismic data for signals generated by slope failures, as well as the temperature and pressure records for flows evident as pulses of warmer but denser shallow water transported to deeper sites. We distinguish pressure and temperature changes attributable to oceanographic circulation from those due to sediment gravity flows using simulated data from a regional ocean modeling system and from coherence analyses. Finally, we use recorded seismic ground motions and sediment property data from previously collected cores as input parameters to simple slope stability models. We test gravity flow triggering assumptions by comparing slope stability model predictions to our inferences from the comprehensive DONET data.

Keywords: submarine sediment gravity flow, DONET array

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[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS14] Evolution of Pelagic Realm

convener:Atsushi Matsuoka(Department of Geology, Faculty of Science, Niigata University), Toshiyuki Kurihara(Graduate School of Science and Technology, Niigata University), Tetsuji Onoue(Department of Earth and Planetary Sciences, Faculty of Science, Kyushu University), XIN LI(State Key Laboratory of Palaeobiology and Stratigraphy, Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences)

This session focuses on the evolution of ecosystem in the pelagic realm,
including discussions on all aspects of pelagic biota covering biostratigraphy,
biochronology, evolution, and biogeography, which are important to the
reconstruction of the spatio-temporal framework in the pelagic realm.
Reconstructions of plate configuration through time are included in the scope of
 this session. Biological, geochemical, sedimentological approaches to the
pelagic environments are welcomed.

Introduction

[MIS14-01] Permian radiolarians from chert distributed in the Hashidate area, Itoigawa City, Niigata Prefecture, central Japan

*Toshiyuki Kurihara[1], Urara Murakami[2], Atsushi Matsuoka[2] (1.Graduate School of Science and Technology, Niigata University, 2.Faculty of Science, Niigata University)

[MIS14-02] Myr-scale monsoon records paced with Milankovitch cycles during Triassic-Jurassic

*Masayuki Ikeda[1], Kazumi Ozaki[2], Shintaro Kadoya[3] (1.Shizuoka University, 2.Toho University, 3.Washington University)

[MIS14-03] The oldest oceanic plate and Minami Tori Shima: Minato Project

★Invited Papers

*Yoshihiko Tamura[1], Tomoki Sato[1], Yasuhiro Hirai[1], Kenta Yoshida[1], Mathieu Rospabé[1], Osamu Ishizuka[1], Takashi Miyazaki[1], Qing Chang[1] (1.Research Institute for Marine Geodynamics, Japan Agency for Maine-Earth Science and Technology)

[MIS14-04] Detailed stratigraphy around the Jurassic–Cretaceous boundary in the Bosso Valley section, central Italy and international correlation based on radiolarian biostratigraphy

*Atsushi Matsuoka[1], Xin Li[2], Marco Chiari[3], Angela Beritinelli[4] (1.Department of Geology, Faculty of Science, Niigata University, 2.Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, 3.Institute of Earth Sciences and Georisources, Florence, Italy, 4.University of Perugia, Italy)

[MIS14-05] **Ocean Plate Stratigraphy and accretionary process of the Yarlung-Tsangpo suture zone based on radiolarian biostratigraphy of mélanges near Najiu, southern Tibet**

*XIN LI[1], Matsuoka Atsushi[2], Yalin Li[3] (1.State Key Laboratory of Palaeobiology and Stratigraphy, Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, 2.Department of Geology, Faculty of Science, Niigata University, 3.China University of Geosciences, Beijing)

Discussion

Permian radiolarians from chert distributed in the Hashidate area, Itoigawa City, Niigata Prefecture, central Japan

*Toshiyuki Kurihara[1], Urara Murakami[2], Atsushi Matsuoka[2]

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We report Permian radiolarians from chert distributed in Itoigawa, Niigata Prefecture, central Japan. The Permian siliceous and clastic rocks belonging to the Akiyohi belt in Itoigawa have been recognized as the Himekawa Complex (Kawai and Takeuchi, 2001). This geologic unit distributes in the east of the Omi Complex (Nagamori et al., 2010) which is composed mainly of Carboniferous to Permian limestone with minor basalts. The chert from which we obtained Permian radiolarians is exposed in the Hashidate area, western Itoigawa City. The outcrop of this chert is located in the west of Omi Complex and is isolated from the siliceous and clastic rocks of the Himekawa Complex. The apparent total thickness of this chert 30 m, although several layer-parallel faults are observed. Red-colored bedded cherts are occupied in the outcrop, and minor pale green-colored cherts also occur.

By using standard HF etching technique, we obtained well-preserved radiolarian fossils from red cherts. The radiolarian assemblage is dominated by Latentefistularia and Entactinaria. Albaillellarians are minor, and the following species are identified: *Albaillella sinuata* Ishiga and Imoto, *Pseudoalbaillella scalparata* Holdsworth and Jones, and *Albaillella* sp. Based on the unitary association zone by Xiao et al. (2018), these species indicate the Kungurian age of late Early Permian. The Kungurian age of chert has been commonly reported from the Akiyoshi belt (e.g., Kanmera et al., 1990). Therefore, the chert of the Hashidate area can be considered to be belonged to the Akiyoshi belt.

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Myr-scale monsoon records paced with Milankovitch cycles during Triassic-Jurassic

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Earth's orbital variations on timescales of 10^4-10^5 years, known as Milankovitch cycles, have played a critical role in pacing climate change and ecosystem dynamics, through glacial and/or monsoon dynamics. However, the climatic and biotic consequences of these cycles on much longer (~10^7 years) timescales remain unclear, due to a lack of long proxy records with precise age constraints. Here, we show ~10-Myr scale variations in early Mesozoic (250-180 Ma) records of pelagic biogenic-silica burial flux, atmospheric pCO_2, and sea-surface-temperature (SST). Their phase relationships, coupled with carbon cycle modeling results, suggest that orbitally-paced summer monsoon dynamics modulates changes in global weatherability, affecting changes in pCO_2 and SST.

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The oldest oceanic plate and Minami Tori Shima: Minato Project

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Minato Project started in 2017 to study submarine volcanoes of Minami Tori Shima and its adjacent areas, which are part of the Marcus-Wake Seamount Chain. The main scientific target of the Minato Project is to unravel the origin of these submarine volcanoes erupted on the Jurassic Pacific plate, which is the oldest part of the Pacific plate produced at the Jurassic midocean ridge between the Pacific and Izanagi plates. The old midocean ridge and the Izanagi plate had subducted beneath Japan and have not remained now on the Earth’ s surface.
The formation ages of Marcus-Wake seamounts are another enigma. As shown by Koppers et al. (2003), volcanoes in the western area are older than those of the eastern area, but their age variations are not systematic, and are different from age variation expected if they were hot spot tracks. Moreover, each volcano itself seems to have a wide age variation. For example, the small seamount Seth shows the eruption ages of lavas ranging from 114 to 139 Ma. Did the hot spot stayed beneath this small volcano for 25 million years? This is impossible, but actually, Minami Tori Shima has the similar problem. Preliminary Ar-Ar age determinations by Osamu Ishizuka (unpublished) showed that lava blocks collected from Minami Tori Shima during KM17-E01 have two different ages. One sample from KM-ROV#47, which dived southern ridge of Minami Tori Shima and another sample from KM-ROV#49 collected from southeastern ridge of the volcano have Ar-Ar ages of 108.5 Ma and 35.8 Ma, respectively.
The chemistry of lava blocks also shows two different patterns, which could correspond to the two different ages. Lava blocks from the southern ridge (KM-ROV#47 R02) shows light REEs and incompatible elements enriched patterns, which are typical to oceanic island basalts. On the other hand, samples from southeastern ridge (KM-ROV#49 R06) are depleted in Nb and Ta, and Zr and Hf, in comparison to neighboring elements, which patterns are typical of subduction related arc magmas (Figure7right diagram). Apparently, the lavas having arc signatures are younger than those having ocean island basalt signatures, in spite of the fact that both lava types are definitely plume-related magmas.

Keywords: Minami-Tori Shima, eruption ages, magma chemistry

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Detailed stratigraphy around the Jurassic–Cretaceous boundary in the Bosso Valley section, central Italy and international correlation based on radiolarian biostratigraphy

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The Global Boundary Stratotype Section and Point (GSSP) of the Jurassic–Cretaceous boundary (JKB) is the last among the GSSPs in the Phanerozoic. The formal definition was decided in 2016 to use the base of the *Calpionella alpina* Subzone as the primary marker by the Berriasian Working Group of the International Subcommission on Cretaceous Stratigraphy.

We carried out detailed field observations and careful sample collections in a 10-m interval around the calpionellid-based JKB in the Bosso Valley section (northern Apennines, central Italy), which is one of potential candidates for GSSP of the JKB. The Maiolica Formation, which includes the JKB, is characterized by white to light gray, well-bedded micritic limestones with abundant light gray to black chert layers and nodules. The best preserved radiolarian tests are included in micritic limestone near chert layer or nodules.

Careful and systematic sampling enables us to get enough material to establish phylogenetic analysis on radiolarians. The calpionellid-based JKB in the section is located within the *Pseudodictyomitra carpatica* radiolarian zone. We discuss worldwide correlation of the JKB based on radiolarian biostratigraphy.

Keywords: Jurassic-Cretaceous boundary, GSSP, radiolaria, international correlation

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Ocean Plate Stratigraphy and accretionary process of the Yarlung-Tsangpo suture zone based on radiolarian biostratigraphy of mélanges near Najiu, southern Tibet

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The southernmost Yarlung–Tsangpo suture zone (YTSZ) in the Tibet plateau is widely accepted as the youngest suture zone that separates the Indian continent to the south and the Lhasa terrane to the north. The study area is located in the southern belt of the YTSZ. This area includes incomplete and mostly peridotitic massifs and Jurassic–Cretaceous mélanges of marine sediments. The volcanic-sedimentary strata near Najiu County are located to the south of Yarlung–Tsangpo River. On the basis of various combinations of matrices and blocks and the tectonic contacts between them, the mélanges are divided regionally into two types, the Erba mélange and the Maquanhe mélange. Radiolarian assemblages of the *Trillus elkhornensis* (JR2) zone (Pliensbachian), the *Kilinora spiralis* (JR6) zone (Oxfordian), the *Hsuum maxwelli* (JR7) zone (Kimmeridgian), the *Loopus primitivus* (JR8) zone (lower Tithonian), *Pseudodictyomitra carpatica* (KR1) Zone (latest Tithonian to earliest Valanginian), the *Cecrops septemporatus* (KR2) Zone (Valanginian), the *Turbocapsula costata* (KR4) (Aptian) and the *Spoletoensis* zone (KR5) (Albian) were yielded from siliceous rocks in the mélanges. Accretionary complexes usually grow from the continental side to the ocean side because of the oceanward migration of subduction sites. A significant temporal gap exists between the accretion of the Erba mélange and the Maquanhe mélange. The age of siliceous mudstone becomes younger southward. The arrangement of the mélanges shows the oceanward (southward) migration of the accretion. It seems that the Erba mélange and the Maquanhe mé lange consist of successively and systematically southward-accreted materials scraped off from the subducted oceanic plate.

Keywords: Ocean Plate Stratigraphy, accretionary process, radiolarian, Yarlung-Tsangpo suture zone

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[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS15] Global climate change driven by the Southern Ocean and the Antarctic Ice Sheet

convener:Osamu Seki(Institute of Low Temperature Science, Hokkaido University), Akira Oka(Atmosphere and Ocean Research Institute, The University of Tokyo), Yoshifumi Nogi(National Institute of Polar Research), Robin Elizabeth Bell(Lamont Doherty Earth Observatory)

The Southern Ocean and Antarctic ice sheet, which are the giant reservoirs of heat, water, and materials, have a potential to play central roles in long-term global climate change. This system is composed of the following sub-systems; ice shelf which is a place of the interaction of ice sheet and ocean, flowing iceberg, seasonal sea ice zone, Antarctic bottom water which drives the thermohaline circulation, active biological production and Antarctic Circumpolar Current. These sub-systems are interacted with each other and have significant impact on changes in the global environmental system. This session aim to summarize recent observational and simulation studies from various fields relating to the past and present changes in the Antarctic Ice sheet and Southern Ocean, which are essential elements for unraveling the changes in the global climate system. Further, future science plans for understanding of the environmental changes of the Antarctic Cryosphere is also discussed.

[MIS15-01] Shallow Sea Trial of the Under Ice AUV “MONACA”

*Hirokazu Yamagata[1], Toshihiro Maki[1], Hiroshi Yoshida[2], Yoshifumi Nogi[3] (1.Institute of Industrial Science, The University of Tokyo, 2.Japan Marine Science and Technology Cente, 3.National Institute of Polar Research)

[MIS15-02] Modeling warm water intrusion into Lützow-Holm Bay, East Antarctica

*Kazuya Kusahara[1], Daisuke Hirano[2], Masakazu Fujii[3], Alexander D. Fraser[4], Takeshi Tamura[3] (1.Japan Agency for Marine-Earth Science and Technology, 2.Hokkaido University, 3.National Institute of Polar Research, 4.University of Tasmania)

[MIS15-03] Estimation of the Antarctic ice sheet surface mass balance using the polar regional climate model NHM-SMAP

*Masashi Niwano[1], Akihiro Hashimoto[1], Shun Tsutaki[2], Hideaki Motoyama[2], Naohiko Hirasawa[2], Ayako Abe-Ouchi[3] (1.Meteorological Research Institute, 2.National Institute of Polar Research, 3.Atmosphere Ocean Research Institute, University of Tokyo)

[MIS15-04] Accurate chronology and climatic reconstruction around MIS 11 from the Dome Fuji ice core

*Kenji Kawamura[1,2,3], Ikumi Oyabu[1], Shuji Aoki[4], Takakiyo Nakazawa[4], Ayako Abe-Ouchi[5], Fuyuki SAITO[3] (1.National Institute of Polar Research, Research Organization of Information and Systems, 2.Graduate School for Advanced Studies, SOKENDAI, 3.Japan Agency for Marine-Earth Science and Technology (JAMSTEC), 4.Tohoku University, 5.University of Tokyo)

[MIS15-05] Deglaciation history of the East Antarctic Ice sheet revealed by exposure ages and marine-lake sedimentary records in Lutzow-Holm Bay

*Yusuke Suganuma[1,2], Moto Kawamata[2], Yuki Haneda[1], Takeshige Ishiwa[1], Kota Katsuki[5], Takuya Itaki[3], Osamu Seki[4], Jun'ichi Okuno[1,2] (1.National institute of Polar Research, 2.The Graduate University for Advanced Studies (SOKENDAI), 3.Geological Survey of Japan, AIST, 4.Hokkaido University, 5.Shimane University)

[MIS15-06] Cross-check of dust-magnetic correlation and oxygen isotope stratigraphy in the Southern Ocean

*Hiroki Matsui[1], Minoru Ikehara[1], Yusuke Suganuma[2,3], Osamu Seki[4], Jun'ichi Okuno[2,3], Ikumi Oyabu[2], Kenji Kawamura[2,3] (1.Center for Advanced Marine Core Research, Kochi University, 2.National Institute of Polar Research, 3.Department of Polar Science, School of Multidisciplinary Sciences, The Graduate University for Advanced Studies (SOKENDAI), 4.Institute of Low Temperature Science, Hokkaido University)

Shallow Sea Trial of the Under Ice AUV “MONACA”

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This presentation introduces the AUV MONACA (Mobility Oriented Nadir AntarctiC Adventurer) and reports the results of shallow sea trials held in Oct. 2019 and Feb. 2020.

The AUV MONACA was developed for under ice survey of Antarctica, supported by JSPS Grant-in-Aid for Scientific Research on Innovative Areas No.4902, to measure the sea ice/shelf ice and seafloor for research of ice sheet-ocean interaction. MONACA is 2 m long, 230 kg weigh, and it can cruise for about 8 hours. Depth rating is 1500m. The vehicle is designed to go into ice covered oceans as far as 10 km. The flat body is filled with buoyancy materials at the top so that the battery units and main unit can be accessed from the side. The vehicle has five degrees of freedom (surge, heave, roll, pitch, and yaw) by 4 vertical thrusters and 2 horizontal thrusters. Although the survey range is limited compared with large AUVs, it can conduct a highly precise survey with lower costs. Its modular design enables the necessary and sufficient compositions for various survey needs. Its sensor unit consisting of a multi-beam sonar, an INS (Inertial Navigation System), and a DVL (Doppler Velocity Log) can be flipped upside down, so that the vehicle can survey both the ice and seafloor with minimum modification.

The initial sea experiment was held in Oct. 2019 at Uchiura Bay. The vehicle was deployed with tether cable, and its basic performance such as depth and heading control were veirfied at the open and calm water. Bathymetry data was also collected by the multibeam sonar. The second experiment is planned in Feb. 2020 at Monbetsu Port, located in Hokkaido and covered by ice, where low temperature endurance test will be carried out. The performance to detect floating ice and measure its shape will be also evaluated.

Keywords: Under-ice Survey, AUV

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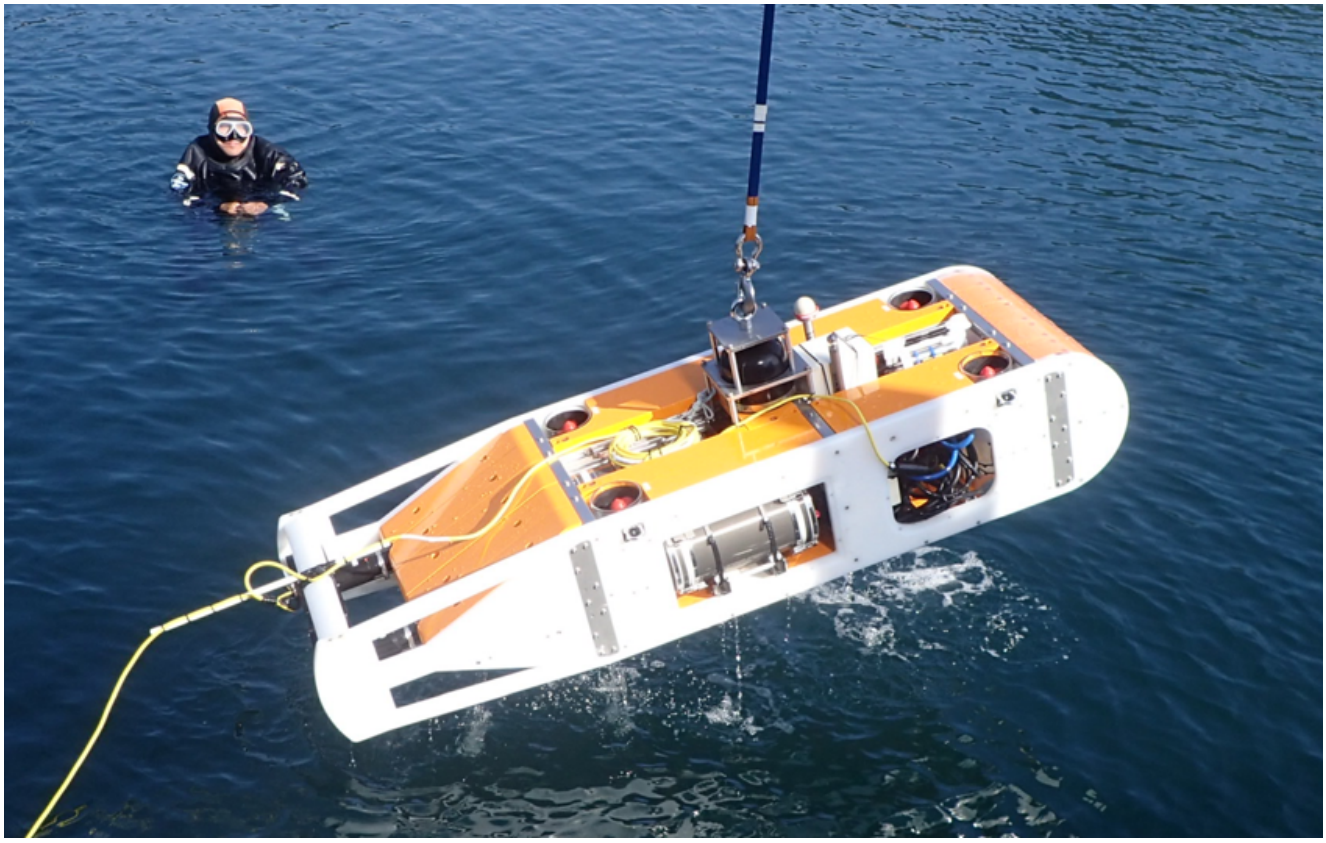

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Modeling warm water intrusion into Lützow-Holm Bay, East Antarctica

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Recent satellite observations suggest that more than half of mass loss from the Antarctic Ice Sheet can be explained by the basal melting of Antarctic ice shelves. Many studies have focused on active basal melt at ice shelves in the Amundsen-Bellingshausen Sea and the Totten Ice shelf, East Antarctica. These ice shelves' bases are exposed to Circumpolar Deep Water, the warmest water mass below the subsurface layer over the Southern Ocean. The warm water mass on the Antarctic coastal margins is a key component for understanding intense basal melting. There is a common oceanographic feature in the two regions: Antarctic Circumpolar Current is very close to the coastal regions, and thus Circumpolar Deep Water can affect regional coastal water masses. The Shirase Glacier Tongue in Lützow-Holm Bay, East Antarctica, is located in the south-eastern part of the Weddell Gyre in the Atlantic sector, where the southward-directed flows advect the relatively warm water toward the coastal region. A recent in-situ oceanographic observational study showed that Circumpolar Deep Water intrudes into Lützow-Holm Bay from the shelf break and similarity of the strong ice-ocean interaction at ice shelves in the Amundsen-Bellingshausen Sea and the Totten Ice Shelf. Here, we conduct a high-resolution numerical simulation with an ocean-sea ice-ice shelf model to understand ocean structure in the Lützow-Holm Bay and the seasonal variation in strong basal melting at the Shirase Glacier Tongue. The model results demonstrate that the basal melt rate reaches a maximum in summer, which is consistent with seasonal change in the strength of Circumpolar Deep Water intrusion. Furthermore, experiments with and without fast ice in the bay show that fast ice plays a role as a surface thermal insulator in the bay and that the existence of fast ice can enhance the basal melting at the Shirase Glacier Tongue.

Keywords: ice-ocean interaction, Circumpolar Deep Water, Lützow-Holm Bay

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Estimation of the Antarctic ice sheet surface mass balance using the polar regional climate model NHM-SMAP

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In the Antarctic ice sheet (AIS), the largest ice body in the world, snow and ice mass loss is accelerated since the 1990s. In the future in a warming world, more surface melt and its resultant further mass loss are expected in the AIS like the present-day Greenland ice sheet, where contribution to mass loss by the reduction of surface mass balance (SMB) is now higher than that from the increase in ice discharge. Because mass losses from these big ice sheets affect the global sea level, it is imperative to understand physical mechanisms of the ice sheet surface mass balance modulation. In the present study, we use the state-of-the-art polar regional climate model NHM-SMAP (Niwano et al., 2018) and attempt to simulate the present-day AIS SMB realistically. Although we use the latest version of NHM-SMAP, which participated in the Greenland ice sheet SMB model inter-comparison project GrSMBMIP (Fettweis et al., 2019, in review) recently, the Richards equation to calculate detailed vertical water movement in snow and firn is not employed due to its high computational cost in the current AIS version: a simple so-called “bucket scheme” is used instead. Using the model-calculated results, we will investigate the governing physical process of the AIS SMB modulation. Here, the default horizontal resolution of NHM-SMAP for the AIS is now set to be 12 km, although a horizontal resolution of 6 km has been tested for some selected years as well. Recently, Mottram et al. (2019, in review) conducted an inter-comparison of numerical models that can calculate the AIS SMB for the first time. The horizontal resolutions we set for NHM-SMAP (6 and 12 km) are higher than those employed in the models described by Mottram et al. (2019, in review). Our preliminary results indicate that the AIS-integrated annual SMB simulated by NHM-SMAP is more positive in the 6 km version than the 12 km one. Also, the annual AIS-integrated SMB simulated by the default 12 km NHM-SMAP tends to be less positive than other regional climate models like HIRHAM5, RACMO2.3p2, and MAR v3.10, although it is close to the result by COSMO-CLM2. In the presentation, we will also discuss model validation results by comparing the model-simulated SMB as well as the surface meteorological conditions with in-situ measured data.

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Keywords: Antarctic ice sheet, surface mass balance, polar regional climate model, NHM-SMAP

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Accurate chronology and climatic reconstruction around MIS 11 from the Dome Fuji ice core

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Marine Isotope Stage (MIS) 11 is characterized by long glacial termination and interglacial period, with higher sea level than today, despite moderate atmospheric CO2 concentration and small variations in summer insolation (due to small Earth’ s orbital eccentricity). To investigate the roles of different forcings (e.g. orbital variations and greenhouse gases) on climate and ice sheets, paleoclimatic proxy records need to be accurately dated and precisely synchronized with each other. An accurate chronology for the past 360 ky was constructed through orbital tuning of O_2/N_2 ratio of trapped air in the Dome Fuji and Vostok ice cores with local summer insolation (Kawamura et al., 2007), and its improvement has been underway (Oyabu et al., this session). We are also extending the O_2/N_2 chronology towards older periods to constrain the timing and duration of the past climatic changes.

Marine sediment cores from the northern North Atlantic region exhibit millennial-scale variations with abrupt climatic shifts and bipolar seesaw, during glacial periods and terminations in various proxy records. By correlating the millennial-scale changes recorded in the marine sediment cores (e.g. in sea surface temperature and ice-rafted debris) with those in the Dome Fuji ice core (CH4 concentration and d18O of ice), it may be possible to transfer the Dome Fuji chronology to the marine cores from the North Atlantic. We attempt to correlate planktonic $\delta^{18}O$ and IRD records from marine core ODP 980 with the Dome Fuji CH_4 around MIS 11, and constrain the durations of interglacial periods recorded in the marine core. However, the current resolution of the Dome Fuji gas records (measured at ~2-kyr intervals) is not sufficient to undoubtedly identify all millennial-scale events, thus we are conducting new measurements to improve the resolution of the gas records. In the presentation, we will show the results of the new measurements and synchronization, and discuss the timing, duration and possible mechanisms for the very long interglacial period 400-kyr ago.

Keywords: Dome Fuji, Ice core, MIS11, Interglacial, Antarctica

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Deglaciation history of the East Antarctic Ice sheet revealed by exposure ages and marine-lake sedimentary records in Lutzow-Holm Bay

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The Antarctic Ice Sheet (AIS) is one of the most significant potential contributors to future sea-level changes. Recently, the acceleration of mass loss of the AIS has been reported by several studies based on satellite observations, such as radar altimetry, interferometer, and gravity measurements. In these studies, the main cause of the modern ice mass loss is thought to be an inflow of modified Circumpolar Deep Water (mCDW). However, the role of the mCDW for the large-scale deglaciation of the AIS, such as the deglaciation since the Last Glacial Maximum (LGM), remains unclear due to the lack of the geological data. Therefore, highly-resolved reconstruction of the deglaciation history of the AIS since the LGM is essential to understand the role of the mCDW, which will be a useful analog for calibrate the climate and ice sheet models and refine the future ice sheet retreat projection. In this presentation, we show an overview of our recent activities in the Lützow-Holm Bay, Dronning Maud Land, East Antarctica. Newly obtained surface exposure ages and sedimentary records from the Lützow-Holm Bay show a rapid thinning of the EAIS during the early-mid Holocene likely due to an inflow of mCDW. We, therefore, suggest that it will be a key to obtain both terrestrial and marine-based geological data in the Antarctic margin to understand the potential impact of ocean warming to the rapid and large scale ice sheet melting of the AIS.

Keywords: Antarctica Ice Sheet and Southern Ocean, Giant Reservoirs - Antarctic, Solid Earth

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Cross-check of dust-magnetic correlation and oxygen isotope stratigraphy in the Southern Ocean

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Southern Ocean (SO) marine core chronology forms the basis of understanding the past SO climates. Since the traditional oxygen isotope stratigraphy has difficulty in the SO due to general lack of calcareous foraminifera, dust-magnetic correlation is a promising way for chronology. However, the reliability of the circum-Antarctic dust-magnetic correlation was not fully confirmed, even beyond the last 100 kyrs. Here we show dust-magnetic correlation coupled to oxygen isotope stratigraphy at the marine core in the Indian sector of the SO, and compile the available sites in the Atlantic and Pacific sectors of the SO in order to validate the dust-magnetic correlation. The oxygen isotope stratigraphy confirmed that dust-magnetic correlation is applicable in the SO at least through the last 450 kyrs but revealed non-negligible difference between the two age models. The dust age models tended to be a few thousand kyrs older than the oxygen isotope stratigraphy especially at the glacial terminations. We conducted the phase analysis to show that sedimentation process cannot fully account for the observed difference between the two age models. We then compared, based on dust age models, SO oxygen isotope records with the global benthic stack curve and found that SO oxygen isotope changes earlier than the stack curve. Thus, the early rise in SO bottom water temperature and late response of ice sheet volume would be responsible for the differences between the two age models.

Keywords: Southern Ocean, Chronology, Oxygen isotope stratigraphy, Dust-magnetic correlation

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[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS15] Global climate change driven by the Southern Ocean and the Antarctic Ice Sheet

convener:Osamu Seki(Institute of Low Temperature Science, Hokkaido University), Akira Oka(Atmosphere and Ocean Research Institute, The University of Tokyo), Yoshifumi Nogi(National Institute of Polar Research), Robin Elizabeth Bell(Lamont Doherty Earth Observatory)

The Southern Ocean and Antarctic ice sheet, which are the giant reservoirs of heat, water, and materials, have a potential to play central roles in long-term global climate change. This system is composed of the following sub-systems; ice shelf which is a place of the interaction of ice sheet and ocean, flowing iceberg, seasonal sea ice zone, Antarctic bottom water which drives the thermohaline circulation, active biological production and Antarctic Circumpolar Current. These sub-systems are interacted with each other and have significant impact on changes in the global environmental system. This session aim to summarize recent observational and simulation studies from various fields relating to the past and present changes in the Antarctic Ice sheet and Southern Ocean, which are essential elements for unraveling the changes in the global climate system. Further, future science plans for understanding of the environmental changes of the Antarctic Cryosphere is also discussed.

[MIS15-07] IODP Expedition 382 (Iceberg Alley) – Preliminary results on dust-climate couplings

★Invited Papers

*Michael E Weber[1], Maureen E Raymo[2], Victoria L Peck[3], Trevor Williams[4], Osamu Seki[5], Yuji Kato[6], Mutsumi Iizuka[5], and IODP 382 Scientists (1.Steinmann Institute, University of Bonn, Bonn, Germany, 2.Lamont-Doherty Earth Observatory of Columbia University, Palisades, New York, USA, 3.British Antarctic Survey, Cambridge, UK, 4.International Ocean Discovery Program, Texas A&M University, College Station, USA, 5.Institute of Low Temperature Science, Hokkaido University, Japan, 6.Center for Advanced Marine Core Research, Kochi University, Japan)

[MIS15-08] Property of eddy and AABW observed off Cape Pointset

*Kitade Yujiro[1], Kohei Mizobata[1], Daisuke Hirano[2], Keishi Shimada[1], Shigeru Aoki[2], Takeshi Tamura[3] (1.Tokyo University of Marine Science and Technology, 2.Hokkaido University, 3.National Institute of Polar Research)

[MIS15-09] Antarctic Bottom Water and global ocean meridional overturning circulation

★Invited Papers

*Katsuro Katsumata[1] (1.JAMSTEC)

[MIS15-10] Temporal variation of the Antarctic Bottom Water revealed by the mooring measurements off the Vincennes Bay

*Kohei Mizobata[1], Yujiro Kitade[1], Keishi Shimada[1], Daisuke Hirano[2], Yoshimasa Matsumura[3], Cheng Lingqiao[4], Shigeru Aoki[2], Takeshi Tamura[5] (1.Tokyo University of Marine Science and Technology, 2.Institute of Low Temperature Science, Hokkaido University, 3.Atmosphere and Ocean Research Institute, The University of Tokyo, 4.Shanghai Ocean University, 5.National Institute of Polar Researc)

[MIS15-11] Foraging movements and prey of short-tailed shearwaters in the Southern Ocean

★Invited Papers

*Yutaka Watanuki[1], Sarara Azumi[1], Akinori Takahashi[2], Nobuo Kokubun[2], Yasuhiro Ando[1], Masato Moteki[3], Fernando Arce, Mary-Anne Lea, Mark Hindell (1.Faculty of Fisheries Science, Hokkaido University, 2.National Institute of Polar Research, 3.Tokyo University of Marine Science and Technology)

IODP Expedition 382 (Iceberg Alley) –Preliminary results on dust-climate couplings

*Michael E Weber[1], Maureen E Raymo[2], Victoria L Peck[3], Trevor Williams[4], Osamu Seki[5], Yuji Kato[6], Mutsumi Iizuka[5], and IODP 382 Scientists

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International Ocean Discovery Program (IODP) Expedition 382, Iceberg Alley and Subantarctic Ice and Ocean Dynamics, took place from March 20 to May 20, 2019 with RV JOIDES Resolution (Weber et al., 2019). The primary goal is to investigate the long-term history of Antarctica in order to better understand the dynamics of the Antarctic Ice Sheet (AIS), how the pace and magnitude of past ice-mass loss responded and contributed to global sea-level evolution. Another goal is to decipher how past changes in ocean bioproductivity and dust deposition in the Antarctic zone might have influenced atmospheric CO_2 variability. We drilled five sites with multiple holes east of the Drake Passage with a total core recovery of ~2.8 km.

Three sites were collected in the center of Iceberg Alley, between –57.4˚S and –59.4˚S in the southern Scotia Sea. We recovered continuously deposited late Neogene sediments covering at least the last 3.5 Ma. Preliminary biostratigraphic assessment indicates over 45 first and last occurrences of biosiliceous species that are pristinely preserved. Also, all known magnetic boundaries since the Late Neogene are clearly documented. Resulting sedimentation rates are ~20–10 cm/kyr for Sites U1536 and U1537, and ~40–20 cm/kyr for Site U1538. Accordingly, all sediment physical and optical properties determined onboard at 1–2 cm increments, translate into sample resolutions in the upper decadal to lower centennial band. Overall, we retrieved the first high-resolution and long-term, continuous climate and ice-sheet record in the Antarctic zone.

The sites from Iceberg Alley will be used to study the Plio-Pleistocene flux of icebergs through Iceberg Alley, the main pathway along which icebergs calved from the margin of the AIS travel as they move equatorward into the warmer waters of the Antarctic Circumpolar Current (ACC). In particular, the continuous and rather highly-resolved sediment record from Iceberg Alley should enable us to assess the magnitude of iceberg flux and dust climate couplings for key time periods of AIS evolution, e.g., the middle Miocene glacial intensification of the East Antarctic Ice Sheet, the mid-Pliocene warm period, the late Pliocene glacial expansion of the West Antarctic Ice Sheet, the mid-Pleistocene transition (MPT), “warm interglacials” and glacial terminations of the last 800 kyr. We will use the geochemical provenance of iceberg-rafted detritus (IBRD) and other glacially eroded material to determine regional sources of AIS mass loss. We will also address interhemispheric phasing of ice sheet growth and decay, study the distribution and history of land-based versus marine-based ice sheets around the continent over time, and explore the links between AIS variability and global sea level.

Comparing changes in dust proxy records between the Scotia Sea and Antarctic ice cores will also provide a detailed reconstruction of changes in the Southern Hemisphere westerlies on millennial and orbital timescales for the last 800 kyr. Extending the ocean dust record beyond that time is a critical goal and will help evaluating dust-climate couplings since the Pliocene, the potential role of dust in iron fertilization

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and atmospheric CO_2 drawdown during glacials, and whether changes in dust input to Antarctica played a role across the MPT for subsequently slightly lowered glacial atmospheric pCO_2.

Reference

Weber, M.E., Raymo, M.E., Peck, V.L., Williams, T., and Expedition 382 Scientists, 2019. Expedition 382 Preliminary Report: Iceberg Alley and Subantarctic Ice and Ocean Dynamics. International Ocean Discovery Program, 1-40.

Keywords: Antarctica, paleoclimate, ice-sheet

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Property of eddy and AABW observed off Cape Pointset

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In recent years, attention has been focused on the acceleration of melting of the Totten ice sheet, so our research group is focusing on clarifying the mechanism that the melting of the Totten ice sheet by expanding our observation area from Vincennes to the east. According to Mizobata et al.(2020), satellite sea level records show that Pointset eddy are constantly observed in this area, but the formation mechanism of the eddy has not been clarified. This eddy may play an important role, such as supplying warm water to the continental shelf. Elucidation of the actual state and formation mechanism of the eddy is considered as a key for the promotion mechanism of ice sheet melting.

The observations by TR/V Umitaka-Maru this year were conducted from January to February 2020. Since the Pointset eddy was detected from satellite SSH data during the observation period, observation line along 64°S and 115°N were established to clarify the structure of the eddy. At each site, hydrographic observations were carried out up to 10m just above the sea floor. As a result of the observation, the eddy was also confirmed in the temperature and salinity structure. From the combined results of SSH and dynamical calculation, it was estimated that the flow due to the pointset eddy was about 6 cm/s near the sea surface and about 1 cm/s near the sea floor. In addition, it was found that high salinity Antarctic Bottom Water (AABW), which is relatively special around this area, was distributed on the bottom of the continental slope off Cape Pointset.

The relatively high-salinity AABW was distributed along a 3000 m isobath around the Cape Pointset. It is difficult to clarify the source of this high salinity AABW from the observations of Umitaka Maru alone. However, in February 2019, observations were made on the continental shelf by Shirase, and it has been found that modified Circumpolar Deep Water (mCDW) with a high salinity exceeding 34.65 has been found in the depressions on the continental shelf. Since this mCDW has a high temperature of 0.3°C, the mCDW cannot directly become the high-salinity AABW. While the high-salinity signal like observed off the Pointset also appeared at the upper part of AABW at 63.5°S, it does not be dense enough to sink to the bottom of the Australian Antarctic Basin. However, the submerging process of high-salt and low-temperature water on the slope may contribute to the excitation of cyclonic eddies, and the supply of warm water on the continental shelf may also be an important mechanism of this area. In the future, we plan to clarify formation mechanisms of eddy and the high salinity water by combining with other data.

Keywords: Antarctic bottom water, Southern Ocean, Ocean eddy

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Antarctic Bottom Water and global ocean meridional overturning circulation

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1. JAMSTEC

Antarctic Bottom Water (AABW) originates from dense shelf water mixing with surrounding (modified) Upper Circumpolar Deep Water as it flows down the shelf slope. In the past, the variability of AABW had been hardly observed, but since the 1980's, ship-based observations have clarified decadal variabilities of AABW, including its volume reduction and freshening. I review the role of AABW in the global overturning meridional circulation which stirs the world oceans in millenium time scales. I discuss the difficulty involved in the question what "drives" (the term used in the session name) the meridional overturning circulation. I also report recent findings on the variability and formation processes of AABW observed in recent ship-based observation in the 2018/19 and 2019/20 seasons along the Antarctica shelves.

Keywords: Antarctic Bottom Water, Ship-based observation, Meridional overturning circulation

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Temporal variation of the Antarctic Bottom Water revealed by the mooring measurements off the Vincennes Bay

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The newly formed Antarctic Bottom Water (AABW), which is originated from the Vincennes Bay Polynya, has been confirmed off the Vincennes Bay, East Antarctica. In recent years, the T/RV Umitaka-maru hydrographic observations suggests the variety of the AABW off the Vincennes Bay and off the Totten Ice Shelf. In this study, we conducted the mooring observations off the continental slope (Sta. KC6: 64° -59.94’ S, 109° -59.52’ E, Water depth: 2580m) and the eastern side of the ridge (Sta. KM2: 64° -26.01’ S, 106° -59.58’ E, Water depth: 2590m) extending north off the Vincennes Bay from January 19 th 2019 to January 21st 2020. The mooring system includes RBR Solo3T temperature sensors, SeaBird MicroCAT CTD sensors and Seaguard recording current meters (Sta. KM2 only). The ship-based CTD measurements were also made at the both stations, along 110°E line, off the Vincennes Bay and Off the Dalton Polynya region. At Sta. KM2, temperature and salinity gradually increased from January to the middle of July, and then decreased from the middle of July to late September. From October, temperature and salinity gradually increased again. During winter when temperature and salinity dropped indicating the AABW signal, changes in salinity and potential temperature were about 0.01 and 0.15 °C, respectively. At Sta. KC6, temperature and salinity gradually increased from January to early June, and then decreased from the middle of June. This decreased in temperature and salinity also indicates the AABW signal. However, compared to Sta. KM2, the water temperature change (about 0.1°C) was small, and the minimum water temperature was high, Moreover, salinity was relatively high (annual average difference is about 0.006). For instance, the difference of salinity between Sta. KC6 and Sta. KM in early September was about 0.009. The mooring measurements at Sta. KC6 illustrated the water mass property (salinity = 34.65~34.66) before recruitment of newly formed AABW from the Vincennes Bay Polynya. This result corresponds to relatively high salinity observed by T/RV Umitaka-maru hydrographic observations off the Cape Poinsett in January 2020.

Keywords: Antarctic Bottom Water, Vincennes Bay, Mooring Observation

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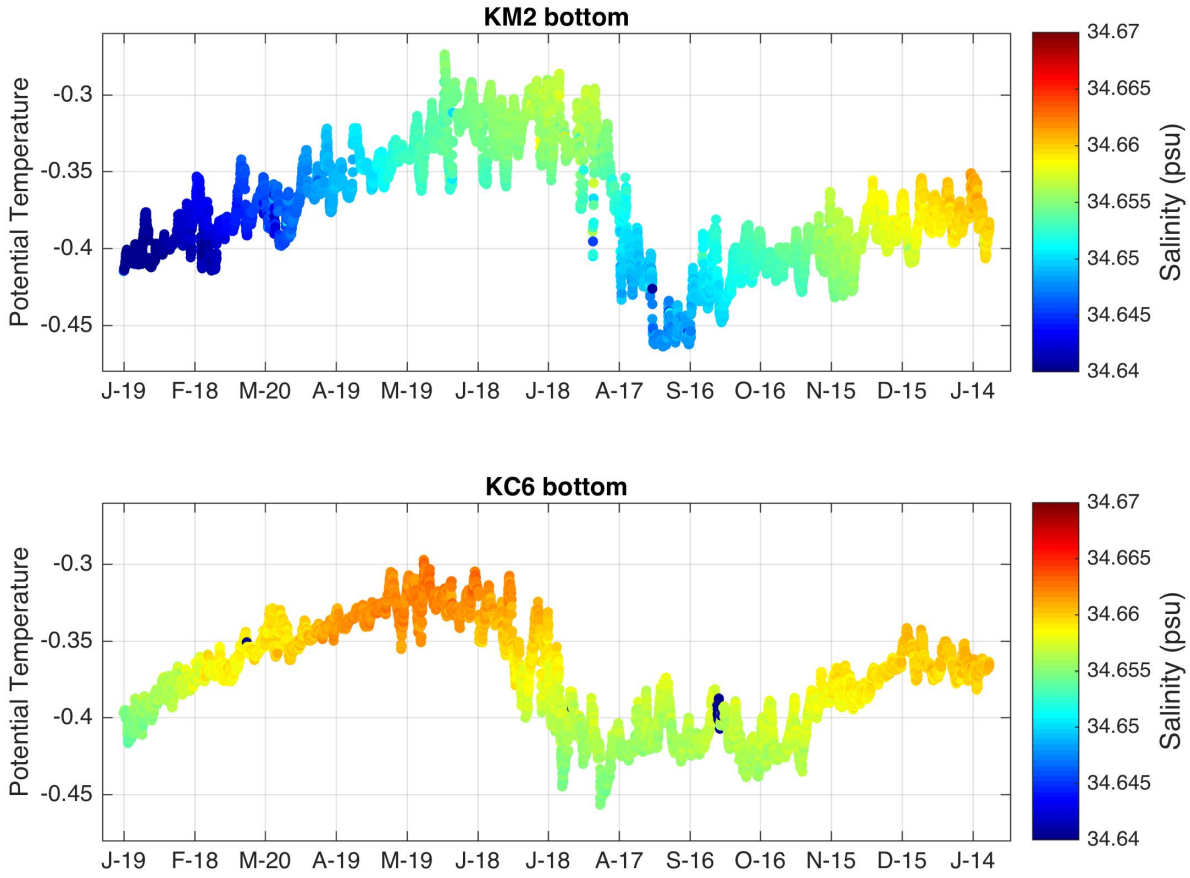

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Foraging movements and prey of short-tailed shearwaters in the Southern Ocean

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In the Southern Ocean food web, Antarctic krill is believed to be the key prey species in the sea-ice related shelf and shelf-slope regions; feeding mainly on ice algae and being a major food of predators (predatory fish, marine mammals and seabirds). However, myctophids can be an alternative food source when Antarctic krill is less abundant, especially in the basin region. These spatial and temporal variations in the abundance of krill and myctophids may indicate the change of overall food web. Thus it is important to know when and where this shift occurs and to explore the underlying mechanisms. During the summer, seabirds feed in offshore habitats and come back to the nests often to exchange incubation duties and to feed their chicks. At this time of year, they are relatively easy to capture and the composition of their prey has been well studied. A review study of seabird diet indicates that myctophids appear to be important food in penguins and shearwaters/petrels, in locations where birds are foraging in oceanic basin/slope habitat and among those feeding often in the night. Many recent studies of the fatty acid signature of stomach oil of Procellarriformes (shearwaters, petrels, prions, storm-petrels) also showed that myctophids are important prey when these birds are exploiting oceanic habitats distant from the colonies. Stomach oil, which consists of undigested lipids of prey species (triacylglycerols and wax esters) is often found in the adult Procellariiformes returning from long (~ca. two weeks) foraging trips. Fatty acid profiles of undigested lipids reflect that of the prey consumed about ~ a week earlier. Therefore, seabirds can be a tool to explore spatial and temporal variation of key prey species and their interactions with predators in the Southern Ocean. Short-tailed shearwaters (STSH) breeding in Tasmania employ a dual foraging strategy; the birds feed in the Tasman Sea during short trips (<2days) and feed in the Indian Ocean sector of Southern Ocean during long trips (>10 days). In the Indian Ocean sector, krill abundance is relatively low compared to the Scotia-Weddell Sea, and it is expected that krill-dependent food web may be dominant over the shelf slope while krill-independent food web may exist in oceanic zone. To understand how STSH move in these two habitats, we tracked the movements of adult birds using GPS loggers and identified their prey species using fatty acid signatures of stomach oils that were collected when they returned to the colony after long trips. We collected 14 long trip tracks and two oil samples from STSH breeding on Wedge Island in Tasmania in Jan- Feb 2019. We identified the areas where birds were feeding or resting on the water from slow movement speed (<7m/s). Two core-use areas (50% kernel density) of feeding/resting were recognized. One (named "Core-2") was in 160˚E 67˚S in the shelf-slope around Burny Islands and the other ("Core-3") was in 120˚E 57˚S in the basin of Polar Frontal Zone. 93% of birds used Core-2 during the long trips. We analyzed the fatty acid composition of stomach oil in two birds spending 7 days in Core-2 area c 10days before coming back to the colony. The fatty-acids profile of these stomach oil samples indicated that the two birds fed on myctophids. Core-3 might also be important to some extent but no diet samples were available in 2019. In Core-2 area, birds often made short-distance movements and fed or rested on the water both in day and night, while in Core-3 area, birds fed or rested on the water in the night time more often than they did during the day. Thus at least some individuals fed on myctophids even over the shelf-slope both in day and night in the basin around Burny Islands. This study indicates the importance of myctophids for seabirds in the Southern Ocean ecosystem.

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Keywords: krill, myctophids, food web, tracking, fatty acids, Indian Ocean sector

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[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS17] Astrobiology

convener:Hikaru Yabuta(Hiroshima University, Department of Earth and Planetary Systems Science), Seiji Sugita(Department of Earth and Planetary Science, Graduate School of Science Sciece, The University of Tokyo), Misato Fukagawa(National Astronomical Observatory of Japan), Fujishima Kosuke(Tokyo Institute of Technology, Earth-Life Science Institute)

Twenty years have passed since when the field of Astrobiology, which aims to unveil the origins, evolution, and habitability of life by integrating multidisciplinary fields, was established. Individual themes related to Astrobiology, such as chemical evolution in the early Solar System, formation of planetary system, prebiotic chemistry in the early Earth, evolution of life in the Earth's history, extremophile, and habitable planetary environments, has been studied by the knowledge and methods from the multiple fields, which has enabled us to explain "Where we came from" in some ways. However, despite an overwhelming number of investigations and discussions through gathering of the scientists from different fields, there has remained the long-standing unsolved question: How did abiotic materials gain biological function in the Earth and elsewhere in universe? There is still a large gap between prebiotic organic chemistry and biochemistry toward Origins of Life and planetary habitability. Therefore, the JpGU Astrobiology session focuses on pathfinding of "integration of astronomy, geoscience, and biochemistry", which will face an increasing need for the future Astrobiology. In order to enhance our understanding of "What is life", we propose to discuss the biochemical events linked with planetary systems, which is beyond the knowledge in a test tube, by an integration of exoplanets and molecular biology, etc. Through this approach, we will lead the discussions and developments of life-detection strategies for the future exploration of life in universe.

[MIS17-01] Observations and modelling of exoplanetary atmospheres

★Invited Papers

*Giovanna Tinetti[1] (1.UCL)

[MIS17-02] Astrochemistry in planetary system formation: from molecular clouds to protoplanetary disks and planetary system material

★Invited Papers

*Yuri Aikawa[1] (1.Department of Astronomy, Graduate School of Science, University of Tokyo)

[MIS17-03] Formation of Complex Amino Acid Precursors by Cosmic Rays in Interstellar Environments

★Invited Papers

*Kensei Kobayashi[1], Soushi Kuramoto[1], Tomohito Sato[1], Miki Nakayama[2], MITA Hajime[2], Satoshi Yoshida[3], Hitoshi Fukuda[4], Yoshiyuki Oguri[4], Hiromi Shibata[5], Yoko Kebukawa[1] (1.Department of Chemistry, Yokohama National University, 2.Fukuoka Institute of Technology, 3.National Institutes for Quantum and Radiological Science and Technology, 4.Tokyo Institute of Technology, 5.Osaka University)

[MIS17-04] Ground-based transmission spectroscopy of TRAPPIST-1g

*Mayuko Mori[1], Akihiko Fukui[1], Norio Narita[2], Hannu Parviainen[4], Yui Kawashima[3], John H. Livingston[1], Kiyoe Kawauchi[1], Motohide Tamura[1,2,5] (1.The University of Tokyo, 2.Astrobiology Center, NINS, 3.Netherlands Institute for Space Research, 4.Instituto de Astrofisica de Canarias, 5.National Astronomical Observatory of Japan)

[MIS17-05] UV irradiation and organic synthesis on growing dust particles in protoplanetary disks

*Kazuaki Homma[1], Satoshi Okuzumi[1] (1.Tokyo Institute of Technology)

Observations and modelling of exoplanetary atmospheres

*Giovanna Tinetti[1]

1. UCL

It is now accepted that exoplanets are ubiquitous. However little is known about those planets we have detected beyond the fact they exist and their location. For a minority, we know their weight, size and orbital parameters. How do we progress from here?

Key observables to understand the nature of planets are the chemical composition and state of their atmosphere. Pioneering results were obtained in the past couple of decades with Hubble, Spitzer and ground-based facilities, enabling the detection of ionic, atomic and molecular species and of the planet’s thermal structure.

With the arrival of improved or dedicated instruments in the coming decade (JWST, ARIEL, Twinkle, ELT, TMT), planetary science will expand beyond the narrow boundaries of our Solar System to encompass our whole Galaxy. These dedicated missions will enable the use of the atmospheric chemical composition and structure as powerful diagnostics of the history, formation mechanisms and evolution of gaseous and rocky exoplanets.

Keywords: Exoplanets, Atmospheres, Remote sensing

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Astrochemistry in planetary system formation: from molecular clouds to protoplanetary disks and planetary system material

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Earth-like planets are formed via coagulation of solid material in protoplanetary disks. Since volatiles are one of the essential ingredients of habitable planets, the distribution of volatiles between the solids and the gas phase in the raw material of planetary systems are of special importance. In this presentation, I will review astrocchemistry of volatiles in planetary system formation.

Sun-like starts and protoplanetary disks are formed by the gravitational collapse of molecular cloud cores. In the central region of a cloud core, most of the volatile species, except for H2 and He, are frozen onto dust grains due to low temperature (\sim 10 K) and high density (\gt 10^5 cm^{-3}). As collapse proceeds, the temperature rises, and various molecules sublimate to be observed around a forming protostar: e.g. water and organic molecules such as CH_3OH. Since radio observations of gaseous molecular are more sensitive and have more diagnosing power than infrared observations of solid material, molecular line observations have been performed towards several protostars to constrain the raw material for planetary system formation. Towards the protostar IRAS 16293 and FU Ori star V883 Ori, the molecular composition of the sublimates is found to be similar to that of comet 67P/C-G. It suggests that the raw material of other planetary systems is as rich in volatiles and organic molecules as that of Solar system.

When the parental molecular cloud dissipates, a protostar evolves to a T Tauri star, and its circumstellar disk is called a protoplanetary disk. ALMA found ring-gap structures in many protoplanetary disks. While various mechanisms are proposed for the ring-gap structures, one of the promising mechanisms is the disk-planet interaction; i.e. the disks may already harbor planets. Observations also suggest radial migration of large dust grains. Since grains are covered with ice mantles, volatiles could also be enriched in inner radii and ring regions. The snow line of CO is now spatially resolved in a few disks, while water snow line is hard to resolve even with ALMA, except for disks in outburst.

Keywords: astrochemistry, planetary system formation

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Formation of Complex Amino Acid Precursors by Cosmic Rays in Interstellar Environments

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Wide variety of amino acids have been detected in water-extract of carbonaceous chondrites (CCs) [1], and it is suggested that such extraterrestrial amino acids are important for chemical evolution toward the generation of the first life on the Earth. It was shown that meteoritic amino acids increased after acid-hydrolysis, which means that at least a part of amino acids found in CCs are *precursors* of amino acids. Experiments simulating interstellar and asteroid environments showed that amino acid *precursors*, rather than free amino acids, were formed in prebiotic reactions [2, 3]. Amino acid precursors, however, have not been characterized. It has often been said that a-amino acids found in CCs were formed by the Strecker-type reactions. If so, aminonitriles (NH_2-CHR-CN) are precursors of a-amino acids, but the evidence has not been shown, nor aminonitriles have not been detected in CCs. Hydantoin has been identied in extracts of CCs [4], and it is a candidate of precursors of glycine. Extraterrestrial amino acid precursors found in CCs were probably synthesized in molecular cloud environments [2] or small celestial bodies [3]. We irradiated possible interstellar media, such as mixture of carbon monoxide, ammonia and water to simulate possible reactions among interstellar media in dense clouds. The irradiation products were analyzed by HPLC and mass spectrometry to characterize amino acid precursors in the products.

Experiment: A gaseous mixture of CO and NH_3 was sealed in a Pyrex glass tube with liquid water. The gaseous mixture was irradiated with 2.5 MeV protons from a Tandem accelerator at Tokyo Institute of Technology. Total quantity of electricity was 2 mC. The irradiation products is hereafter referred to as CAW. A mixture of CH_3OH, $NH_3$and H_2O (molar ratio 1:1:2.8) was sealed in a pyrex glass tube, frozen in liquid nitrogen, and irradiated with 290 MeV/u carbon ions from HIMAC accelerator (NINS, QST, Japan). The irradiation products is hereafter referred to as MeAW.

Aminoacetonitrile, a precursor of glycine, in CAW and MeAW was determined by cation-exchange HPLC after derivatized with orthophthalaldehyde and N-actyl-L-cysrtein. Hydantoin in the both product was determined by reversed-phase HPLC. Both products were fractionated by gel filtration chromatograpy (column: Shodex OHpak SB-802.5 HQ) and/or ultrafiltration (Pall Ultrafiltration device 3K). Each fraction was acid-hydrolyzed and amino acids in the fractions were determince by the cation-exchange HPLC (shown above). Both products were also characterized by LC/Orbitrap-MS.

Results and Discussion: Both CAW and MeAW had little amino acids before hydrolysis, but various amino acids were detected after hydrolysis. Glycine was predominant in all the case. Thus, not free amino acids but amino acid precursors were formed in the simulation experiments. It was shown that neither aminoacetonitrile nor hydantoin were major glycine precursors, but complex amino acid precursors were major amino acid precursors. In the case of CAW, amino acid precursors whose molecular weights were over 3000 were predominant. Peaks of m/z = 1000 or over were detected by mass spectrometry. These results strongly suggested that complex amino acid precursors with large molecular weitghts could be directly generated from small molecules such as CO or CH_3OH in interstellar environments. It was suggested that the Strecker-type reaction was not a major pathway of amino acid formation in molecular

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clouds: Flash-and-quench-type reactions might be important for the formation of complex molecules in space.

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Keywords: Amino Acid Precursors, Non-Strecke-Type Reactions, Cosmic Rays, Molecular Clouds, Complex Organic Compounds, Chemical Evolution

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Ground-based transmission spectroscopy of TRAPPIST-1g

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Measuring the compositions of planetary atmospheres is important for understanding planetary formation, evolution, and habitability. The TRAPPIST-1 system, which has seven Earth-sized planets orbiting an M-dwarf, provides an exceptional opportunity for the atmospheric characterization of temperate Earth-sized exoplanets (Gillon et al. 2017). Based on previous studies using the Hubble Space Telescope (de Wit et al. 2018), most of the TRAPPIST-1 planets seem not to have clear H2/He-dominated atmospheres. However for TRAPPIST-1g, the largest planet in the system, the result was not conclusive in the observed wavelengths (1.1-1.7um). In addition, the effect of stellar surface inhomogeneity on the transmission spectra has recently begun to be considered (Rackham et al. 2017). With this effect, the planetary transmission spectra can be considerably distorted, especially in the optical wavelength range. To study the atmosphere of TRAPPIST-1g, we observed a TRAPPIST-1g transit event on the night of UT 2017 September 2 simultaneously with the Gemini Telescope / Gemini Multi-Object Spectrographs (GMOS) at 600nm and the Subaru Telescope / Multi-object infrared camera and spectrograph (MOIRCS) at 1300-2300nm. The observed wavelength range is useful to constrain the planet's atmosphere because it covers strong methane absorption lines around 2300nm and signatures of Rayleigh scattering in the optical wavelength range.

We jointly model the light curve as the combination of a transit and a Gaussian Process. We fit the 14 light curves in each wavelength bin simultaneously and estimate the model parameters using Markov Chain Monte Carlo. The resultant transit depths are consistent with the results of other telescopes, although the derived transit depths have uncertainties that are too large to distinguish between different atmospheric models. However, our results are important to constrain the stellar surface model of TRAPPIST-1. We compare the validity of several stellar surface models obtained from previous studies and three different atmospheric models. The derived relatively flat transmission spectrum can rule out the existence of large hot spots on the surface of TRAPPIST-1. We find that it is important to observe transmission spectra simultaneously in a wide wavelength range to constrain stellar models prior to conducting intensive planetary atmosphere studies using next-generation large telescopes.

Keywords: TRAPPIST-1, Atmosphere, Spectroscopy, Observation, Habitable Planets

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UV irradiation and organic synthesis on growing dust particles in protoplanetary disks

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Organic-mantled dust particles are commonly found in interplanetary dust particles. Organics have high stickiness in warm environments where they become soft. In warm regions of protoplanetary disks, aggregates of organic-mantled particles may avoid fragmentation at high-speed collisions and grow directly into planetesimals (Kouchi et al. 2002; Homma et al. 2019).

However, it is still unclear how organic mantles can form on dust grains in protoplanetary disks. One possible scenario is that they form by UV irradiation and subsequent heating of volatile ices on the grains. Ciesla & Sandford (2012) show that volatiles in small icy dust particles can be transformed into some radicals by interstellar UV in the outer part of disks. They suggest that the radicals may form organic matter when the icy particles migrate to the inner part of the disks and experience heating. However, Ciesla & Sandford (2012) determine UV-flux ignoring the evolution of distribution, the growth and the fragmentation of dust particles that are dominant components determining UV-flux.

The purpose of this study is to reveal the effects of the evolution of distribution, the growth and the fragmentation of dust aggregates on the UV-absorption of ice dust aggregates. We simulate the growth, vertical transport, and UV absorption of icy aggregates in a protoplanetary disk. We assume interstellar UV radiation near the disk surface and count the number of UV photons absorbed by ice on individual aggregates. We take into account the exchange of UV-absorbed ice between colliding aggregates, a key process that delivers UV-absorbed ice to large aggregates lying near the disk midplane. Based on the results of previous laboratory experiments, we convert the amount of absorbed UV photons into the amount of organics that would form after the aggregates are transported into inner disk regions and experience heating.

We find that UV-absorbed ice is delivered to large aggregates through the cycle of the production, vertical mixing, and reaccretion of small grains. The small grains, which are produced by high-speed collisions of large aggregates, are efficiently transported to the disk surface by turbulent diffusion and receive UV radiation there. These UV-irradiated grains are then incorporated into larger aggregates through collisions. Incorporation of UV-irradiated ice into large aggregates is important because large aggregates generally migrate toward the central star by gas drag (Adachi et al. 1976) and will thereby naturally experience heating that may lead to organic synthesis. We discuss the possibility that aggregates of organic-mantled grains forming this way directly grow into rocky planetesimals in the warm inner region of protoplanetary disks.

Keywords: planet formation, dust , organic synthesis

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[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS17] Astrobiology

convener:Hikaru Yabuta(Hiroshima University, Department of Earth and Planetary Systems Science), Seiji Sugita(Department of Earth and Planetary Science, Graduate School of Science Sciece, The University of Tokyo), Misato Fukagawa(National Astronomical Observatory of Japan), Fujishima Kosuke(Tokyo Institute of Technology, Earth-Life Science Institute)

Twenty years have passed since when the field of Astrobiology, which aims to unveil the origins, evolution, and habitability of life by integrating multidisciplinary fields, was established. Individual themes related to Astrobiology, such as chemical evolution in the early Solar System, formation of planetary system, prebiotic chemistry in the early Earth, evolution of life in the Earth's history, extremophile, and habitable planetary environments, has been studied by the knowledge and methods from the multiple fields, which has enabled us to explain "Where we came from" in some ways. However, despite an overwhelming number of investigations and discussions through gathering of the scientists from different fields, there has remained the long-standing unsolved question: How did abiotic materials gain biological function in the Earth and elsewhere in universe? There is still a large gap between prebiotic organic chemistry and biochemistry toward Origins of Life and planetary habitability. Therefore, the JpGU Astrobiology session focuses on pathfinding of "integration of astronomy, geoscience, and biochemistry", which will face an increasing need for the future Astrobiology. In order to enhance our understanding of "What is life", we propose to discuss the biochemical events linked with planetary systems, which is beyond the knowledge in a test tube, by an integration of exoplanets and molecular biology, etc. Through this approach, we will lead the discussions and developments of life-detection strategies for the future exploration of life in universe.

[MIS17-06] Everyone’s an Astrobiologist

★Invited Papers

*Mary A Voytek[1,2] (1.NASA Headquarters, 2.Earth-Life Science Institute, Tokyo Institute of Technology)

[MIS17-07] New strategies for extraterrestrial life exploration compatible to planetary protection

★Invited Papers

*Yohey Suzuki[1] (1.Graduate School of Science, The University of Tokyo)

[MIS17-08] Polyester microdroplets, coacervates, and other membraneless non-biological assemblies as primordial compartments

★Invited Papers

*Tony Z Jia[1], Kuhan Chandru, Yayoi Hongo, Rehana Afrin, Tomohiro Usui, Kunihiro Myojo, H. James Cleaves (1.Earth-Life Science Institute, Tokyo Institute of Technology)

[MIS17-09] Reconstruction of the original core of RNA polymerase from short peptide

*Sota Yagi[1], Aditya K. Padhi[2], Kam Y. J. Zhang[2], Shunsuke Tagami[1] (1.Laboratory for Advanced Biomolecular Engineering, RIKEN Center for Biosystems Dynamics Research, 2.Laboratory for Structural Bioinformatics, RIKEN Center for Biosystems Dynamics Research)

[MIS17-10] Screening RNA-binding peptides using restricted set of amino acids

*Shota Nishikawa[1], Hidenori Watanabe[2], Naohiro Terasaka[3], Takayuki Katoh[3], Kosuke Fujishima[2] (1.School of Life Science and Technology, Tokyo Institute of Technology, 2.Earth Life Science Institute, Tokyo Institute of Technology, 3.Department of Chemistry, Graduate school of Science, The University of Tokyo)

Everyone’s an Astrobiologist

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Humankind has been interested in our origins and the possibility of life beyond Earth for over 2500 years. Initially this interest was in the realm of the philosophers, but research focusing on the origin, evolution and distribution of life in the universe began in earnest more than 60 years ago. Since then, the field of Astrobiology was established to be an interdisciplinary effort that draws on knowledge from across the sciences to understand how a planet, e.g. Earth, evolved from an abiotic to a biotic state and to understand how 'life' could be identified against the complex backdrop of planetary processes that occur on terrestrial bodies. This is a critical time for astrobiology as space agencies identify the search for life as a top priority and plan missions to investigate bodies within our solar system and beyond. It is time to synthesize what we know and work together to understand how and where to look for life.

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New strategies for extraterrestrial life exploration compatible to planetary protection

*Yohey Suzuki[1]

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It is critical to obtain samples returned from Martian biosphere for demonstrating the existence of extant life and life’ s signatures by high-sensitivity and high-resolution analytical procedures. Rovers named Mars2020 and ExoMars equipped with drilling devices and life-detection instruments will be launched this year. National Aeronautics and Space Administration (NASA) and European Space Agency (ESA) are planning to start Mars Sample Return Mission (MSR) from 2026. From the circumstances, the MSR Science Planning Group (MSPG) is internationalizing the planning for the Returned Sample Science component of MSR, whereas Committee on Space Research (COSPAR) is responsible for establishing analytical protocols with best available technology to determine whether returned materials are biohazard or not.

The presenter is currently serving as a sole non-US and non-EU member of COSPAR Sample Safety Assessment Protocol Working Group (SSAP WG). In this presentation, it is attempted to share information about the current status of MSR and backward planetary protection. More importantly, scientific and technological advances achieved by the presenter will be presented to convince the necessity of new strategies for extraterrestrial life exploration compatible to planetary protection.

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Polyester microdroplets, coacervates, and other membraneless non-biological assemblies as primordial compartments

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Compartmentalization was likely essential for primitive chemical systems during the emergence of life, both for preventing leakage of important components, i.e., genetic materials, and for enhancing chemical reactions. Although life as we know it uses lipid bilayer-based compartments, the diversity of prebiotic chemistry may have enabled primitive living systems to start from other types of boundary systems. Here, we demonstrate membraneless compartmentalization based on prebiotically available organic compounds, α-hydroxy acids (αHAs), which are generally coproduced along with α-amino acids in prebiotic settings. Facile polymerization of αHAs provides a model pathway for the assembly of combinatorially diverse primitive compartments on early Earth. We characterized membraneless microdroplets generated from homo- and heteropolyesters synthesized from drying solutions of αHAs endowed with various side chains. These compartments can preferentially and differentially segregate and compartmentalize fluorescent dyes and fluorescently tagged RNA, providing readily available compartments that could have facilitated chemical evolution by protecting, exchanging, and encapsulating primitive components. Protein function within and RNA function in the presence of certain droplets is also preserved, suggesting the potential relevance of such droplets to various origins of life models. As a lipid amphiphile can also assemble around certain droplets, this further shows the droplets' potential compatibility with and scaffolding ability for nascent biomolecular systems that could have coexisted in complex chemical systems. These model compartments could have been more accessible in a "messy" prebiotic environment, enabling the localization of a variety of protometabolic and replication processes that could be subjected to further chemical evolution before the advent of the Last Universal Common Ancestor. We also highlight other membraneless compartments generated from both biomolecules and non-biomolecules as a way to probe other possibilities of primitive compartments both on Earth and other extraterrestrial bodies.

Keywords: Origins of Life, Prebiotic Chemistry, Astrobiology, Protocell, Life Detection, Evolution

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Reconstruction of the original core of RNA polymerase from short peptide

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The origin and evolution of the transcription system is a key to understanding how DNA-based life emerged on the earth. DNA-dependent RNA polymerase (DdRP) is the most fundamental molecular machine in transcription. Although DdRP is a huge multi-subunit enzyme with over 400 kDa molecular mass, its catalytic core is composed of a small domain with a simple beta fold called double-psi-beta-barrel (DPBB, ~80 a.a.). On the DPBB domain from DdRP three aspartates are highly conserved in its catalytic loop and coordinate the catalytic Mg^{2+}. Thus, it was considered that the DdRP originated from the Mg^{2+} coordinating DPBB. If so, how the ancestral DdRP with DPBB scaffold worked in early life? How DPBB emerged from ancient peptides? In order to answer these questions, we tried to reconstruct the ancestral DPBB experimentally.

We first tried to isolate the Mg^{2+} coordinating DPBB domain from modern DdRPs. However, the isolated DPBBs could not fold well. Then, we searched structurally homologous DPBB folds from PDB and found that the DPBB domain from putative thymidine phosphorylase (ptpDPBB) is well exposed on the protein surface. We successfully isolated ptpDPBB and solved its crystal structure to confirm it adopts the DPBB fold. Furthermore, we grafted the conserved catalytic loop from DdRP into the corresponding position of ptpDPBB and optimized its sequence by computational calculation to enhance structural stability. The engineered ptpDPBB seems to be folded as monomer and can bind Mg^{2+} as intended. Now, we are doing further structural analysis of the engineered ptpDPBB and trying to install a DdRP related function onto the engineered ptpDPBB scaffold.

Interestingly, the DPBB fold has an internal pseudo-twofold symmetry and it is thought to have evolved from a homo-dimeric peptide. To prove this evolutionary scenario, we designed symmetrical DPBBs in which two identical sequences of 45 a.a. were repeated. Three symmetrical DPBB designs could be purified as folded monomers. Then, crystal structures for two of them have been determined at 1.6Å resolution in both cases. Additionally, we have designed a 45 a.a. peptide derived from the N-terminal half sequence of symmetric DPBB and determined its crystal structure at 1.6Å resolution. Surprisingly, the short peptide formed DPBB fold through homo-dimerization. These results strongly support that the DPBB fold evolved from a short peptide with only ~40 a.a..

Furthermore, the designed short peptide showed high refolding capability. Even after thermal denaturation, the designed short peptide quickly refolded to the native structure. Also, when this sequence was chemically synthesized, the lyophilized peptide molecule can form DPBB structure by just being dissolved in physiological buffer solution. These results imply that the ancient short peptide, which formed DPBB fold by self-dimerization, encoded a safeguard against irreversible aggregation and unfolding for surviving in extreme conditions.

Keywords: Protein evolution, RNA polymerase, Folding

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Screening RNA-binding peptides using restricted set of amino acids

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RNA stores the genetic information and catalyzes various chemical reactions. RNA with catalytic activities are called ribozymes, e.g. ribosome, whose function probably emerged in the context of a complex chemical environment. Especially, the functional cooperation between RNA and polypeptides appears to be quite important for the occurrence of ribozymes. Ribosome is consisted of RNA and polypeptides. Therefore, the interactions between RNA and polypeptides are considered to be essential in maintaining the structural stability and the function of ribosome (Lupas, A.N. & Alva, 2017).
In order to screen for RNA-binding peptides, we have recently established mRNA display technology (Reyes et al., in prep). mRNA display is a high-throughput technique to synthesize mRNA-peptide conjugate and identify peptide aptamers against proteins or RNA by using *in vitro* translation system. mRNA display allows for the preparation of peptide libraries with far greater complexity than is possible with other *in vitro* display methods, like phage display and ribosome display.
In this study, we screened for RNA-binding peptides from the libraries using restricted set of amino acids, which can serve as a model of the initial RNA-peptide complex. We investigated the peptide sequences by using mRNA display technology. So far, we designed DNA libraries against each RNA polymers (polyA, polyG, polyC, polyU (12mer)), and we succeeded in synthesizing the mRNA-peptide library for the polyC RNA by using *in vitro* translation system (PURE system). Now, we are performing an iterative selection against the RNA target (PolyC). In poster session, I would like to discuss the progress and problems of the method.

Keywords: Synthetic biology, Cell-free system, Screening

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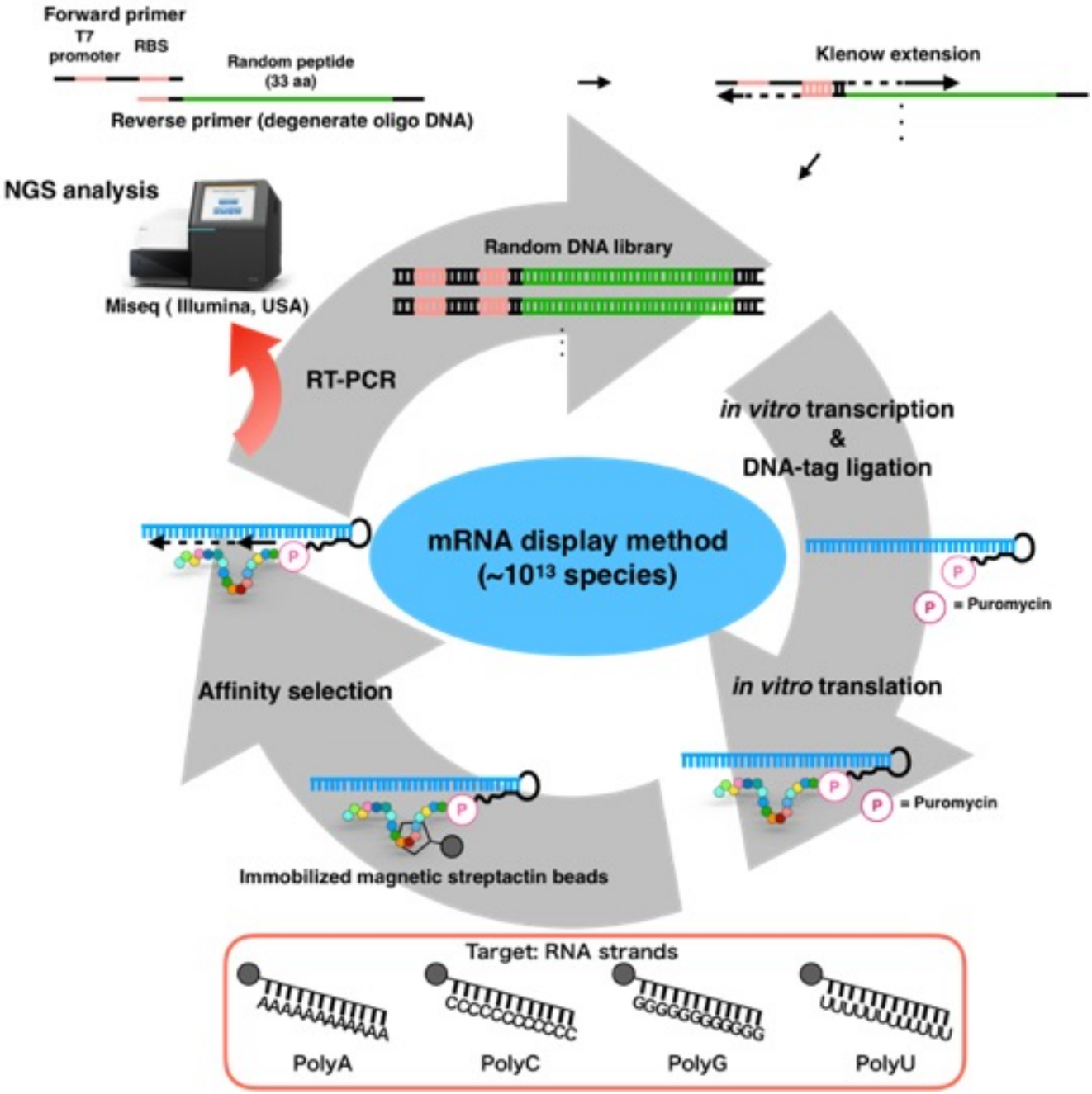

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[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-IS Intersection

[M-IS17] Astrobiology

convener:Hikaru Yabuta(Hiroshima University, Department of Earth and Planetary Systems Science), Seiji Sugita(Department of Earth and Planetary Science, Graduate School of Science Sciece, The University of Tokyo), Misato Fukagawa(National Astronomical Observatory of Japan), Fujishima Kosuke(Tokyo Institute of Technology, Earth-Life Science Institute)

Twenty years have passed since when the field of Astrobiology, which aims to unveil the origins, evolution, and habitability of life by integrating multidisciplinary fields, was established. Individual themes related to Astrobiology, such as chemical evolution in the early Solar System, formation of planetary system, prebiotic chemistry in the early Earth, evolution of life in the Earth's history, extremophile, and habitable planetary environments, has been studied by the knowledge and methods from the multiple fields, which has enabled us to explain "Where we came from" in some ways. However, despite an overwhelming number of investigations and discussions through gathering of the scientists from different fields, there has remained the long-standing unsolved question: How did abiotic materials gain biological function in the Earth and elsewhere in universe? There is still a large gap between prebiotic organic chemistry and biochemistry toward Origins of Life and planetary habitability. Therefore, the JpGU Astrobiology session focuses on pathfinding of "integration of astronomy, geoscience, and biochemistry", which will face an increasing need for the future Astrobiology. In order to enhance our understanding of "What is life", we propose to discuss the biochemical events linked with planetary systems, which is beyond the knowledge in a test tube, by an integration of exoplanets and molecular biology, etc. Through this approach, we will lead the discussions and developments of life-detection strategies for the future exploration of life in universe.

[MIS17-11] Formation of organic compounds by hypervelocity impacts on terrestrial planets

*Yoshihiro Furukawa[1], Yuto Takeuchi[1], Takamichi Kobayashi[2], Toshimori Sekine[3], Naoki Terada[1], Takeshi Kakegawa[1] (1.Tohoku University, 2.NIMS, 3.Center for High Pressure Science & Technology Advanced Research)

[MIS17-12] Following the fundamentals of serpentinization: an experimental approach to mineral and organic reaction pathways at serpentinizing conditions

*Kristin N Johnson-Finn[1,2], Akira Yamaguchi[2], Ryuhei Nakamura[1,3] (1.Earth-Life Science Institute, 2.Tokyo Institute of Technology, 3.RIKEN Center for Sustainable Resource Science)

[MIS17-13] Third year results and current status of Tanpopo: Capture and exposure experiment of micrometeoroids and microbes on Exposure Facility of International Space Station

*Akihiko Yamagishi[1,2], Hirofumi Hashimoto[2], Hajime Yano[2], Yuko Kawaguchi[9], Shin-ichi Yokobori[1], Kensei Kobayashi[3], Mita Hajime[4], Hikaru Yabuta[5], Masumi Higashide[6], Makoto Tabata[7], Eiichi Imai[8] (1.Tokyo University of Pharmacy and Life Science, Department of Molecular Biology, 2.ISAS/JAXA, , 3.Yokohama National University, , 4.Fukuoka Institute of Technology, , 5.Hiroshima University, 6.Japan Aerospace Exploration Agency, 7.Chiba University, 8.Nagaoka University of Technology, 9.Chiba Institute of Technology)

[MIS17-14] THE BIOPAUSE PROJECT: SCIENTIFIC BALLOON EXPERIMENTS FOR SAMPLING STRATOSPHERIC BIOAEROSOL

*Sohsuke Ohno[1], Norimune Miyake[1], Ko Ishibashi[1], Yuko Kawaguchi[1], Osamu Okudaira[1], Keisuke Maeda[1], Issei Iijima[2], Yuya Kakehashi[2], Manabu Yamada[1], Akihiko Yamagishi[3], Kazuhiko Yamada[2], Yusuke Takahashi[4], Satoshi Nonaka[2], Segawa Takahiro[5], Hideyuki Fuke[2], Tetsuya Yoshida[2], Takafumi Matsui[1] (1.Chiba Institute of Technology, 2.Japan Aerospace Exploration Agency, 3.Tokyo University of Pharmacy and Life Sciences, 4.Hokkaido University, 5.University of Yamanashi)

[MIS17-15] Microscope for Life-signature Detection in Venus Cloud

*Satoshi Sasaki[1], Akihiko Yamagishi[2,5], Yoshitaka Yoshimura[3], Keigo Enya[5], Sosuke Ohno[4], Atsuo Miyakawa[2], Tomohiro Usui[5], Kazuhisa Fujita[5], Sanjay Limaye[6] (1.Tokyo University of Technology, 2.Tokyo

University of Pharmacy and Life Sciences, 3.Tamagawa University, 4.Chiba Institute of Technology, 5.JAXA, 6.University of Wisconsin)

[MIS17-16] Discussion

*Hikaru Yabuta[1] (1.Hiroshima University, Department of Earth and Planetary Systems Science)

Formation of organic compounds by hypervelocity impacts on terrestrial planets

*Yoshihiro Furukawa[1], Yuto Takeuchi[1], Takamichi Kobayashi[2], Toshimori Sekine[3], Naoki Terada[1], Takeshi Kakegawa[1]

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Synthesis of life’s ingredients from reduced carbon and nitrogen sources have been shown in many previous early Earth simulation experiments. Impact events have been regarded as one of such events that synthesize amino acids and nucleobases with a reduced nitrogen source, NH_3. However, such reduced species are regarded as minor compounds in Hadean ocean and atmosphere. Formation of amino acids from the abundant C and N sources, i.e., CO_2 and N_2, have only been demonstrated by spark discharge, previously. Thus, it remains unclear whether amino acids form in other geochemical events.

We conducted shock-recovery experiments to simulate an impact-induced reaction associated with hypervelocity impacts of Fe-bearing meteorites on ocean with CO_2-N_2 atmosphere. The typical starting materials contains iron, nickel, forsterite, water, sodium bicarbonate, and gaseous nitrogen. Shock wave was provided by an impact of metal disc plate on a metal container containing the starting materials. The products were analyzed with liquid chromatography mass spectrometry. Powder X-ray diffractometer was used for mineral identification.

The product contained many organic compounds. These yields depend on the compositions of redox state of the minerals in the starting materials. The most reduced mineral mixture provided the highest organic yields. Metallic iron was oxidized to iron carbonate, siderite.

The preset results indicate that ancient impact events formed organic compounds including essential ingredients of life from the major C and N species on prebiotic Earth. This results also suggests that this type of synthesis was happened on Noachian Mars, since major component of atmosphere on Noachian Mars is estimated as oxidized C and N, i.e., CO_2 and N_2.

Keywords: Origin of life, Early Earth, Meteorite, Mars

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Following the fundamentals of serpentinization: an experimental approach to mineral and organic reaction pathways at serpentinizing conditions

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Before life on Earth, organic compounds and minerals coexisted in geologic settings. Different geologic processes likely shaped the metabolic pathways we see today. But what geologic processes altered the first organic matter? If an essential geologic process is common throughout the universe, could it play a part in the formation of new life on other worlds? Of geologic processes, serpentinization is potentially the most common water-rock reaction in our solar system. The progressive hydration from ultramafic silicates to serpentine minerals provides an array of alkaline and redox active chemical environments that could facilitate different organic chemical reactions. The impact that these newly formed minerals and the resulting fluid chemistry can have on organic reactions is still largely unknown. Understanding the mechanisms of organic reactions in the presence of minerals will give a better overview of the chemistry available in abiotic environments and ideas for how metabolisms, as we know them, could be connected.

By performing simplified experiments using both hydrothermal and electrochemical methods, I can determine the role of minerals in abiotic organic reactions. The experimental mixtures contain only one organic compound as the starting material and one pure mineral phase so that detailed kinetic studies can be investigated. By focusing on a singular functional group, the exact reactions can be pursued as a component of the overall reaction web for many different functional groups. My focus is the reaction pathways of carboxylic acids. Carboxylic acids are prevalent in Earth-based metabolism and abundant in abiotic samples such as the Murchison meteorite [1]. Previous work has demonstrated that at hydrothermal conditions, phenylacetic acid ($C_6H_5CH_2COOH$; PAA) in the presence of magnetite (Fe_3O_4) or hematite (Fe_2O_3) results in the formation of several different organic product pathways at hydrothermal conditions (300˚C, 100 MPa) [2]. Dibenzyl ketone ($(C_6H_5CH_2)_2CO$; DBK) and benzoic acid (C_6H_5COOH; BA) were both observed products in these experiments. It was proposed that the reaction path to form BA from PAA was a stepwise oxidation through the reaction intermediates of benzyl alcohol ($C_6H_5CH_2OH$) and benzaldehyde (C_6H_5CHO) by the loss of electrons to redox active metal cations in solution or at the surface of a mineral [2,3]. Magnetite, a prominate mineral product of serpentinizing reactions with iron-containing starting minerals, may serve as an electron conductor during hydrothermal reactions. The exact mechanism is unknown and the extent to which magnetite and hematite differ as potential electron acceptors during organic reactions is unclear.

I performed experiments with propanol ($CH_3(CH_2)_2OH$) and propionaldehyde (CH_3CH_2CHO) as analogs to the benzyl alcohol and benzaldehyde intermediates hypothesized in hydrothermal experiments. Propanol and propionaldehyde, unlike aromatic compounds, are soluble in room temperature water and have been used previously in experiments to investigate the formation of acetic acid in oil field brines [4]. I will discuss the results of preliminary experiments to probe the use of magnetite as a catalyst for the electrochemical oxidization of propanol to propanoic acid (C_3H_5COOH) at the basic pH conditions of serpentinization. I am conducting complimentary hydrothermal experiments starting with butanoic acid ($CH_3(CH_2)_2COOH$) to see if propanoic acid will still form in hydrothermal conditions. In this way, electrochemistry can be used as a tool to understand the mechanisms of hydrothermal reactions and the

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role that minerals can play as electron acceptors for carboxylic acid reaction pathways.

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Keywords: hydrothermal, astrobiology, electrochemistry, catalysis, experiments, organic chemistry

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Third year results and current status of Tanpopo: Capture and exposure experiment of micrometeoroids and microbes on Exposure Facility of International Space Station

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Tanpopo, a dandelion in Japanese, is a plant species whose seeds with floss are spread by wind.We proposed this mission to examine possible interplanetary migration of microbes, and organic compounds at the Exposure Facility of Japan Experimental Module (JEM: KIBO) of theInternational Space Station (ISS) [1-4]. The Tanpopo mission consists of six subthemes: Capture of microbes in space (Subtheme 1), exposure of microbes in space (Subtheme 2), analysisof organic compounds in interplanetary dust (Subtheme 3), exposure of organic compounds inspace (Subtheme 4), measurement of space debris at the ISS orbit (Subtheme 5), and evaluationof ultralow-density aerogel developed for the Tanpopo mission (Subtheme 6). Exposure Panels for exposure of microbes and organic materials and Capture Panels for aerogel were launched onApril 2015. The Panels were placed on the Exposed Experiment Handrail Attachment Mechanism (ExHAM) in the ISS. The ExHAM with Panels were placed on the Exposure Facilityof KIBO (JEM) with the Japanese robotic arms through the airlock of KIBO. The trays andpanels were exposed for more than one year. The first set of Capture Panels and an ExposurePanel were retrieved on June 2016, returned to the ground and passed over to Tanpopo teamfor the analyses in September. Second- and third- year sets have been returned in 2017 and2018, respectively. Aerogel blocks in Capture Panels are inspected by the automated microimage detector CLOXS. Tracks and particles identified will be used for organic and inorganiccompounds, as well as microscopic analyses [3]. An Exposure Panel consists of 20 ExposureUnits. The returned Exposure Panel was disassembled to the units, each was handed overto the researchers for organic compound and microbiological analyses [4] to test the panspermia hypothesis in the latter [5,6]. Environmental data and survival of a radioresistant speciesDeinococcus aetherius after one-year exposure in space have been published [7]. Current statuswill be presented.

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Keywords: Microbes, Organics, Internationa Space Station

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THE BIOPAUSE PROJECT: SCIENTIFIC BALLOON EXPERIMENTS FOR SAMPLING STRATOSPHERIC BIOAEROSOL

*Sohsuke Ohno[1], Norimune Miyake[1], Ko Ishibashi[1], Yuko Kawaguchi[1], Osamu Okudaira[1], Keisuke Maeda[1], Issei Iijima[2], Yuya Kakehashi[2], Manabu Yamada[1], Akihiko Yamagishi[3], Kazuhiko Yamada[2], Yusuke Takahashi[4], Satoshi Nonaka[2], Segawa Takahiro[5], Hideyuki Fuke[2], Tetsuya Yoshida[2], Takafumi Matsui[1]

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The location of "biopause", the upper boundary of the biosphere, and the biological flux across the biopause on Earth are the key to understand the universality and distribution as well as the origin and evolution of life in the universe. The most direct information to elucidate the biopause is the distribution and dynamicity of life in the middle atmosphere. We carried out a scientific project named "Biopause" using JAXA’s scientific balloons in order to grasp the dynamics of biological flux in the stratosphere. We had the third balloon experiment of the Biopause project in last year and collected aerosol particles in the stratosphere using a descending inertial impactor. The stratospheric samples were recovered successfully and analyzed using a fluorescence microscope and cultivation. In the presentation, we report the new results of the balloon experiment in this year and the initial results of the sample analysis.

Keywords: Biopause, Panspermia, Stratosphere, Microbe, Balloon

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Microscope for Life-signature Detection in Venus Cloud

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The sulfuric acid is not sufficient to explain the observed albedo and cloud contrasts of the planet Venus, although Venus clouds consist of droplets of 75-85% sulfuric acidic-water [1]. Proposal of the contribution of other chemical species involved in the absorption has been indicated [2]. The presence of active volcanos suggested on Venus, [3] and the possible existence of the past liquid water, evolution and emergence of thermophilic or sulfur-metabolizing bacteria have been postulated [4]. The temperature and pressure are moderate several tens km above surface on Venus, although the planet surface is too extreme for living organism and organic compound to survive. The presence of microorganisms is suspected in the clouds [4] that might contribute to the spectroscopic characteristics. Life-signature detection instruments will, therefore, be useful for the missions on astrobiology with aerial platforms. A Life-signiture Detection Microscope (LDM) have been developed to obtain visible images of particles and to search for the life signature including possible “cells” in the Venus cloud samples. A pigment system has also been designed to distinguish abiotic organic compounds from biotic ones. The pigments are now being tested to function under the acidic conditions similar to the Venus cloud environment. The system can detect both organic compounds surrounded by membrane representing “cells”, and metabolism in the typical cells of terrestrial life [5] [6]. The system resolution of 1 micrometer/pixel fulfills the requirements for the observation of almost all terrestrial microbes. The proposed LDM system fit for Aerial platforms such as Venus Atmospheric Mobile Platform [7] to analyze the aerosol.

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Keywords: Venus, cloud particle, microscope

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Discussion

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We would like to share ideas and requests with participants for new developments of the JpGU-AGU Astrobiology session.

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[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-IS Intersection

[M-IS19] Conservation of geoparks, natural geosites, and cultural heritage: weathering and damage assessment

convener:Luigi Germinario(Saitama University), Celine Schneider(University of Reims-Champagne-Ardenne), Chiaki T. Oguchi(Institute for Environmental Science and Technology, Graduate School of Science and Engineering, Saitama University), Tetsuya Waragai(Graduate School of Science and Engineering, Nihon University), Miguel Gomez-Heras(Universidad Autonoma de Madrid), Patricia Vazquez(GEGENAA EA 3795 University of Reims Champagne-Ardenne), Magdalini Theodoridou(Cardiff University), Wonsuh Song(Waseda University)

Geoparks, geosites, World Heritage Sites, and historical structures represent an important natural and/or cultural heritage. They have been exposed to weathering in the geological and human time scale, so that the rocks and other geological materials they are made of, may often face severe deterioration. In order to preserve those sites, conservation measures should be considered. Several studies were carried out on this topic, involving a wide range of research fields: geomorphology, engineering geology, geoarchaeology, conservation science, geoconservation, materials science, petrophysics, geochemistry, geotechnical engineering, etc. However, our knowledge on many aspects is still limited. This session welcomes contributions presenting original research, discussions, as well as case studies, on documentation, measurement and monitoring techniques, experimental procedures, predictive models, damage assessment, etc. Papers from all the research fields dealing with the broad topic of geosites and cultural heritage are invited.

[MIS19-01] Representation of three-dimensional cave structure using point cloud data by terrestrial and airborne laser scanning

★Invited Papers

*Yuichi S. Hayakawa[1,3], Takuro Ogura[2], Yasuhiko TAMURA[3], Chiaki T. Oguchi[4] (1.Faculty of Environmental Earth Science, Hokkaido University, 2.Graduate School of Frontier Sciences, The University of Tokyo, 3.Center for Spatial Information Science, The University of Tokyo, 4.Graduate School of Science and Engineering, Saitama University)

[MIS19-02] Detection of microcracks in rock specimens due to thermal changes using the acoustic emission method

*Tetsuya Waragai[1] (1.Graduate School of Science and Engineering, Nihon University)

[MIS19-03] Coupled capillary water uptake and Infrared Thermography to assess crack evolution

★Invited Papers

Thomas Junique[1], *Patricia Vazquez[1], Céline Thomachot-Schneider[1], Myrlène Jean Baptiste[1], Issra Hassoun[1] (1.GEGENAA EA 3795, University of Reims Champagne-Ardenne, France)

[MIS19-04] Study on groundwater quality inside of the Taya cavern

*Chiaki T. Oguchi[1], Sohyun Ahn[1], Yasuhiko TAMURA[2] (1.Institute for Environmental Science and Technology, Graduate School of Science and Engineering, Saitama University, 2.Exective Committee for the prevention of Taya Cavern)

[MIS19-05] Unveiling the underground cultural heritage of Yokohama, Japan – the contribution of geosciences

*Luigi Germinario[1], Chiaki T. Oguchi[1] (1.Saitama University)

[MIS19-06] Reproducing typical strains of a monument through aging tests to anticipate stone weathering.

*Emilie Huby[1], Céline Thomachot-Schneider[1], Patricia Vázquez[1], Gilles Fronteau[1] (1.Université de Reims Champagne-Ardenne, GEGENAA EA 3795, 51097 Reims, France)

Representation of three-dimensional cave structure using point cloud data by terrestrial and airborne laser scanning

*Yuichi S. Hayakawa[1,3], Takuro Ogura[2], Yasuhiko TAMURA[3], Chiaki T. Oguchi[4]

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Effective conservation of underground cultural heritage is often required for the sustainable development of the local area. Although the awareness of underground cultural heritage is often limited among local people and society due partially to its invisibility, it would be necessary to promote the awareness of the heritage by various approaches including primary education and outreach activities. Non-destructive visualization of the shape and structure of underground cultural heritage is one of the fundamental approaches for its further recognition by local people. For this purpose, we propose to utilize a combined point cloud data by both airborne and terrestrial laser scanning (ALS/TLS). The study site is Taya Cave, a registered cultural heritage in Yokohama City, Kanagawa Prefecture in central Japan. While land surface point cloud data was taken by ALS, point cloud data of the inner area of the cave was obtained by TLS, for which georeferencing was applied by control points with GNSS-derived geographical coordinates. 3D point cloud data and associated mesh data were utilized for the visualization of the cave environment. A stability analysis was also performed using the 3D data, although detailed structural parametrization requires further data collection regarding the geological structures. Communications among researchers, residents, and local governments are recommended for the effective and sustainable protection of the cave, and the visualized 3D dataset will be utilized for evaluating the value of the underground cultural heritage in the local society.

Keywords: lidar, point cloud data, three dimensional

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Detection of microcracks in rock specimens due to thermal changes using the acoustic emission method

*Tetsuya Waragai[1]

1. Graduate School of Science and Engineering, Nihon University

The acoustic emission (AE) method can detect microcracks that occur inside rocks. In this study, using the AE method, the temperature change of 80 ℃ at a temperature gradient of 2 ℃/min was given to three kinds of rock specimens (granite, marble, and sandstone) often used for stone cultural heritages, and the microcrack formation was monitored. As a result, it was found that the AE amplitude was largest in the granite specimen and decreased in order of the marble and the sandstone specimens. The AE generation is thought to depend on the mineral composition, the thermal expansion properties of minerals, and the porosity.

Keywords: thermal weathering, microcrack, acoustic emission, thermal expansion property

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Coupled capillary water uptake and Infrared Thermography to assess crack evolution

Thomas Junique[1], *Patricia Vazquez[1], Céline Thomachot-Schneider[1], Myrlène Jean Baptiste[1], Issra Hassoun[1]

1. GEGENAA EA 3795, University of Reims Champagne-Ardenne, France

Stones are submitted to thermal cyclic variations due to diary, monthly and seasonal changes. In addition, summer storms may drop the temperature of the insulated stone very fast, producing a contraction of the minerals. These processes, if repeated during years, may produce a crack development and irreversible damage to the stone. When a stone is used in buildings, its resistance to external phenomena must be tested in order to avoid great structural damages at long term. For this reason, two parameters are important: i) the crack threshold or the temperature from which the stone starts to crack and ii) the thermal fatigue, that is the following cycles that make the crack to growth irreversibly. The thermal properties of a stone and its heat equilibrium kinetics with the environment vary in relation to its fracturation state. When fractured, a stone has faster cooling and water absorption kinetics as well.

Infrared thermography is a non-destructive technique that measures temperature and emissivity changes. To probe the effectiveness of IRT to evaluate the evolution of fracturation, three stones (chalk, sandstone and granite) were submitted to two tests consisting in different heating cycles. The first test consisted in five progressive heating cycles from 90˚C to 130˚C with 10˚C of increasing interval. The aim was to determinate the crack threshold by an increase in cooling velocity or capillary coefficient. The second test consisted in five cycles of repeated heating at 200˚C in order to assess the evolution of a cracked stone in time.

For both cycles, the heating rate was of 6˚C/min to assure the fracturation at least of the two quartz-rich stones and the temperature was maintained for 4 hours in order to reach the stone core. Once the heating finished, the stones cooled down freely up to 40˚C. This temperature was selected to avoid wrong measurements from the balance but to keep enough contrast to be observed with the IRT camera. The samples were placed on a water film and suspended from a balance that recorded automatically the weight every 10 seconds. At the same time, a IRT FLIR A-655 camera measured the thermosignal of the process every second.

The analysis of the samples allowed to follow the capillary fringe of the sandstone and the granite, and the time to fill the chalk by water uptake. Capillary coefficient evolved during the cycles indicating a fracture distribution and development for the sandstone and the granite while the chalk did not show a great variation with heating.

The cooling rate index (CRI), that is the temperature difference for the 10 first minutes of cooling, was calculated from the IRT data in two areas: the bottom part of the sample that cooled down by the water that rise by capillarity, and the upper part, not reached by the capillary water and cooled down by the room temperature (the latter only for the granite and the sandstone). The chalk experimented few variations during the first test of progressive heating, while a faster cooling (higher CRI) during the fatigue test, that implies an increase in porosity. Sandstone developed cracking during the first cycles for both heating tests probed by a higher CRI, followed by a stabilization. The fracturing was slightly higher for the progressive tests, due possibly to a higher quartz irreversible expansion at 200˚C. Granite showed a

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redistribution of cracks, with higher and lower values through the cycles.

This test showed that IRT data treatment give reliable results to evaluate evident fracturation, although the IRT images were blurred by evaporation process.

Keywords: Infrared thermography, non-destructive technique, fracturation, temperature

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Study on groundwater quality inside of the Taya cavern

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The Taya Cave, located in the precincts of Josenji Temple, is registered as one of the region historical properties by Yokohama city. This cave originated from the Kamakura period (13th Century). The Buddhist priests excavated and enlarged it to be about 570 m length and 3 floors. There are 11 dome-shaped spaces with various sizes inside, as well as there are more than 300 bas-reliefs engraving Buddhist murals on the walls and ceilings. However, at present, deterioration and weathering have progressed inside the cave in Taya. Salt precipitation, cracks and peeling are observed. In the present study, the geological properties, local environment and the groundwater quality were analyzed for the purpose of salt origin from the viewpoint of water-rock interaction. The results revealed that the temperature inside the cave is kept almost constant, while the humidity varies depending on the location inside the cave because of seasonal changes such as rainfall. The quality of the groundwater in the cave was also affected by seasonal changes which are shown by time-lag, and by location inside of the cave broadly reflecting the difference in depth of from the earth surface.

Keywords: Taya Cave, groundwater

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Unveiling the underground cultural heritage of Yokohama, Japan –the contribution of geosciences

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1. Saitama University

In the outskirts of Yokohama (Kanagawa, Japan) lies an underground wonder known as Taya Caves, a complex network of subterranean halls and galleries, decorated with hundreds of stunning rock-cut reliefs, excavated by Shingon Buddhist monks in the 13–19th c. The caves were dedicated to ascetic training and rituals, and later on became a pilgrimage destination. Multidisciplinary studies, aimed at exploring, preserving, and promoting this site of historical importance, began only in the very last years, and the preliminary results were introduced during the JpGU Meeting 2019. Here, the contribution of geosciences is presented, providing the first comprehensive information about the properties and decay of the rock of Taya Caves, and the relevant microenvironmental setting. Taya stone is a very soft and porous siltstone, which suffers of diverse decay processes, the most significant being salt weathering –associated with crust and efflorescence formation –and slake deterioration. The most crucial factor is the constant interaction with water, related to percolating rainfall, rising damp, and the extremely high relative humidity inside the caves. That regulates the stability of rock-forming minerals and weathering phases, provokes dissolution and hydration phenomena, brings in pollutants from the nearby soils and bodies of water, and produces microstructural damage. The preservation of a semi-natural site like Taya Caves and of the artifacts enshrined therein is very problematic to achieve, but many of the most critical points to address in the future conservation may be inferred from the results of this study.

Keywords: Taya Caves, Rock art, Soft porous rock, Stone decay, Environmental survey

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Reproducing typical strains of a monument through aging tests to anticipate stone weathering.

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Stones on a monument are subjected to different kinds of strains due to micro-environmental variations. These strains intervene in weathering processes and can damage the stones through fatigue effect. The study of stones' response to typical strains will allow to **anticipate weathering** and help **identify risk areas**. As destructive analysis of the stones is often limited on monuments, especially on protected ones, the chosen approach was to study the micro-environmental variations through an ***in situ* monitoring** and then to study the stone's response to these variations through **relevant aging tests**.

Recurring temperature and humidity variations were identified on the Saint-Remi Basilica in Rheims (France), inscribed on UNESCO's World Heritage List, with the two years long ***in situ* monitoring**. Typical events were categorized and modeled: a **sunny day** (24h cycle of temperature between 20 and 35°C), a **rainy day** (24h cycle of temperature between 20 and 35°C with a high humidity), a **frost day** (24h cycle of temperature between 10 and -5°C with a high humidity), and **short events** (20-minute cycle of temperature between 20 and 25°C).

The experimental setup used was designed to reproduce as close to reality as possible these **thermal and hydric strains on stone samples.** The largest side of the sample (10x5x4,5cm) was placed against a vertical heating plate surrounded by a thermal insulator, simulating a stone on a vertical façade exposed to the environment. The temperature of the plate was controlled with predefined temperature cycles, and rain events were simulated by removing the sample from the plate and placing it in 5mm water for 1h. Five cycles of each strain type (sunny day, rainy day, frost day, short events) were applied to the samples. Thermocouples and strain gauges measured **heat transfer** and **differential micro-dilatation**, allowing to **monitor the sample's behavior** through the experiments.

Two typical stones of the Saint-Remi Basilica were studied: the **Courville limestone**, considered the original stone, and the **Savonnières limestone**, considered the restoration stone. They presented different properties and reacted differently to the thermal and thermo-hydric strains. The Courville limestone showed a more intense deformation than the Savonnières limestone under the same temperature conditions. The thermal strain during sunny day cycles and even the low-intensity temperature variations of the short events caused **a significant response from the Courville limestone**. As expected, the closer to the heating plate the gauges were, the higher the deformation was. On the other hand, the **Savonnières limestone showed little to no deformation**. With the introduction of the humidity factor, rain event simulated by imbibition, water transfer properties of the stones came into play. A supercooling phenomenon could be observed during the frost cycles, showing that freezing took place. For the Savonnières limestone, the water penetrated deep into the sample; the stone presented a **constant and homogeneous deformation behavior** during rainy and frost cycles. For the Courville limestone, the water stayed in a layer near the surface, inducing a dilatation difference between the water and the dry layers, causing a **strain at the interface**.
The number of cycles did not allow to observe damage of the stones, but it allowed to see the **clear behavior difference between the two limestones**. This difference can also be seen on the monument as the Savonnières limestone is still in a good state, while the Courville has undergone weathering

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(disaggregation, spalling/scaling). The deformation behaviors of the limestones during these typical events will **be correlated to the frequency of those events** in order to estimate the stones' behavior throughout one year. The strains induced by environmental variations presented here have **a relatively low intensity** compared to the mechanical properties of the stones but can **be damageable in the long term through fatigue effect**.

Keywords: Cultural heritage, Limestone, Aging test, Thermal strain

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[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-GI General Geosciences, Information Geosciences & Simulations

[M-GI33] Data assimilation: A fundamental approach in geosciences

convener:Shin ya Nakano(The Institute of Statistical Mathematics), Yosuke Fujii(Meteorological Research Institute, Japan Meteorological Agency), Takemasa Miyoshi(RIKEN), SHINICHI MIYAZAKI(Graduate School of Science, Kyoto University)

Data assimilation is an inversion approach to estimate the evolution of a system by utilizing a constraint given by a dynamical simulation model. Data assimilation is now widely used not only in meteorology and oceanography but also other fields of geosciences such as hydrology, solid earth science, and space science. This session aims at providing
an opportunity for discussion on data assimilation studies among researchers of various field of geosciences. We encourage contributions addressing novel methods and theoretical developments of data assimilation. Contributions dealing with useful applications of data assimilation are also welcome.

[MGI33-01] Inference of Hidden States by Coupled Thermosphere-Ionosphere Data Assimilation:
Applications to Observability and Predictability of Neutral Mass Density

★Invited Papers

*Tomoko Matsuo[1], Chih-Ting Hsu[2] (1.University of Colorado Boulder, 2.National Center for Atmospheric Research)

[MGI33-02] Weight Structure of the Local Ensemble Transform Kalman Filter: A Case with an Intermediate AGCM

★Invited Papers

*Shunji Kotsuki[1], Pensoneault Andrew[3], Okazaki Atsushi[4], Takemasa Miyoshi[2] (1.Center for Environmental Remote Sensing, Chiba University, 2.RIKEN Center for Computational Science, 3.University of Iowa, 4.The Pennsylvania State University)

[MGI33-03] Local Particle Filter Implemented with Minor Modifications to the LETKF Code

*Takemasa Miyoshi[1], Shunji Kotsuki[1,2], Keiichi Kondo[1,3], Roland Potthast[4] (1.RIKEN, 2.Chiba University, 3.Meteorological Research Institute, 4.German Weather Service (DWD))

[MGI33-04] Combining data assimilation and machine learning to predict chaotic dynamics with imperfect observations and models

*Futo Tomizawa[1], Yohei Sawada[1] (1.The University of Tokyo)

[MGI33-05] Socio-hydrologic data assimilation: Analyzing human-flood interactions by model-data integration

*Yohei Sawada[1], Risa Hanazaki[1] (1.University of Tokyo)

[MGI33-06] Observing System Simulation Experiments for Tidal Motion from Wide-Swath Ocean Satellite Altimeter Data

*CAO Jiangwei[1], Naoki HIROSE[2], Osamu ISOGUCHI[3] (1.Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, 2.Research Institute for Applied Mechanics, Kyushu University, 3.Remote Sensing Technology Center of Japan)

Inference of Hidden States by Coupled Thermosphere-Ionosphere Data Assimilation: Applications to Observability and Predictability of Neutral Mass Density

*Tomoko Matsuo[1], Chih-Ting Hsu[2]

1. University of Colorado Boulder, 2. National Center for Atmospheric Research

The ionosphere and thermosphere are a tightly coupled system, thus the predictability and observability of one subsystem affects that of the other. In contrast to the ionosphere, which is relatively well-monitored by diverse instrumentation techniques including ionosondes, coherent and incoherent radars, Global Navigation Satellite System (GNSS) radio occultation, and a network of GNSS ground-based receivers, monitoring of the thermosphere's state is limited. This asymmetric observing capability of the upper atmosphere impedes our ability to predict the dynamic behaviors of this coupled system as a whole. This paper demonstrates how state-of-the-art dynamical data assimilation approaches facilitate inference of hidden thermospheric states from abundant ionospheric observations, by systematically incorporating coupling between neutral and plasma species into the process of data assimilation as well as forecasting. Previously, it has been shown that the observability and predictability of the ionosphere can be extended considerably by estimating neutral compositions and winds from ionospheric observations in a coupled thermosphere-ionosphere data assimilation system. The notion of observability is here used to characterize how well the internal states can be inferred from observations. Observing system simulation experiments and observing system experiments suggest that neutral temperature can also be well-inferred from abundant GNSS radio occultation ionospheric observations. A comparison to independent CHAMP mass density measurements shows that assimilation experiments of actual COSMIC electron density profiles into the NCAR Thermosphere Ionosphere Electrodynamics General Circulation Model (TIEGCM) can reduce the bias existing in the TIEGCM control simulation up to 50%. Ensemble forecast simulations furthermore suggest that initialization of TIEGCM by the coupled thermosphere-ionosphere data assimilation significantly improves the thermospheric mass density forecasting, with its impact lasting longer than 3 days under geomagnetic quiet conditions. Given the ever-expanding GNSS infrastructure, this is indeed a promising prospect for the thermospheric mass density specification and forecasting.

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Weight Structure of the Local Ensemble Transform Kalman Filter: A Case with an Intermediate AGCM

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The Local Ensemble Transform Kalman Filter (LETKF) computes the analysis by a weighted average of the first-guess ensemble with surrounding observations within a localization cutoff radius. Since overlapped observations are assimilated at neighboring grid points, the LETKF results in spatially smooth weights. This study explores the spatial structure of the weights with the intermediate atmospheric model SPEEDY (Simplified Parameterizations, Primitive Equation Dynamics). Based on the characteristics of the weight structure, we aim at improving the weight interpolation (WI) method with which we compute the weights at coarser reference points and interpolate the weights into higher resolution model grid points. The results show that larger localization and sparser observations result in spatially smoother weights. WI is less detrimental for larger localization scales and sparser observations when weight patterns are spatially smoother. An advanced WI method with observation-density-dependent reference points results in better forecasts than those with uniformly distributed reference points. This improvement may be owing to the spatially inhomogeneous localization function realized by WI with observation-density-dependent reference points. The spatial distribution of the optimal localization scales shows that larger (smaller) localization is beneficial in sparsely (densely) observed regions. This presentation will include the most recent progress up to the time of the conference.

Keywords: Data Assimilation, Local Ensemble Transform Kalman Filter, Ensemble Transform Matrix, Weight Interpolation, SPEEDY

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Local Particle Filter Implemented with Minor Modifications to the LETKF Code

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Penny and Miyoshi (2015) developed a Local Particle Filter (LPF) in a form as the ensemble transform matrix of the Local Ensemble Transform Kalman Filter (LETKF). The LETKF has been widely used for various geophysical systems including global and regional numerical weather prediction (NWP) models and Martian atmospheric models. Therefore, implementing consistently with an existing LETKF code is useful. The particle weights of LPF, or equivalently the ensemble transform matrix of LPF, consist of 0 and 1 entries, and the smooth spatial transition of local weights is essential. German Weather Service (DWD) implemented the LETKF for their operational global model ICON based on an icosahedral grid system, where the LETKF weights are computed at a coarser analysis grid and interpolated into a higher-resolution icosahedral model grid. The interpolation brings spatial smoothing similarly to weight interpolation (Yang et al. 2008). The spatial smoothing is beneficial for smooth spatial transition of local weights, particularly for LPF. Potthast et al. (2018) applied the LPF weights in the German LETKF system and reported a stable performance in the operational setup. They called their LPF system LAPF (Local Adaptive Particle Filter). Further, Walter and Potthast (2019) improved their LAPF as a Gaussian mixture filter, what they call the LMCPF (Local Mixture Coefficients Particle Filter). This study aims to sort out the various implementations of LPF consistently with an existing LETKF code. Here we use the LETKF code first developed by Miyoshi (2005) based on an intermediate AGCM known as the SPEEDY model. In this presentation, we would like to focus on the theory and code designs of the LPF and its Gaussian mixture extension, with only minor modifications to the existing LETKF code.

Keywords: Data Assimilation, Particle Filter, LETKF, Local Particle Filter, Gaussian Mixture

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Combining data assimilation and machine learning to predict chaotic dynamics with imperfect observations and models

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Prediction of spatio-temporal chaotic systems is important in various fields. While data assimilation has been widely used to predict chaotic systems in geoscience, machine learning algorithms, such as Reservoir Computing (RC), have recently been recognized as a promising tool for the model-free prediction of chaotic systems. However, most of the previous studies on the machine learning based prediction neglected observation errors or sparsity although they are inevitable in real-world problems. In this study, we evaluate the skill of RC with noisy and sparsely distributed observations. We intensively compare the performances of RC and Local Ensemble Transform Kalman Filter (LETKF) by applying them to the prediction of the Lorenz 96 system. Although RC can successfully predict the Lorenz 96 system if the system is perfectly observed, we find that RC is vulnerable to observation errors and sparsity compared with LETKF. To overcome this limitation of RC, we propose to combine LETKF and RC. In our proposed method, the system is predicted by RC that learned the analysis time series estimated by LETKF. Our proposed combination method can successfully predict the Lorenz 96 system using noisy and sparsely distributed observations. Most importantly, our proposed combination method can predict better than LETKF when the model is imperfect.

Keywords: Data Assimilation, Machine Learning, Reservoir Computing, Chaos, Local Ensemble Transform Kalman Filter

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Socio-hydrologic data assimilation: Analyzing human-flood interactions by model-data integration

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In socio-hydrology, human-water interactions are simulated by mathematical models. Although the integration of these socio-hydrologic models and observation data is necessary to improve the understanding of the human-water interactions, the methodological development of the model-data integration in socio-hydrology is in its infancy. Here we propose to apply sequential data assimilation, which has been widely used in geoscience, to a socio-hydrological model. We developed particle filtering for a widely adopted flood risk model and performed an idealized observation system simulation experiment to demonstrate the potential of the sequential data assimilation in socio-hydrology. In this experiment, the flood risk model’s parameters, the input forcing data, and empirical social data were assumed to be somewhat imperfect. We tested if data assimilation can contribute to accurately reconstructing the historical human-flood interactions by integrating these imperfect models and imperfect and sparsely distributed data. Our results highlight that it is important to sequentially constrain both state variables and parameters when the input forcing is uncertain. Our proposed method can accurately estimate the model’s unknown parameters even if the true model parameter temporally varies. The small amount of empirical data can significantly improve the simulation skill of the flood risk model. Therefore, sequential data assimilation is useful to reconstruct historical socio-hydrological processes by the synergistic effect of models and data.

Keywords: data assimilation, Particle filter, Socio-hydrology, Nature-human interactions

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Observing System Simulation Experiments for Tidal Motion from Wide-Swath Ocean Satellite Altimeter Data

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Satellite altimeters have been measuring sea-level in almost area for about 30 years. A new type of satellite altimeter called Wide-Swath (WS) satellite altimeter was put forward to increase the measurement frequency in time and space. The WS altimeter upgrades the measurement coverage from line to area,basically. Comparing with the nadir altimeters, the WS satellite altimeters can provide more observation per unit period. There are two projected WS satellite altimeter missions. One is Surface Water and Ocean Topography (SWOT) mission from NASA and Coastal, and the other is Ocean Measurement mission with Precise and Innovative Radar (COMPIRA) mission from JAXA.

Observing system simulation experiment (OSSE) is a methodology to estimate observation data, which simulated in different situations, and the initial setting for data assimilation, which means OSSE can estimate several sets of satellite altimeter observations by simulating their observation data for data assimilation.

The purpose of this study is to investigate the contribution of the WS satellite altimeter observation to the accuracy of data assimilation and to find an optimal setting for data assimilated by OSSE.

The study domain is 23N to 55N, 117E to 138E. This area includes the East of China Sea, the Bohai Sea, the Japan Sea, and the northwestern of the Pacific Ocean. A shallow-water model (Kim and Yoon 1996), using potential enstrophy and energy conserving scheme in Arakawa C-grid (Arakawa & Lamb 1981) is used in this study for modeling the tide motion, which is the main course of sea-level variation. Two groups of tide data are set as the initial tide boundary condition. The data from the NAO.99 tidal model drives Nature Run (NR, the control group for OSSE).

On the other hand, Oregon State University tide prediction software (OTPS) is used for Experimental Run (ER, data assimilated in ER with different simulated observation data). The two experiments are also distinguished by bottom topography data (Hirose, 2005; Smith & Sandwell 1997). The WS altimeter data are simulated based on the outcome from NR with artificial pseudo-COMPIRA and SWOT observing error, which is deduced by model. These error does not have representation error (the instrumented error). The representation error is assumed from no tide version of DREAMS_M(Hirose et al., 2013).

Simulated observation data are nudged into the ER by different nudging coefficients. Only data in the first 50 days are calculated by the model. The harmonic analysis allows the prediction after 100day.

SSH assimilated by COMPIRA Along-Track measurement data reduces the error by 52.2% from the first guess ER. Meantime, the WS altimeter measurement reduces error by 99.3%. However, some area, like the middle of the East China Sea, 123E, 34N, COMPIRA-WS group, has a big RMSD because of the aliasing error in the simulation of observation since we only considering observation in one year. For the comparison of data assimilating results of COMPIRA and SWOT error types, COMPIRA groups have slightly (only by 2~5%) better performance. RMS of 1-day nudging was larger than that of 1 hour. The optimal

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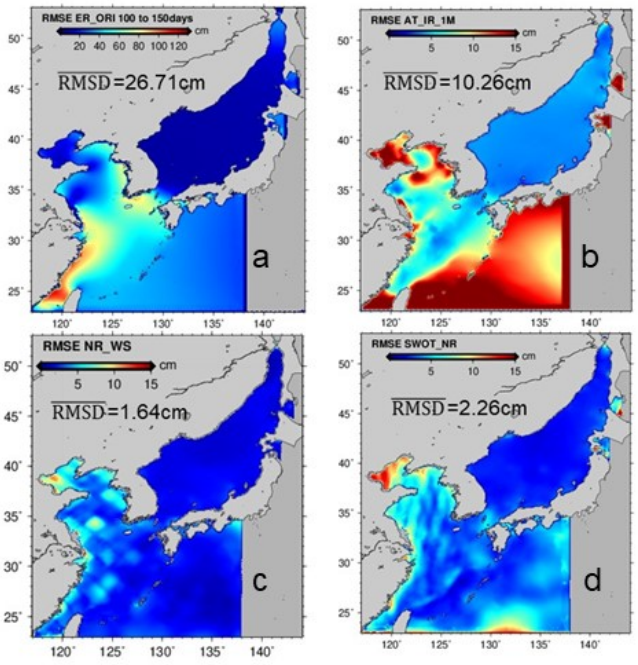
best-nudging coefficient time scale is falls around 1 minute.

The RMSD of the WS groups becomes smaller than the AT groups, although the instrumental error of Nadir-type is smaller than the WS. That indicates the number of observed points influences the RMSD significantly.

The WS did well in all OSSE groups; however, there still some odd rhombus areas appeared in figures (not shown in the abstract) of RMSD between simulated WS-observation and NR. These areas generally have a larger RMSD than the surrounding areas. That is because the simulation of observation based on only one year's observation error data in this study. Some points only have 1 or 2 measurements in one satellite cycle (about 9.3 days). Aliasing error has a high probability of occurring at these points. The aliasing error can also explain why the area, where has been observed more times, has a smaller RMSD. Therefore, a high precision fitting method is demanded for the high accuracy of analysis, especially in the first early years of the formal use of WS satellite altimeters.

Keywords: Wide-Swath Satellite Altimeter, Tide, OSSEs



The RMSD between NR and ER(a), data assimilation with different pseudo observations. (b) for COMPIRA-AT group. (c) for COMPIRA-WS group. (d) for SWOT-WS group. The nudging coefficient is 1 minute.

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[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-GI General Geosciences, Information Geosciences & Simulations

[M-GI33] Data assimilation: A fundamental approach in geosciences

convener:Shin ya Nakano(The Institute of Statistical Mathematics), Yosuke Fujii(Meteorological Research Institute, Japan Meteorological Agency), Takemasa Miyoshi(RIKEN), SHINICHI MIYAZAKI(Graduate School of Science, Kyoto University)

Data assimilation is an inversion approach to estimate the evolution of a system by utilizing a constraint given by a dynamical simulation model. Data assimilation is now widely used not only in meteorology and oceanography but also other fields of geosciences such as hydrology, solid earth science, and space science. This session aims at providing
an opportunity for discussion on data assimilation studies among researchers of various field of geosciences. We encourage contributions addressing novel methods and theoretical developments of data assimilation. Contributions dealing with useful applications of data assimilation are also welcome.

[MGI33-07] Development of an ensemble Kalman filter-based regional ocean data assimilation system

*Shun Ohishi[1,2], Tsutomu Hihara[3], Hidenori AIKI[2], Joji Ishizaka[2], Yasumasa Miyazawa[3], Misako Kachi[4], Takemasa Miyoshi[1] (1.RIKEN, 2.Nagoya Univ., 3.JAMSTEC, 4.JAXA)

[MGI33-08] Dealing with Model Uncertainty and Deficiencies when Assimilating Thermal Breakthrough Observations

★Invited Papers

*Elvar Karl Bjarkason[1], Anna Suzuki[1] (1.Tohoku University)

[MGI33-10] EnKF estimation of the viscoelastic deformation and the viscosity

*Makiko Ohtani[1] (1.Earthquake Research Institute, the University of Tokyo)

[MGI33-11] Ensemble Kalman Filter estimation of frictional parameters and slip evolution on L-SSE faults : application to the Bungo Channel L-SSE fault

★Invited Papers

Megumi Fujita[1], Takuya NISHIMURA[2], *Kazuro Hirahara[3,4], Mamoru Hyodo[5], SHINICHI MIYAZAKI[1] (1.Graduate School of Science, Kyoto University , 2.Disaster Prevention Research Institute, Kyoto University , 3.Institute of Education, Research and Regional Cooperation for crisis Management Shikoku, Kagawa University , 4.Riken AIP center, 5.JAMSTEC)

[MGI33-12] Iterative ensemble variational methods and its application for the prediction of geomagnetic secular variation

*Shin ya Nakano[1], Takuto Minami[2], Futoshi Takahashi[3], Masaki Matsushima[4], Hisayoshi Shimizu[5], Hiroaki TOH[6] (1.The Institute of Statistical Mathematics, 2.Graduate School of Science, Kobe University, 3.Faculty of Science, Kyushu University, 4.Department of Earth and Planetary Sciences, School of Science, Tokyo Institute of Technology, 5.Earthquake Research Institute, the University of Tokyo, 6.Data Analysis Center for Geomagnetism and Space Magnetism, Graduate School of Science, Kyoto University)

Development of an ensemble Kalman filter-based regional ocean data assimilation system

*Shun Ohishi[1,2], Tsutomu Hihara[3], Hidenori AIKI[2], Joji Ishizaka[2], Yasumasa Miyazawa[3], Misako Kachi[4], Takemasa Miyoshi[1]

1. RIKEN, 2. Nagoya Univ., 3. JAMSTEC, 4. JAXA

With enhanced observations by satellites and Argo profiling floats, various ocean data assimilation systems based on the optimal interpolation (OI), three- and four-dimensional variational methods (3D- and 4D-Var), and Kalman filter-based methods have been developed, providing high-quality analysis datasets assimilating the observations. So far, a reanalysis dataset was produced with the ensemble Kalman filter (EnKF) (Sakov et al. 2012), and three EnKF-based ocean data assimilation systems have been developed (Miyazawa et al. 2012; Penny et al. 2013; Baduru et al. 2019).
A geostationary satellite Himawari-8 has been observing sea surface temperatures at short time intervals of 10 minutes since July 2015 (Bessho et al. 2016; Kurihara et al. 2016). Assimilating such high-frequency observations would be a challenge because initial shocks by high-frequency gravity waves might result in a degradation of the analysis. To mitigate the problem, the existing EnKF-based systems inflate observation errors and assimilate observations with long intervals of several days. It is important to explore how to use frequent observations with an EnKF.
The following two methods have been proposed to reduce the initial shocks: (i) an incremental analysis update (IAU; Bloom et al. 1996) to apply the analysis increments gradually during the model integration, and (ii) relaxation-to-prior methods (Zhang et al. 2004; Whitaker and Hamill 2012) to inflate the underdispersive ensemble by relaxing the reduction of the ensemble spread at the analysis step. In this study, we investigate the importance of the IAU and relaxation methods for an EnKF-based ocean data assimilation system.
We developed an ocean data assimilation system consisting of the Stony Brook Parallel Ocean Model (sbPOM; Jordi and Wang 2012) and the local ensemble transform Kalman filter (LETKF; Hunt et al. 2007). The sbPOM covers the northwest Pacific region [118°–180°E, 10°–50°N] with a horizontal resolution of 0.25° and 50 sigma layers. Using the LETKF, we assimilate satellite sea surface temperature, salinity, and height, and in-situ temperature and salinity at a 1-day interval. We perform six sensitivity experiments from July 2015 to December 2016 with combinations of three covariance inflation schemes [multiplicative inflation (MULT), relaxation to prior perturbations (RTPP), and relaxation to prior spread (RTPS)] with/without the IAU. The analysis is evaluated using a nonlinear balance equation to estimate dynamical imbalance (Zhang et al. 2001; Shibuya et al. 2015), and spatial correlation coefficients and root mean square deviation relative to observed sea surface height (Ducet et al. 2000).
The results show that the combination of RTPP/RTPS with the IAU demonstrates the best performance. Experiments with RTPP/RTPS without the IAU show less dynamical balance and reproducibility. MULT experiments are unstable regardless of the use of the IAU because of numerical instability. Therefore, the combination of RTPP/RTPS and the IAU plays an important role in maintaining dynamical balance and providing high-quality analysis. The results imply further possibilities to improve atmospheric data assimilation systems with MULT and to implement the EnKF into other models in which gravity waves have substantial contributions.

Keywords: Ocean data assimilation, Ensemble Kalman filter, Relaxation to prior, Incremental analysis update, Himawari-8, Dynamical balance

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Dealing with Model Uncertainty and Deficiencies when Assimilating Thermal Breakthrough Observations

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1. Tohoku University

Thermal breakthrough models are simplified representations of thermal and fluid transport processes occurring within geothermal systems which consist of hot, fractured porous rocks. Since simple thermal breakthrough models only require modest computational resources and are easy to use, they are widely adopted in practice to describe observed temperature changes in geothermal fields. However, those models have various model deficiencies (model errors), which can severely impact uncertainty estimates and model predictions. This study considers methods to enhance data assimilation of temperature changes in geothermal fields. To account for or soften the effects of model errors, we use a total observation error covariance matrix. This total covariance matrix is used to account for both model errors as well as observation errors, which, like the model errors, might be underestimated initially by the model developers. For estimating model parameter uncertainty, we apply an iterative ensemble smoother and update the total covariance matrix iteratively based on the posterior ensemble of observation residuals given by the ensemble smoother. We applied the total covariance approach to geothermal field data from two different sites. The results suggest that the total covariance approach can provide better thermal breakthrough predictions for real geothermal field studies. The total covariance scheme gives wider predictive temperature intervals than those found when neglecting model errors. Consequently, the total covariance approach gives a better portrayal of potential future temperature changes. In conjunction with the total covariance approach, we, additionally, discuss the importance of refining imperfect thermal breakthrough models to improve model predictions under uncertainty.

Keywords: Data assimilation, Model error, Model uncertainty, Geothermal, Ensemble smoother

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EnKF estimation of the viscoelastic deformation and the viscosity

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Following large earthquakes, postseismic crustal deformations are often observed for more than years. They include the afterslip and the viscoelastic deformation of the crust and the upper mantle, activated by the coseismic stress change. The viscoelastic deformation gives the stress change on the neighboring faults, hence affects the seismic activity of the surrounding area for a long period after the large earthquake. So, it is important to estimate the viscoelastic deformation after the large earthquakes.

In order to estimate the prospective time evolution of the viscoelastic deformation after a large earthquake, we need to know the viscoelastic structure around the area. Recently, the Ensemble Kalman filter method (EnKF), a sequential data assimilation method, starts to be used for the crustal deformation data to estimate the physical variables (van Dinther et al., 2019, Hirahara and Nishikiori, 2019). By assimilating the observational data to the time-forward model, we get a more provable estimation than only using the data. Hirahara and Nishikiori (2019) used synthetic data and showed that EnKF could effectively estimate the frictional parameters on the SSE (slow slip event) fault, addition to the slip velocities. In this study, I applied EnKF to estimate the viscosity and the inelastic strain after a large earthquake, both the physical property and the variables.

I employed the BIEM-based equivalent body force method (Barbot and Fialko, 2010; Barbot et al., 2017) as the forward model simulating the evolution of the viscoelastic deformation. In this method, the viscoelastic region is discretized into cuboid cells with uniform strain and stress. The time derivative of the inelastic strain is represented by the value at the moment, and the history is not required. So, this method is appropriate for applying EnKF. With this method, we can calculate the displacement rate on the ground due to the inelastic strain of a cuboid cell is calculated as the form of green function times the strain at the moment. Then, based on the forward model, I constructed a method to estimate the time evolution of the deformation and the viscosity from the displacement on the ground surface, using the EnKF method.

In this presentation, I show an assimilation experiment using the synthetic ground displacement, called as the twin experiment. I set a simple model where the medium consists of two layers of a homogeneous viscoelastic region with viscosity $\eta = 10^{18}$ [Pa s] underlying an elastic region. I set a fault in the elastic layer and give a slip at time $t = 0$, and calculated the time evolution of the ground surface displacement. I add a Gaussian noise on the displacement and set as the synthetic observation data. For assimilation, I assumed that the slip on the fault and the stress distribution just after the large earthquake is known. Then we executed the assimilation every 30 days after the earthquake ($t = 0$) to estimate the strain and the viscosity. I found that I can get a good estimation of the viscosity after $t > 150$ days.

Keywords: postseismic deformation, viscoelastic rebound, Ensemble Kalman Filter

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Ensemble Kalman Filter estimation of frictional parameters and slip evolution on L-SSE faults : application to the Bungo Channel L-SSE fault

Megumi Fujita[1], Takuya NISHIMURA[2], *Kazuro Hirahara[3,4], Mamoru Hyodo[5], SHINICHI MIYAZAKI[1]

1. Graduate School of Science, Kyoto University , 2. Disaster Prevention Research Institute, Kyoto University , 3. Institute of Education, Research and Regional Cooperation for crisis Management Shikoku, Kagawa University , 4. Riken AIP center, 5. JAMSTEC

We have been developing a real-time estimation system of frictional properties and slip evolution on long-term slow slip event (L-SSE) faults from the observed GNSS data with the ensemble Kalman filter (EnKF), a sequential data assimilation method, which has been developed in atmosphere and ocean sciences. Nishikiori(2018) and Hirahara and Nishikiori(2019) executed identical twin numerical experiments for the Bungo Channel L-SSE with the effect of the locking Nankai megathrust fault and showed the potential for estimating the frictional parameters and slip evolution on the L-SSE fault together with the assumed constant slip deficit rate of the megathrust fault.

Now we are trying to apply our method to actual GEONET data. Here, we give our progress report. First, we introduced the actual geometry of the Philippine Sea plate interface instead of the flat square plane previously assumed. For this actual geometry, we constructed a frictional model with the slip deficit the megathrust fault referring to the GNSS-A observation (Yokota et al., 2016) to produce the L-SSE similar to the observed Bungo Channel L-SSE. Then we compared the synthetic displacement rates in GEONET stations from this model with the observed ones including trend components and found the discrepancy between them, which might be due to large slip concentration in the shallow portion of L-SSE fault caused by the slip deficit of the locked Nankai fault. And we found also that we need to select the initial ensemble members in a narrower space around the true parameters than those proposed in previous studies to execute stable EnKF estimates without breaks. Therefore, we used the slip rate histories on the L-SSE fault as data, which were kinematically obtained from the detrended GEONET data (Yokoi, personal communication). We analyzed the data from the year 2009 to the time just before the 2011 Tohoku earthquake. With the grid search, we obtained some pairs of frictional parameters that minimize the sum of squared residuals of the observed and the simulated slip rates in all cells within the circular L-SSE patch during only the period of the 2010 L-SSE occurrence. With the initial ensemble members constructed from such pairs of frictional parameters, the frictional parameters are successfully updated to converged values without breaks. The discrepancy of the observed and the estimated slip rates in the L-SSE patch cells is large at the early period of the L-SSE occurrence, but thereafter becomes smaller in the L-SSE occurrence period. Further, we examined the forecast capability of slip evolution based on the analyzed parameters in some data assimilation times. During the early period of L-SSE occurrence, the forecast slip rates are different from the observed ones, but the analyzed parameter values around the time of maximum slip rate correctly forecast the ending time of the L-SSE.

Thus, this is the first study where we successfully applied our EnKF method to the actual data for the L-SSE fault. There are, however, left some problems to be solved. First, we should consider the use of the actual displacement rate data observed in GEONET stations. Or we might need to use displacement data. Secondly, we need to use the data including the trend components to estimate also the slip deficit rates

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in the locked Nankai fault existing at the updip portion. In this case, we might consider the effect of inland block motions as in Nishimura et al. (2018). Third, we applied only to the 2010 L-SSE data. The Bungo Channel L-SSEs have recurred several times, which have slightly different slip evolution and recurrent times. Our frictional model at present is simply uniform and would be extended to include inhomogeneity.

Keywords: Ensemble Kalman Filter, Slow Slip Events, Rate and State Friction Law, Slip Evolution, Bungo Channel L-SSE

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Iterative ensemble variational methods and its application for the prediction of geomagnetic secular variation

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The 4-dimensional ensemble variational method (4DEnVar) is a data assimilation method which is easy to implement as a post-process. The iterative version of the 4DEnVAR, which is sometimes referred to as the iterative ensemble smoother, is also regarded as a useful tool for nonlinear data assimilation problems. Since these methods are derived based on a linear approximation of a dynamical system model, the behavior of the algorithm under ths situations with large uncertainties is not trivial. In this study, the accuracy of the algorithm was evaluated after considering second and higher order terms of the Taylor expansion of a system model. The sufficient conditions for finding a local maximum of the objective function are then explored, and the behavior of the algorithm under the situation with nonlinearity is discussed. The applications for the prediction of geomagnetic secular variation based on the above approach will also be introduced.

Keywords: Data assimilation, Ensemble variational method, Geomagnetic field, Geomagnetic secular variation

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[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-GI General Geosciences, Information Geosciences & Simulations

[M-GI34] Near Surface Investigation and Modeling for Groundwater Resources Assessment and Conservation

convener:Jui-Pin Tsai(National Taiwan University, Taiwan), Hwa-Lung Yu(National Taiwan University), Makoto Taniguchi(Research Institute for Humanity and Nature), Ping-Yu Chang(National Central University)

[MGI34-01] Conjunctive Use Simulation and Applications with MODFLOW-OWHM

*Scott E Boyce[1], Claudia C Faunt[1], Wesley Henson[1], Marisa M Earll[1], Randall T Hanson[1] (1.U.S. Geological Survey, California Water Science Center)

[MGI34-02] Estimating the specific yields and groundwater variations with the resistivity method in the northern Pingtung Plain

*Ping-Yu Chang[1,2] (1.National Central University, 2.Earthquake Disaster Evaluation and Management Center, National Central University)

[MGI34-03] Development of a multi-level groundwater monitoring system using fiber Brag grating approach

*Jui-Pin Tsai[1], Yen-To Ho[2], Liang-Cheng Chang[3] (1.National Taiwan University, Taiwan , 2.Citpo technology, Taiwan, 3.National ChiaoTung University, Taiwan)

[MGI34-04] **Objective Modeling Method of Hydrogeological Structure Applied in MODFLOW Modeling – A Case Study of Taipei Basin**

*Ting Hua Tseng[1], Hwa-Lung Yu[1] (1. National Taiwan University)

[MGI34-05] Master Plan of Water Resources Management for Central Taiwan

*Chih Chao Ho[1], TA-WEI CHIEN[2] (1.Feng Chia University, 2.Taiwan Hsin-Chu Irrigation Association)

[MGI34-06] **Geotemperature distributions due to surface temperature variations and groundwater flow in a stratum with a convection boundary**

*Chia-Hao Chang[1], Jui-Pin Tsai[1] (1.National Taiwan University, Taiwan)

Conjunctive Use Simulation and Applications with MODFLOW-OWHM

*Scott E Boyce[1], Claudia C Faunt[1], Wesley Henson[1], Marisa M Earll[1], Randall T Hanson[1]

1. U.S. Geological Survey, California Water Science Center

The U.S. Geological Survey's MODFLOW One-Water Hydrologic Flow Model (MF-OWHM) is a MODFLOW-based conjunctive use simulation software. The first version[1] was selected by the World Bank Water Resource Software Review[2] as one of three recommended simulation programs for conjunctive use and management modeling. MF-OWHM builds upon the MODFLOW-2005 groundwater-flow simulation framework and multiple MODFLOW-2005 variants. This fusion of the MODFLOW-2005 variants and MF-OWHM specific enhancements allow for the following process-based simulations: saturated groundwater flow (three-dimensional); surface-water flow (one- and two-dimensional); landscape and irrigated agriculture; estimation of unknown agricultural irrigation and additional irrigation requirements for salinity flushing; reservoir operations and management; aquifer compaction and subsidence; seawater intrusion by a sharp-interface assumption; karst-aquifer and fractured-bedrock flow; and vertical unsaturated groundwater flow (one-dimensional). This presentation introduces the second major release[3] and briefly introduces the application of MF-OWHM to the California Central Valley, Salinas Valley, and Pajaro Valley.

[1]Hanson, R.T., Boyce, S.E., Schmid, Wolfgang, Hughes, J.D., Mehl, S.M., Leake, S.A., Maddock, Thomas, III, and Niswonger, R.G., 2014, One-Water Hydrologic Flow Model (MODFLOW-OWHM): U.S. Geological Survey Techniques and Methods 6-A51, 120 p., https://dx.doi.org/10.3133/tm6A51.

[2]Borden, John Carter; Gaur, Anju; Singh, Chabungbam Rajagopal, 2016, Water resource software: application overview and review. Washington, D.C.: World Bank Group.

[3]Boyce, S.E., Hanson, R.T., Ferguson, I., Schmid, W., Henson, W., Reimann, T., Mehl, S.M., and Earll, M.M., 2020, One-Water Hydrologic Flow Model: A MODFLOW Based Conjunctive Use and Integrated Hydrologic Flow Model: U.S. Geological Survey Techniques and Methods 6-A60, 576 p

Keywords: Conjunctive Use Simulation, Integrated hydrologic Modeling, Numerical Modeling of Hydrological Processes, Groundwater Modeling, Groundwater-Surface water modeling, Landscape Use Simulation

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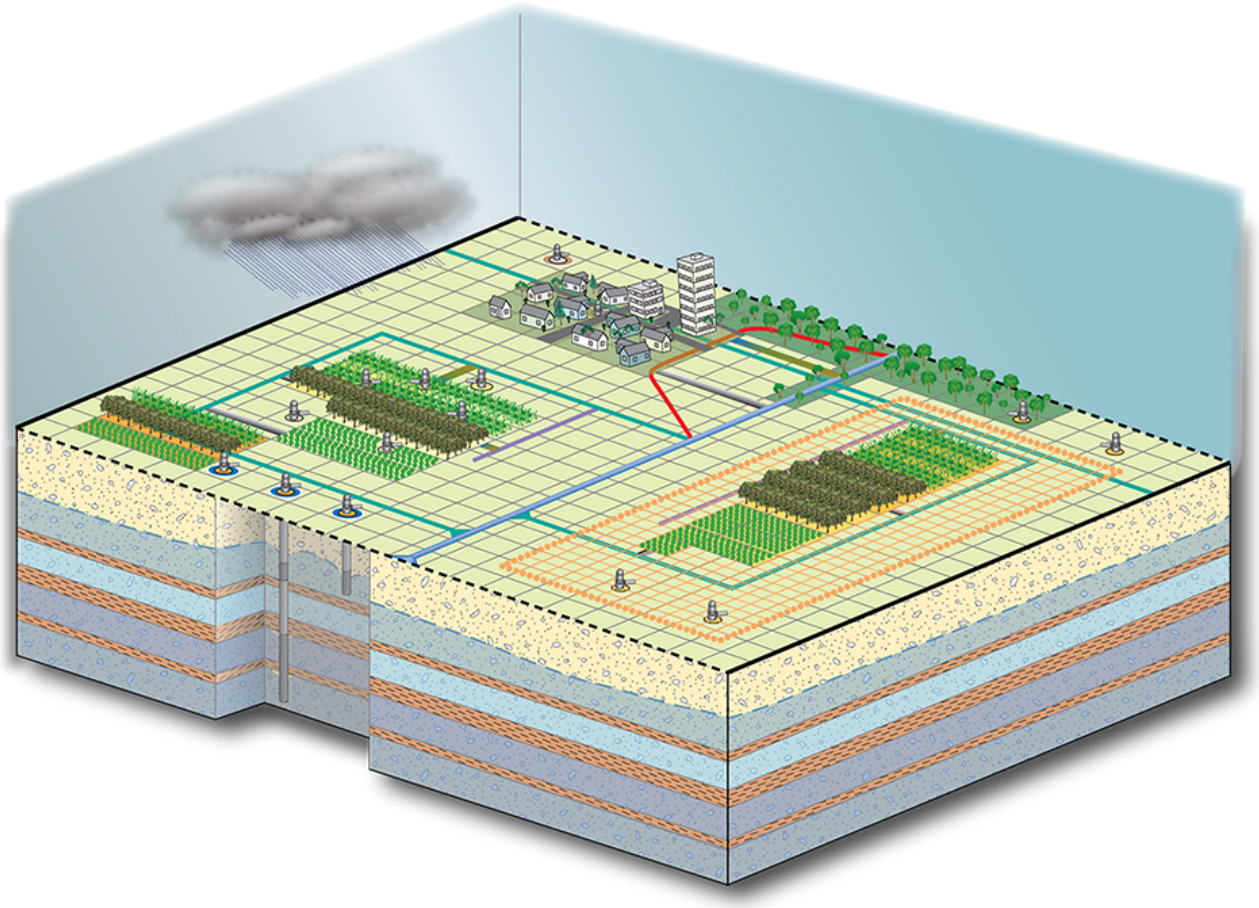

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Estimating the specific yields and groundwater variations with the resistivity method in the northern Pingtung Plain

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We have conducted the time-lapse electrical resistivity imaging surveys in the northern Pingtung area, in order to learn the variation of the groundwater level and estimate the hydraulic parameters. We selected 10 sites for the time-lapse resistivity surveys, and collected measurements in February, May, July, and September in the Pengtsuo Farm area. The resistivity images suggest that the estimated groundwater level were at a depth between 7-11 meters in the area. And the average estimated groundwater level drops to the lowest due to the dry condition in May. The Groundwater level were raised for 2 to 6 meters deep because the increased precipitation in July and September. From the distribution pattern of the groundwater level, we concluded that the Wuluo creek may serve as a local recharge source and the pumping activity in the area may shape the distribution pattern of the local groundwater table. The estimated specific yield from the resistivity measurements were in a range of 0.16 to 0.22. The resistivity-estimated specific yields are consistent to those estimated from the gravity measurements, which indicates 0.14, 0.11, and 0.18 of the specific yields at the Wanlung, Szelin, and the Pengtsuo elementary schools, respectively.

Keywords: specific yield, groundwater , resistivity method

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Development of a multi-level groundwater monitoring system using fiber Brag grating approach

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Measuring the groundwater pressure and temperature at multiple depths of a well improves the observation efficiency and is more economical than the traditional well, which usually measures the lumped groundwater pressure at a specific depth depending on the screen length and depth. The traditional approach to measuring the discrete pressure and temperature needs seal, which takes a high risk of failure interrupting the vertical hydraulic connection. Some commercial multi-level groundwater monitoring systems have developed recently, and they work well in the field. However, some of them still need the sealing process, and most of them are electric system, which needs high-quality water-proof casing for long-term observation under high water pressure condition and may not validate for the site with flammable gas and liquids. To overcome these issues, this study develops a multi-level monitoring system to measure discrete groundwater pressure and temperature in a single well based on fiber Brag grating system. The developed system has been examined in the laboratory and a field site. The accuracy and capability of the proposed system are demonstrated in this study.

Keywords: discrete groundwater monitoring, fiber Brag grating , groundwater pressure and temperature, multi-level groundwater monitoring system

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Objective Modeling Method of Hydrogeological Structure Applied in MODFLOW Modeling –A Case Study of Taipei Basin

*Ting Hua Tseng[1], Hwa-Lung Yu[1]

1. National Taiwan University

Taipei Basin is the capital of Taiwan. It suffered by land subsidence in the past, however, have highly soil liquefaction potential now. The appropriate groundwater model is needed to help to solve geological disasters in this area.

Groundwater modeling in previous research usually uses subjective methods to set boundary conditions, relative hydrogeological parameters and hydrogeological structure. It will result in many different models that people made in the same research area. This research is trying to use objective methods, the perspective of data, to build the groundwater model including hydrogeological structure modeling.This study mainly focuses on MODFLOW modeling and uses several statistic methods to support modeling. The Categorical Bayesian maximum entropy(BME) method and kernel density estimation are used to model the hydrogeological structure. The BME method also applied to estimate the hydraulic conductivity in each MODFLOW grid. And using the empirical orthogonal function(EOF)method to set the rainfall boundary condition.

Keywords: MODFLOW, Hydrogeological Structure modeling

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Master Plan of Water Resources Management for Central Taiwan

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The master plan of water resources management is high-level plans for guiding promotion of regional water resources plans and case engineering. The study assesses the present availability, withdrawals, losses and uses of the water resources; formulate alternative development scenarios for water resources and demand/use at various planning horizons; perform the balancing of resources versus demands for the recent past as well as for the alternative development options and Identify technical and operational options in order to bridge the gap between resources and demands. The purpose is fulfill the water demand of target year of 2041. In order to resolve problem of industrial use water growth, population urbanization, reservoir siltation, lower percentage of actual meter readings, groundwater over-pumping, and serious river dust, the study proposing short-term, mid-term and long-term plans based on four strategies, “exploiting new water sources”, “saving water sources”, “allocating water resources “, and “Backup”, and feasibility and urgency of plans.

Keywords: master plan, water resources management

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Geotemperature distributions due to surface temperature variations and groundwater flow in a stratum with a convection boundary

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1. National Taiwan University, Taiwan

The temperature in a stratum (geotemperature) has been extensively considered as a tracer to estimate the groundwater flow in aquifers. Previous studies commonly assume the stratum with a semi-infinite thickness to simplify the mathematical models for the geothermal problems. However, it is expected that the simplified models are unable to depict the heat flow in a finite-thickness stratum induced by the effects of a medium at the subsurface boundary of the stratum (boundary effects). This study develops a heat transfer model for describing the spatiotemporal distributions of the geotemperature in a stratum of a finite thickness. The geotemperature distributions are governed by a heat conduction-advection equation subject to a convection boundary condition at the bottom of the stratum. The surface temperature is set to change with time. The solution to the present model is derived by the application of the Laplace transform. The results predicted by the present solution show that the effects of the convection boundary on the geotemperature enhances when the stratum thickness decreases. The effects are dominated by a parameter called the heat transfer coefficient of the medium. Additionally, the Darcy groundwater flux significantly influences the geotemperature.

Keywords: convection boundary condition, geotemperature, groundwater, heat transfer

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[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-GI General Geosciences, Information Geosciences & Simulations

[M-GI36] Open Science in Progress: Data Sharing, e-Infrastructure, and Transparency in International Contexts

convener:Yasuhisa Kondo(Research Institute for Humanity and Nature), Baptiste Cecconi(LESIA, Observatoire de Paris, CNRS, PSL Research University), Yasuhiro Murayama(Strategic Program Produce Office, National Institute of Information and Communications Technology), Shelley Stall(American Geophysical Union)

Open Science is widely accepted as a new research paradigm to accelerate scientific innovation. Deployed by ICSU-WDS (2008), G8 Open Data Charter (2013), deployment of Research Data Alliance (2013), OECD Global Science Forum's research projects (2016), and G7 Science Ministers' Communique (2017), it commonly refers to the top-down policies making results of publicly-funded research freely available and accessible. Open Science also refers to the participatory bottom-up approaches such as citizen science, crowdfunding, and transdisciplinary research (Kitamoto 2016). It is noted that both approaches envision the transformation of research process to more findable, accessible, interoperable, and reusable one (Wilkinson et al. 2016).
Followed by the JpGU-AGU Great Debate "Role of open data and open science in Geoscience" at JpGU Annual Meeting 2018, follow-up sessions at the AGU Fall Meetings 2018 and 2019, and JpGU 2019, this session reviews the current broad spectrum of Open Science in international contexts. The session welcomes a wide range of papers and posters covering (but not limited to) open research data, open source licenses, data papers and journals, data repository, e-infrastructures and platforms for sharing data, citizen science, crowdsourcing, crowdfunding, transdisciplinary research, capacity building, international networking, and deployment in earth and planetary sciences.

[MGI36-01] Metadata from findable to searchable at PADC

★Invited Papers

*Pierre Le Sidaner[1], Stephane Erard[1,2,3], Baptiste Cecconi[1,2,3] (1.Observatoire de Paris, 2.PSL, 3.CNRS)

[MGI36-02] FAIR and Open Data: Current progress within the Earth, Space, and Environmental Sciences to Share Our Data (and Software)

*Shelley Stall[1] (1.American Geophysical Union)

[MGI36-03] Multi-source, Multi-wavelength FAIR Data and Science-driven E-infrastructure challenges toward OpenScience in Earth, Planetary and Astronomy Sciences: an overview of the CNRS-INSU ongoing initiatives

★Invited Papers

*Jean-Pierre Vilotte[1] (1.Institut de Physique du Globe de Paris)

[MGI36-04] The Path Toward Open Collections and Samples

★Invited Papers

*Kerstin Lehnert[1], Jens F Klump[2], Lesley Wyborn[3], Sarah Ramdeen (1.Columbia University, 2.CSIRO, Perth, Australia, 3.Australian National University, Canberra, Australia)

[MGI36-05] Open Science Policy and its Implementation in Japan: Trials of Monitoring and Developing an Advanced Data Management

★Invited Papers

*Kazuhiro Hayashi[1] (1.National Institute of Science and Technology Policy)

[MGI36-06] Five key elements to enable open science for society

*Yasuhisa Kondo[1,2], Kei Kano[3,2,1], Terukazu Kumazawa[1], Satoe Nakahara[1], Ken'ichiro Nakashima[4,1], Noboru Okuda[1], Hideyuki Onishi[5,1], Takeshi Osawa[6,1], KAZUHIKO OTA[1] (1.Research Institute for Humanity and Nature, 2.National Institute of Science and Technology Policy, 3.Shiga University, 4.Hiroshima University, 5.Doshisha Women's College of Liberal Arts, 6.Tokyo Metropolitan University)

Metadata from findable to searchable at PADC

*Pierre Le Sidaner[1], Stephane Erard[1,2,3], Baptiste Cecconi[1,2,3]

1. Observatoire de Paris, 2. PSL, 3. CNRS

Paris Astronnomical Data Centre (PADC) is the data centre of the Paris Observatory that distributes data using interoperability standards. Its mission is to preserve and makes available scientific data in Astronomy, planetary science and associated fields such as atomic and molecular physics or simulations. As an open archive, PADC follows the FAIR principle and uses the interoperability standards of the IVOA, but not only. In addition to the Findable and Interoperable side, PADC works on the Searchable side. Although the difference seems small, it implies a lot of work on the preparation of the data.
Findable can be limited to letting Google indexes the data. Searchable in the sense of the IVOA is to describe the data provider (institute, team ...) but especially all the metadata that allow data mining within data collections. This search in large and often heterogeneous masses of data requires the entire interoperability infrastructure. We will describe the process of registering a data collection in the IVOA as well as the steps involved in integrating metadata for searching.

Keywords: FAIR, metadata, interoperability

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FAIR and Open Data: Current progress within the Earth, Space, and Environmental Sciences to Share Our Data (and Software)

*Shelley Stall[1]

1. American Geophysical Union

The Earth, space, and environmental sciences have been working across continents to recognize scientific data (and software) as valuable research contributions that must be “available, preserved, documented, and fairly credited” as stated in AGU’s data position statement. (https://www.agu.org/Share-and-Advocate/Share/Policymakers/Position-Statements/Position_Data) To make this possible, stakeholders from communities such as publishers, repositories, funders, institutions, and researchers have begun to better preserve and cite their data and software. This talk will describe the current progress and efforts to make data (and software) sharing a common practice.

Keywords: Open Science, Open Data, FAIR Data, Data Sharing, Software Sharing, Data Citation

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Multi-source, Multi-wavelength FAIR Data and Science-driven E-infrastructure challenges toward OpenScience in Earth, Planetary and Astronomy Sciences: an overview of the CNRS-INSU ongoing initiatives

*Jean-Pierre Vilotte[1]

1. Institut de Physique du Globe de Paris

The Institut des Sciences de l’ Univers (INSU) is a multidisciplinary institute of the French Centre National de la Recherche Scientifique (CNRS) for Astronomy and Astrophysics, Planetary, Ocean and Atmosphere, ans solid Earth sciences.
The impact of Earth, planetary and astronomy sciences and data it produces can be dramatically increased through transnational collaborations and interdisciplinary approach in order to accelerate scientific discoveries and socioeconomic innovation.
Science in this domains is being accelerated by the growing wealth and diversity of multi- source and multi wavelength data produced in edge environments by a wide range of large instruments and observation systems (eg., ground, sea, air, space) and in centralised environments (HPC, Cloud) by large multi-physics and multi-scales simulations and data assimilation.
This creates a collection of problems to support the full cycle of data use from capture, data access, management and curation, data analysis and modelling, through collating and distilling the evidence into forms that will be routinely used in research and decision-making. An important challenge is data logistics and software platform of FAIR services across a continuum of edge and centralised infrastructures that can support all along wide-area workflows with provenance system for open-science.
The emergence of machine learning and deep learning, which are gaining increasing attention, is facing new challenges associated to the wealth of multi-source and multi wavelength data and at the same time raise new challenging issues for open science and FAIR data e- infrastructures.
This will be illustrated through an overview of a number of science-driven and organisational challenges in different disciplines of the CNRS-INSU and how these are addressed at the national and trans-national levels. Synergy with recent initiatives at the national level (e.g., French open science and FAIR data strategic plan, CNRS research data strategic plan) and the European and international (e.g., Belmont Forum, RDA, Go-FAIR, and the European Open Science Cloud) will be discussed.

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The Path Toward Open Collections and Samples

*Kerstin Lehnert[1], Jens F Klump[2], Lesley Wyborn[3], Sarah Ramdeen

1. Columbia University, 2. CSIRO, Perth, Australia, 3. Australian National University, Canberra, Australia

While the paradigm of Open Science has substantially advanced open access to scientific publications, data, and software, with pertinent changes to policies, infrastructure, and funding structures that support open access, similar improvements to broad and consistent accessibility of physical samples and collections in the Earth and environmental sciences are lagging behind. Physical samples in the Earth, environmental, and planetary sciences are a basic element for reference, study, and experimentation, collected and studied because they represent a wider population or a larger context. Collections of samples represent highly valuable, often irreplaceable records of nature that carry enormous potential for future discoveries. We state that in the era of open, transparent, and reproducible science, preservation and persistent access to samples is no longer an option, but a mandate. Samples and collections in the geosciences need to be findable and accessible for reuse by a global research community, and to ensure transparency and reproducibility of research in the modern research ecosystem.
Essential requirements for Open Samples pertain both to their digital and to their physical management, making the path toward open samples challenging. For example, physical infrastructure (boxes, shelves, cabinets, sheds and warehouses) is needed to properly store samples. Humans are usually needed to physically retrieve specimens from their storage and prepare them for transport to the lab. Digital infrastructure is needed to publish information about samples and collections in online catalogs to make them discoverable, to ensure their unambiguous identification, and to link them to data and publications. New digital infrastructures have been emerging to make samples and collections more open and accessible. The IGSN Global Sample Number, an international persistent identifier system for samples, is already cataloguing 7 million samples that have been registered by sample repositories, museums, national geological surveys, labs, and hundreds of individual researchers. IGSNs are increasingly used to reference samples in publications and in digital datasets, allowing tools to emerge that take advantage of a new level of networked scholarly products. We will report on recent developments and initiatives that advance open and FAIR samples, and that promote and support cross-domain convergence on key issues related to the digital representation of physical samples and collections. We will also discuss the need for community agreed policies and procedures that can guide researchers, institutions, and funding agencies to plan and implement solutions for reliably and persistently curating and providing access to both the samples and the sample metadata to achieve truly Open and FAIR samples.

Keywords: Samples , Open Science, Persistent Identifiers

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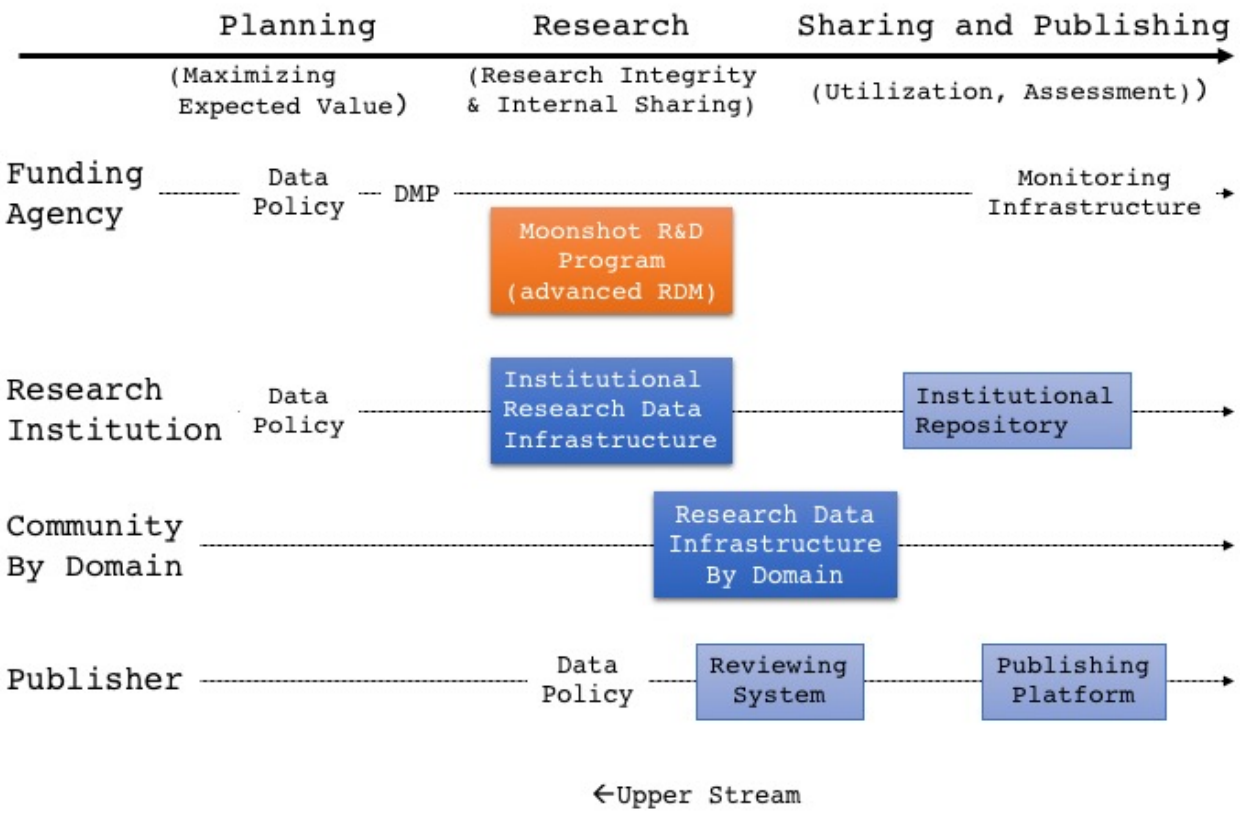
Open Science Policy and its Implementation in Japan: Trials of Monitoring and Developing an Advanced Data Management

*Kazuhiro Hayashi[1]

1. National Institute of Science and Technology Policy

Author introduces the latest state of Open Science Policy and its implementation in Japan as of January 2020. Integrated innovation Strategy 2019 focuses more on the development of research data infrastructure. For monitoring the promotion of Open Science, NISTEP is gathering some use cases in Japan to have an image of research data management and sharing, studying which factor is crucial and suitable for monitoring the advancement of Open Science. Also Moonshot research development program is setting an agenda to develop an advanced research data management, aiming to have a champion case of research data sharing followed by research data management system such as the NII research data cloud. Leading and established societies with domain repositories would have to be compatible with such policy implementation to make a seamless and comfortable research data management and sharing for researchers accelerating the advancement of Science.

Keywords: Open Science Policy, Moonshot Research and Development Program, research data infrastructure , monitoring



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Five key elements to enable open science for society

*Yasuhisa Kondo[1,2], Kei Kano[3,2,1], Terukazu Kumazawa[1], Satoe Nakahara[1], Ken'ichiro Nakashima[4,1], Noboru Okuda[1], Hideyuki Onishi[5,1], Takeshi Osawa[6,1], KAZUHIKO OTA[1]

1. Research Institute for Humanity and Nature, 2. National Institute of Science and Technology Policy, 3. Shiga University, 4. Hiroshima University, 5. Doshisha Women's College of Liberal Arts, 6. Tokyo Metropolitan University

This paper discusses how open science can serve for addressing social issues, particularly for those caused by environmental deterioration. To address wicked social-ecological problems, solution-oriented research has involved research experts from different domains (interdisciplinarity) and also practitioners such as governments, funders, industries, non-profit organizations, and civil members (transdisciplinarity). However, such team science is often disrupted by asymmetric information, knowledge, wisdom, value, socio-economic status, and power among above-mentioned actors. Such socio-psychological asymmetry is possibly reduced by boundary spanning with special attention to the following five key elements: (1) considering ethical equity with special attention to empowering marginalized (or “small voice”) actors; (2) developing visualization of data based on the FAIR (findable, accessible, interoperable, and reusable) Principles as well as information; (3) building trust by securing transparency in the research process; (4) facilitating dialogue; and (5) discovering and sharing the goals that actors with different interests can tackle together (transcend) where necessary. Civic Tech can be applied as a holistic approach, in which civic engineers develop a solution to local issues by using disclosed data and information and communication technologies. This proposed methodology is cyclically assessed and improved through practical case studies, with special interest in developing a method to measure participants’ perceptual transformation through interventions.

Keywords: Open science, Social engagement, Ethical equity, Trust building

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[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-GI General Geosciences, Information Geosciences & Simulations

[M-GI36] Open Science in Progress: Data Sharing, e-Infrastructure, and Transparency in International Contexts

convener:Yasuhisa Kondo(Research Institute for Humanity and Nature), Baptiste Cecconi(LESIA, Observatoire de Paris, CNRS, PSL Research University), Yasuhiro Murayama(Strategic Program Produce Office, National Institute of Information and Communications Technology), Shelley Stall(American Geophysical Union)

Open Science is widely accepted as a new research paradigm to accelerate scientific innovation. Deployed by ICSU-WDS (2008), G8 Open Data Charter (2013), deployment of Research Data Alliance (2013), OECD Global Science Forum's research projects (2016), and G7 Science Ministers' Communique (2017), it commonly refers to the top-down policies making results of publicly-funded research freely available and accessible. Open Science also refers to the participatory bottom-up approaches such as citizen science, crowdfunding, and transdisciplinary research (Kitamoto 2016). It is noted that both approaches envision the transformation of research process to more findable, accessible, interoperable, and reusable one (Wilkinson et al. 2016).
Followed by the JpGU-AGU Great Debate "Role of open data and open science in Geoscience" at JpGU Annual Meeting 2018, follow-up sessions at the AGU Fall Meetings 2018 and 2019, and JpGU 2019, this session reviews the current broad spectrum of Open Science in international contexts. The session welcomes a wide range of papers and posters covering (but not limited to) open research data, open source licenses, data papers and journals, data repository, e-infrastructures and platforms for sharing data, citizen science, crowdsourcing, crowdfunding, transdisciplinary research, capacity building, international networking, and deployment in earth and planetary sciences.

[MGI36-07] Looking back on World Data System and WDS International Programme Office in the last decade from Japan

*Yasuhiro Murayama[1], Takashi Watanabe[2] (1.Strategic Program Produce Office, National Institute of Information and Communications Technology, 2.World Data System International Programme Office)

[MGI36-08] The World Data System – Building Trust in Scientific Data

*Rorie Edmunds[1] (1.World Data System of the International Science Council)

[MGI36-09] Active Data Product Archive Tracking (ADAPT) and the Future of Heliophysics Data Access

*Lee Frost Bargatze[1] (1.Earth, Planetary, and Space Sciences, Institute of Geophysics and Planetary Physics, University of California Los Angeles)

[MGI36-10] Introduction of TG-Data: IPCC Task Group on Data Support for Climate Change Assessments

*Michio Kawamiya[1] (1.Japan Agency for Marine-Earth Science and Technology)

[MGI36-11] Issues and progress of Open Science in geodesy

*Yusuke Yokota[1], Tadashi Ishikawa[2], Basara Miyahara[3], Toshimichi Otsubo[4] (1.Institute of Industrial Science, The University of Tokyo, 2.Hydrographic and Oceanographic Department, Japan Coast Guard, 3.Geospatial Information Authority of Japan, 4.Hitotsubashi University)

[MGI36-12] Open Data for Seismology

*Yasuyuki Kano[1] (1.Earthquake Research Institute, The University of Tokyo)

Looking back on World Data System and WDS International Programme Office in the last decade from Japan

*Yasuhiro Murayama[1], Takashi Watanabe[2]

1. Strategic Program Produce Office, National Institute of Information and Communications Technology, 2. World Data System International Programme Office

In this paper we intend to review and looking back on activity, side-effects and its influences of the academic data enterprise established by the world biggest academic entity ICSU or International Council for Science, which was merged with ISSC (Intl. Social Science Council) to start ISC Intl. Science Council 2018. Foundation of "World Data System" or WDS, and WDS International Programme Office was agreed by ICSU General Assembly2008, and they have made an international open call for a host institute of WDS's international programme office (WDS-IPO) in 2010, and then Science Council of Japan actively worked with NICT (National Institute of Information and Communications Technology) as well as Ministry of Communications and Internal Affairs of Japanese Government to make the NICT's proposal successful. The NICT won the call and ICSU and NICT have started WDS-IPO at NICT 2011. Since then there has been various kind of domestic and international discussions on data science, open data, change of how scientific data must be managed in scientific institutions and societies. The intention of this paper is to pick up several topics of new stream of Open Science and a changing global landscape of research data in science, science-technology policy, government strategy and implementation, where Japan has been influenced and been benefited from hosting WDS-IPO for the nearly 10 years.

Keywords: Open Science, research data sharing, World Data System

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The World Data System –Building Trust in Scientific Data

*Rorie Edmunds[1]

1. World Data System of the International Science Council

The World Data System (WDS) is a Research Programme of the International Science Council. It was formed to help realize the vision of universal and equitable access to scientific data and information. To this end, WDS promotes long-term data stewardship that will deliver quality-assured scientific data, data services, products, and information. WDS promotes ‘communities of excellence’ by helping organizations become persistent, robust, and trustworthy components of a data infrastructure from which a knowledge system that is both interoperable and distributed can be based.

In September 2017, WDS and the Data Seal of Approval (DSA), based on a partnership established under the umbrella of the Research Data Alliance, established the CoreTrustSeal standard for certifying the trustworthiness of data repositories. CoreTrustSeal sets overarching Requirements that harmonize the prior standards of WDS and DSA, act as a foundation for the ISO 16363 and DIN 31644 standards, and embrace the FAIR principles. The certification is an embodiment of the new TRUST principles of Transparency, Responsibility, User Focus, Sustainability, and Technology.

Since its formation, over 70 repositories have been certified by CoreTrustSeal, a similar number are being processed, and demand is growing. Such demand is driven through recognition of the importance of CoreTrustSeal certification by the European Commission, by the American Geophysical Union (AGU) / Coalition for Publishing Data in the Earth and Space Sciences (COPDESS), and increasingly by publishers. The CoreTrustSeal Data Repositories Requirements have been nominated for inclusion in the European Commission’s official ICT Technical Specifications, and explicitly named in both the final report and action plan from the European Commission expert group on FAIR data and the AGU/COPDESS Enabling FAIR Data Project.

The year 2019 marked the first review of the CoreTrustSeal Requirements. After an open community review, the revised Requirements for 2020–2022 were released in November 2019 and applications against them are now being accepted. Given the number of repositories continuing to transition to the CoreTrustSeal certification, the Requirements remain fundamentally stable for 2020–2022.

This presentation will give an overview of current status of the World Data System and its successes in helping make data more open. As well as focus on core certification of data repositories by the CoreTrustSeal and an introduction to the TRUST principles, it will briefly discuss:
–The new WDS International Technology Office (ITO), which provides technical infrastructure and services in support of the WDS goals.
–The Scholarly Link Exchange (SCHOLIX), a high-level interoperability framework for exchanging information about the links between scholarly literature and data.
–WDS strategic activities with partners, such as the joint WDS–CODATA Task Group on ‘Citizen Science for the SDGs –Aligning Citizen Science outcomes to the UN Sustainable Development Goals’, and the Belmont Forum funded PARSEC project ‘Building New Tools for Data Sharing and Reuse through a Transnational Investigation of the Socioeconomic Impacts of Protected Areas’.

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Keywords: Scientific Data, Open Science, Trustworthiness, Repository Certification, CoreTrustSeal, SCHOLIX

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Active Data Product Archive Tracking (ADAPT) and the Future of Heliophysics Data Access

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The Heliophysics Science Division of NASA sponsors research focused on the study of the dynamics of the Sun, the solar wind, and the interaction between the solar wind, the planets, and other solar wind bodies. These studies involve the use of data from a vast armada of spacecraft, sounding rockets, ground station observatories, together called the "Heliophysics System Observatory", coupled with information from data models and data simulations. Access to these data is enabled through the implementation of the NASA Heliophysics Science Data Management Policy, which stresses the need to maximize open access to scientifically relevant data products. The Heliophysics Data Environment, HPDE, has worked to support this policy through the creation of Virtual Observatories, VxOs, such as the Virtual Space Physics Observatory, VSPO, located at Goddard Space Flight Center, GSFC. The VxOs are charged with maintaining registries containing the information required to access Heliophysics data products. And, the HPDE has funded an effort to develop an XML schema called Space Physics Archive, Search, and Extract, SPASE, in order to document data product characteristics and to enable uniform data access. SPASE is the designated standard for documenting Heliophysics data products, as adopted by the Heliophysics Data and Model Consortium. SPASE has also been confirmed as the preferred worldwide standard for documenting Heliophysics data products after the approval of an IAGA Resolution submitted at the COSPAR 2018 meeting in Pasadena. The chore of producing SPASE metadata has proven to be an arduous effort. The VSPO metadata registries do not have a complete set of SPASE metadata to access the data from legacy Heliophysics missions. And, the SPASE registry content needs to be constantly updated in step with the release of data from new missions. Active Data Archive Product Tracking, ADAPT, which is a collection of UNIX shell scripts and IDL software, enables automatic generation of SPASE documents. ADAPT has been designed to use any available self-describing metadata associated with scientific data to produce XML metadata descriptions of any schema in a consistent and organized fashion. The goal of ADAPT focuses on providing blanket access to the full complement of data files stored on a targeted web server. The ADAPT effort is committed to providing accurate, precise, and complete SPASE documentation for data products through the implementation of quality control methods and the adoption of and adherence to uniform metadata populating standards. To date, ADAPT has been utilized to describe the Heliophysics data products that are stored by using the Common Data File, CDF, format served out by either the NASA Space Physics Data Facility, SPDF, Coordinated Data Analysis Web, CDAWeb, web site or the Heliophysics Data Portal, HDP. These CDF data repositories and the data portals, which are hosted at GSFC, are the primary means of community access to NASA Heliophysics data. The SPASE metadata registries are stored via the use of a Git distributed version-control system at https://github.com/hpde. In the spirit of OPEN Science and the initiative to pursue a future where open access to Heliophysics data products and interoperability, we strongly favor the stance that metadata content needs to be openly shared. Accordingly, the HPDE metadata are freely available upon request. This open metadata scenario has many advantages as a coordinated worldwide effort would help to reduce duplication of effort and improve the overall quality of the back-end metadata. As a consequence, the overall ability of the Heliophysics user community to discover, access, and archive data would be enhanced.

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Keywords: Open Science, Informatics, Heliophysics Data Environment (HPDE), Virtual Observatories, Space Physics Archive, Search, and Extract (SPASE), Active Data Product Archive Tracking (ADAPT)

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Introduction of TG-Data: IPCC Task Group on Data Support for Climate Change Assessments

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Task Group on Data Support for Climate Change Assessments (TG-Data), formerly known as Task Group on Scenarios for Climate and Impact Assessment (TGCIA), is a newly established task group on data issues in the 6th assessment cycle of Intergovernmental Panel on Climate Change (IPCC). One of its most important missions is to collaborate with IPCC's Working Groups I-III and Data Distribution Centers in order to secure data traceability and long-term data storage. TG-Data aims at enhancing data reliability used in IPCC reports in line with the "FAIR" concept, which stands for Findable, Accessible, Interoperable, and Reusable. The notion is rapidly obtaining popularity in the field of information science dealing with big data. TG-Data is trying to implement the idea of FAIR in the process of IPCC's assessment. As a first step, it is trying to realize data traceability and transparency for figures appearing in Summary for Policymakers of the Assessment Reports (AR). Specific activities include summarize instructions for Lead Authors on practices following FAIR. The prospect is that, when these efforts bear fruit, scientists in general will gain benefits regarding utilization of data used in ARs.

Keywords: IPCC, FAIR concept, Data Distribution Center

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Issues and progress of Open Science in geodesy

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In the global geodesy field, the data, operating organizations, motivations, and international governing bodies are diverse. For example, RINEX files are MB order, but raw data of VLBI reaches the TB order which makes them difficult to save and distribute. Some implementations of SLR are for map creation, and others are for space exploration. How to manage and maintain a huge amount of data from such observation networks with different properties is a common issue in the current geodesy.

In order to solve these universal problems in the geodesy, it has been considered to advance the Open Science. GGOS Japan (in the Geodetic Society of Japan) and GGOS established working groups about the Data DOI in 2019 to discuss the assignment of DOIs to data with the aim of proper distribution of these diverse data, objective evaluation and permanent management of the data. These working groups are discussing the future handling of geodetic data by large institutes. It is a universal issue in the geodetic field that the problem of data being time-series and that data and services (processed data) exist differently. Also, having data across institutions is a barrier to smooth execution of Open Science.

Data paper publications by the data manager / observer will be important. Currently, we are conducting pilot experiments in the field of seafloor geodesy.

Keywords: geodetic observation data, GGOS, data DOI

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Open Data for Seismology

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The open data movement have become popular in seismology. A special session “Open data for seismology” was included in the 2019 Seismological Society of Japan (SSJ) fall meeting, in which extensive discussion was made to share the situations in and around academia and ideas related to open data. The session consisted of 17 oral presentations including 3 invited presentation and 4 poster presentations. The discussions are classified in 3 major subjects: and academic and political background, practice of data publication, development of tools to utilize published data and public engagement.

The 1995 Kobe earthquake was a point of departure of open data movement in seismology in Japan. Fundamental Seismic Survey and Observation Plan” published by Headquarters for Earthquake Research Promotion declared that the results of the observations based on the plan were opened in principle and were tried to be distributed smoothly. There have been efforts of publishing data by universities and institutes.

In 2019, DOI (Digital Object Identifier) has been minted to each MOWLAS (Monitoring of Waves on Land and Seafloor) observation network operated by NIED. Japan Agency for Marine-Earth Science and Technology (JAMSTEC) and National Institute of Polar Research (NIPR) has already be publishing data with DOI. Some authors have published data via data journal and data repository. There have been a variety of database related to seismology opened for the public constricted by universities, institutes, and research projects.

Some projects adopting open collaboration can be found in seismology. Analogue seismogram digitization and of transcription of historical earthquake documents collaborating with citizens or non-experts are good example. Development of tools both for experts and non-experts are important to utilize the published data or understand the significance of the seismological data.

Keywords: Open data, Observation, Data DOI

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[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-GI General Geosciences, Information Geosciences & Simulations

[M-GI37] Integration of Earth Observations and Multiple Use for Earth Science and Benefits to Societies - GEO

convener:Hiroyuki Muraoka(River Basin Research Center), Kentaro Ando(Japan Agency for Marine and Earth Science and Technology), Osamu Ochiai(Japan Aerospace Exploration Agency), Shinichi Sobue(Japan Aerospace Exploration Agency)

Earthquakes and tsunamis, floods and drought, environment deterioration and pollution, global warming and island losing, and ecosystem degradation endanger the security of water, food, energy, health and ecosystem services. To confront these challenges, there is a demand to foster its application capacity and to develop integrated, sharable, and sustained observation systems. Group on Earth Observations (GEO) is a partnership of 107 national governments including Japan and 132 Participating Organizations that envisions a future where decisions and actions for the benefit of humankind are informed by coordinated, comprehensive and sustained Earth observations. There is a unique regional activity focusing on the Asia-Oceania (AO) region which poses big challenges to the society with its large population, various and fast environmental changes and frequent natural disasters. To develop such capacity, it is necessary to promote a regional cooperation on earth observation with various communities. AOGEO aims to foster regional application activities focusing on water security, biodiversity, carbon and greenhouse gas, ocean and islands, and food security, etc. It is also seeking data sharing, Open Data Cube for AO region and user engagement and communication.
This session aims to 1) introduce the current status of data integration efforts in GEO and AOGEO, 2) engage any contributions of similar activities from outside of GEO and AOGEO, and 3) activate GEO and AOGEO activities and its related activities via any submissions and contributions of analysis of earth observations both from integrated data and single unique data on the earth science and societal applications. We seek submissions which include a) scientific researches by use of earth observation data from various platforms including satellite and in-situ, b) development of new data sets for national, regional and global analyses, and c) development of data integration platform and its broad application.

[MGI37-01] Development and current status of Group on Earth Observation (GEO) and Asia-Oceania GEO (AOGEO)

*Kentaro Ando[1], Hiroyuki Muraoka[2] (1.Japan Agency for Marine and Earth Science and Technology, 2.Gifu University)

[MGI37-02] Strengthening governance and investment for water-related disaster resilience under climate change in Asia

★Invited Papers

*Toshio Koike[1] (1.International Centre for Water Hazard and Risk Management)

[MGI37-03] GEOGLAM Asia Rice Crop Monitoring Activity

*Shinichi Sobue[1], Kei Oyoshi[1], Youichiro Kato[2] (1.Japan Aerospace Exploration Agency, 2.Unversity of Tokyo)

[MGI37-04] Preliminary Study of Water Quality Determination using Spectro-polarimetric Bidirectional Reflectance Factor

*Ahmad Shaqeer Mohamed Thaheer[1], Yukihiro Takahashi[1] (1.Department of Cosmosciences, Graduate School of Science, Hokkaido University)

[MGI37-05] Earth observation data utilization for Global Forest Observation Initiative (GFOI)

*Osamu Ochiai[1] (1.Japan Aerospace Exploration Agency)

[MGI37-06] **Climate and land use changes will degrade the distribution of Rhododendrons in China**

*Fangyuan Yu[1], Tiejun Wang[2], Thomas A Groen[2], Andrew K Skidmore[2], Xuefei Yang[3], Keping Ma[4], Zhifeng Wu[1] (1.Guangzhou University, 2.University of Twente, 3.Laboratory of Biogeography and Biodiversity, Kunming Institute of Botany, Chinese Academy of Sciences, Kunming , 4.State Key Laboratory of Vegetation and Environmental Change, Institute of Botany, Chinese Academy of Sciences)

Development and current status of Group on Earth Observation (GEO) and Asia-Oceania GEO (AOGEO)

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The Group on Earth Observations (GEO) is an intergovernmental organization with 109 member states and 136 participating organizations, working to improve the availability, access and use of Earth observations for the benefit of society. GEO works to actively improve and coordinate global EO systems and promote broad, open data sharing. GEO's global engagement priorities include supporting the UN 2030 Agenda for Sustainable Development, the Paris Climate Agreement, and the Sendai Framework for Disaster Risk Reduction. A central part of GEO's Mission is to build the Global Earth Observation System of Systems (GEOSS). GEOSS is a set of coordinated, independent Earth observation, information and processing systems that interact and provide access to diverse information for a broad range of users in both public and private sectors. GEOSS increases our understanding of Earth processes and enhances predictive capabilities that underpin sound decision-making: it provides access to data, information and knowledge to a wide variety of users.

The ASIA-OCEANIA Group on Earth Observation (AOGEO) is a framework for regional cooperation in Asia-Oceania and will engage regional stakeholders, including national agencies and regional intergovernmental organizations within the AO region. AOGEO will focus on the three areas of GEO's Engagement Strategy by implementing three types of activities: Regional Application Activities, Foundational Tasks and Integrated Priority Studies. Regional Application Activities will address regional challenges related to the GEO's Societal Benefit Areas and the GEO global Flagships and Initiatives. Foundational Tasks will promote regional coordination. Integrated Priority Studies will exemplify the cross-cutting and inter-related nature of various Societal Benefit Areas, and currently we are focusing on 1) Mekong River Basin, 2) Pacific Islands, and 3) Himalayan Mountains, which are vulnerable to on-going climate change.

Keywords: Group on Earth Observation, Asia-Oceania, Earth Observation data

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Strengthening governance and investment for water-related disaster resilience under climate change in Asia

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The number of geophysical events, such as earthquakes and tsunamis, have not changed so much, while the number of water-related disasters, such as floods, cyclones and droughts, have been increasing very rapidly, by more than three times, since 1980. The overall economic losses are also rapidly increasing. Almost half of the events are reported to occur in the high or upper-middle income countries, and more than three-quarters of the economic losses are accounted for in these countries. In contrast, more than 80% of the human losses occurred in the lower-middle or low income countries.

In Japan, we are now experiencing very serious flood and sediment disasters that occur more frequently and affect a wider area than before. In 2018, the historical maximum 48-hour rainfall was recorded at 124 automatic weather stations located in western Japan. In 2019, the historical maximum 12-hour rainfall was recorded at 120 stations in eastern Japan. In the two consecutive years, 2018 and 2019, we experienced historical maximum heavy rainfall events all over Japan. Serious damage was caused by those events, including more than 2500 sediment disasters in 2018 and 140 bank breaches in 2019. Very regrettably, the casualties reached triple-digits in the two consecutive years.

As much effort as possible should be made for recovery, rehabilitation and reconstruction from recurring severe water-related disasters due to climate change. Still, equally important is to present a basic policy which shows the necessity of governance and investment in water-related disaster rick reduction for further growth at all levels. To promote the implementation of essential proactive measures, we need to explore and discuss initiatives and efforts for strengthening governance and investment for water-related disaster resilience under climate change in Asia through transdisciplinary dialogue and collaborative work between the science and technology community and other stakeholders.

Keywords: Resilience, Governance, Investment

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GEOGLAM Asia Rice Crop Monitoring Activity

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The Asia-RiCE initiative (http://www.asia-rice.org) has been organized to enhance rice production estimates through the use of Earth observation satellites data, and seeks to ensure that Asian rice crops are appropriately represented within GEO Global Agriculture Monitoring (GEO-GLAM) to support FAO Agriculture Market Information System (FAO-AMIS). Asia-RiCE is composed of national teams that are actively contributing to the Crop Monitor for AMIS and developing technical demonstrations of rice crop monitoring activities using both Synthetic Aperture Radar (SAR) data (Radarsat-2 from 2013; Sentinel-1 and ALOS-2 from 2015 and extend such activity from a province estimation to national estimation. And also, using GCOM-W, GPM, MODIS, Himawari and other satellites, JAXA provides agro-met information to Asia to support monthly rice crop outlook in cooperation with ASEAN food security information project (AFSIS).

Now, this Asia Rice initiative promote as one of task group (task group 5) activity in Asia Ocean GEO in cooperation
with other task group for water, drought, etc.

This paper reports Asia Rice Crop activity accomplishment in Asia in 2019.

Keywords: Asia Rice, AOGEO, APRSAF, SAR, Agromet

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Preliminary Study of Water Quality Determination using Spectro-polarimetric Bidirectional Reflectance Factor

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All living organisms require water as a foundation to support life and the development of human civilization. However, recent study shows that wetland sizes are decreasing in trend due to the increase in urbanization, climate change, and natural disaster. These lead to the degradation of water resource quality and quantity. The water quality is determined through the study of the biological, chemical, and physical features of the water bodies and currently, researchers have been using the Water Quality Index (WQI) through the *in-situ* measurements methods. However, the methodology has many shortcomings in large scales applications. While, spectral imaging equipped remote sensing can help in combating the problem, light reflecting on water surfaces that are usually roughened by small, wind-driven waves create a challenging measurement condition. As the incoming light arrives at the surface of the water, a portion of the light is reflected in the camera, while the pollutants inside the water reflect the other portion of it. At a particular angle, the light is reflected between the wave structures, due to the water wave, and creates a glittering effect. This produces specular reflection that blocks the actual reflection from the materials inside the water to the instruments. These reflections are in the polarized and unpolarized component of the light, which later can be separated by using a polarizer. These patterns also change shape depending on the water surface roughness and the solar elevation angle, therefore under very light-wind conditions the number of sun glints decreases. This can be better represented by using the bidirectional distribution function (BRDF) that visualize the relation of azimuth, zenith, incident, and camera angle. Combining different measurement angle, spectral, and polarization information reveals a comprehensive optical characteristic of an object in terms of the material compositions as well as surface characteristics, which may not be readily obtained using conventional imaging techniques.

Keywords: Water Quality, Multispectral, BRDF

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Earth observation data utilization for Global Forest Observation Initiative (GFOI)

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The Global Forest Observations Initiative (GFOI) is an informal partnership to coordinate international support to developing countries on forest monitoring and greenhouse gas (GHG) accounting for the purposes of REDD+ and related forums. Under the Lead Team consisted by Australia, Germany, Norway, UK, US, Committee on Earth Observation Satellites (CEOS), Food and Agriculuture Organization (FAO) and European Space Agency (ESA), there are many partners actively participating including developing countries and other research and operational institutes. Through collaborative action, GFOI partners seek to accelerate developing country progress in improved forest monitoring and GHG accounting. Partners coordinate their activities under four interlinked GFOI components, which together make it possible to provide a more holistic and coherent package of support to developing countries than any one international partner could provide alone. GFOI is the product of the collaborative actions of its partners. Specifically GFOI activities include: Facilitating country-led assessments of their forest monitoring needs and gaps; Harmonized work planning to address country-identified priorities; Collaborative implementation of forest monitoring support, including: Complementary and consistent capacity building; Development and dissemination of user friendly guidance for REDD+; Supporting the availability and accessibility of remote-sensing data and other key datasets and tools; Coordinating research and development (R&D) activities to fill knowledge gaps, address obstacles to progress and align the work of the research community with developing-country needs; Fostering a diverse network of experts and practitioners to support developing countries in a targeted and cohesive manner; Facilitating information sharing between partners to avoid duplications and overlap. GFOI is guided by a Leads Group and supported by a secretariat known as the GFOI Office. In this paper, the topic mainly focuses on how Earth observation data can be utilized for supporting country needs of the forest monitoring system and related GHG accounting.

Keywords: Forest monitoring, Earth observation data, Green house gas

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Climate and land use changes will degrade the distribution of Rhododendrons in China

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Biodiversity loss and variation in species responses to climate and land use change have been found across broad taxonomic groups. However, whether species from the same taxonomic group with distinct geographical ranges will respond differently is poorly understood. The aim of this study is to predict the potential impacts of future climate and land use change on the distribution of narrow- and wide-ranging Rhododendron species, and estimate their relative contribution in China. We applied the presence-only ecological niche model MaxEnt to predict the distribution of 10 narrow-ranging and 10 wide-ranging Rhododendron species for the year 2070, using three general circulation models and three scenarios of climate and land use change. We measured the predicted distribution change of each species using change ratio, distance and direction of core range shifts, and niche overlap using Schoener’ s D. We found that the distribution areas of six narrow-ranging species would decrease, of which one species would go extinct. The remaining four narrow-ranging species would experience range expansion. Distribution of all the wide-ranging Rhododendron species would decrease. All Rhododendrons will shift to the northwest. We conclude that Rhododendron species generally will be negatively affected by the climatic and land use change expected in 2070 from the three scenarios evaluated in this study, but some narrow-ranging species may be positively influenced. Narrow-ranging Rhododendron species are more vulnerable compared to wide-ranging Rhododendron species. This study demonstrated that the effects of climate and land use change on alpine and subalpine plant species is species-specific, thereby strengthening our understanding of the impacts of climate and land use change on plant distribution.

Keywords: Geographical range,, conservation, extinction risk, alpine and subalpine species

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[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-AG Applied Geosciences

[M-AG42] CTBT IMS Technologies for Detecting Nuclear Explosion and Their Applications to Earth Science

convener:Ozel Nurcan Meral(Comprehensive Nuclear-Test-Ban Treaty Organization), Hiroyuki Matsumoto(Japan Agency for Marine-Earth Science and Technology), Noriko Kamaya(Earthquake Research Institute, The University of Tokyo), Yosuke Naoi(Japan Atomic Energy Agency)

The Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) was founded in 1996 in response to the adaption of the Treaty in 1996 by the United Nations General Assembly, which bans nuclear explosions on the Earth's surface, in the atmosphere, underwater and underground. The Treaty has a unique and comprehensive verification regime to make sure that nuclear explosion goes detected. The regime is supported by International Monitoring System (IMS) composed of the four state-of-the-art technologies; 1) Seismic, 2) Hydroacoustic, 3) Infrasound, and 4) Radionuclide, by the International Data Centre (IDC), and by the On-Site Inspections (OSI).
IMS will, when complete, consists of 337 facilities worldwide to monitor the planet for signs of nuclear explosion. Around 90 % of the facilities are operational and sending the data to the IDC in Vienna, Austria.
The huge amount of data collected by the IMS network can be used for other purposes such as civil and scientific applications in addition to detecting nuclear explosions. For example, they can provide Tsunami Warning centers with near real-time information about an underwater earthquake. The data could also help better understand of earthquakes, volcanoes, oceans, climate change, and other issues on our planet.
This session will provide the overview of the IMS, the scientific discussion on each technology, and its outcomes. The session strongly welcomes young scientists and engineers who are interested in four IMS technologies.

[MAG42-01] CTBT International Monitoring System (IMS) Reaches the Milestone of 300 Certified Facilities

*Nurcan Meral Ozel[1], Georgios Haralabus[1], Hideaki Komiyama[1] (1.Comprehensive Nuclear-Test-Ban Treaty Organization)

[MAG42-02] Offshore real-time monitoring system and its application to disaster resilience

★Invited Papers

*Yoshiyuki Kaneda[1,2,3], Narumi Takahashi[3,2], Hiroyuki Matsumoto[2] (1.Kagawa University, 2.Japan Agency for Marine-Earth Science and Technology (JAMSTEC), 3.National Research Institute for Earth Science and Disaster Resilience (NIED))

[MAG42-03] Beyond the antipode: Hydroacoustic detection of earthquake activity along the Middle America Trench

*Dirk Metz[1], Julien Vergoz[2] (1.Japan Agency for Marine-Earth Science and Technology, 2.French Alternative Energies and Atomic Energy Commission)

[MAG42-04] Tremendous damage of I30JP by typhoon “FAXAI”

Takanari Fujii[1], Takayuki Otsu[1], Toyomi Sakamoto[1], Soshi Iwata[1], RYOHEI EMURA[1], Mami Nogami[1], Makiko Iwakuni[1], *Masashi Motohashi[1] (1.Japan Weather Association)

[MAG42-05] Observation results of the Fukushima Daiichi accident at CTBT radionuclide monitoring stations

*Yoichi Yamamoto[1], Yuichi Kijima[1], Yutaka Tomita[1] (1.Japan Atomic Energy Agency)

[MAG42-06] A synthesis of worldwide sediment source tracing research including fallout radiocesium (^{137}Cs)

*Olivier Evrard[1], Pierre-Alexis Chaboche[1], Rafael Ramon[1,2], Anthony Foucher[1], J. Patrick Laceby[3] (1.Laboratoire des Sciences du Climat et de l'Environnement (LSCE, joint laboratory CEA-CNRS-UVSQ), University Paris-Saclay, France, 2.Graduate Program in Soil Science, Federal University of Rio Grande do

Sul, Porto Alegre, Rio Grande do Sul, Brazil, 3.Environmental Monitoring and Science Division (EMSD), Alberta Environment and Parks (AEP), Calgary, Alberta, Canada)

CTBT International Monitoring System (IMS) Reaches the Milestone of 300 Certified Facilities

*Nurcan Meral Ozel[1], Georgios Haralabus[1], Hideaki Komiyama[1]

1. Comprehensive Nuclear-Test-Ban Treaty Organization

The Comprehensive Nuclear-Test-Ban Treaty (CTBT) bans nuclear explosions on the Earth's surface, in the atmosphere, underground and underwater. It is a global deterrent for the development or improvement of nuclear weapons and has 184 States signatories (www.ctbto.org).

The Treaty foresees a verification regime that relies on an International Monitoring System (IMS) comprising four complementary monitoring technologies: seismic, with 50 primary and 120 auxiliary stations monitoring vibrations in the Earth; infrasound, with 60 surface stations that monitor ultra-low frequency sound waves in the atmosphere inaudible to the human ear; radionuclide, with 80 stations measuring radioactivity in particles sampled from the air, of which 40 have additional noble gas detection capability, supported by 16 radionuclide laboratories; and hydroacoustic, with 11 stations (6 hydrophone stations and 5 T-phase stations) monitoring acoustic waves in the oceans.

The first facilities were established and certified in 2000 and progress increased rapidly in the following years. However, the few remaining facilities pose the most difficult logistical and political challenges.

The year 2019 was therefore important for CTBTO and the IMS because another three facilities were certified, namely: RN48 Niger (radionuclide particulate monitoring station), IS01 Argentina (infrasound monitoring station) and RL14 South Africa (radionuclide laboratory). This raises the number of certified facilities to 300 out of 337 planned. This is a major achievement because although the CTBTO’s headquarters are in Vienna, Austria, its verification regime includes a global monitoring network of facilities, some of which are located in the most remote places on the planet.

The year 2020 will be equally challenging year as preparations are underway for the installation and certification of remaining IMS facilities leading towards the completion of the entire IMS network. For example, infrasound station IS25 installed in 2009 in Guadeloupe, France is planned to be certified in the first half of 2020 after it has been verified that it meets the necessary requirements and can sustain continued good performance.

Keywords: CTBTO, Certification, 300 stations

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Offshore real-time monitoring system and its application to disaster resilience

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In Japan, some types of offshore real-time monitoring system have been deployed off the coast of the Pacific Ocean including the Nankai Trough seismogenic zone and the Tohoku seismogenic zone (i.e., the Japan Trench). DONET and S-net have been deployed in the Nankai Trough and the Japan Trench, respectively, since the 2010s. Now, new development of next generation real-time monitoring system namely N-net has been launched, which is focusing on the western part of the Nankai Trough.
Many catastrophic earthquakes, volcanic eruptions and tsunamis bring destructive disasters in the world. In Indonesia, for example, the Palu earthquake and the Anak Krakatau volcanic eruption/collapse brought tsunami disasters in 2018. Therefore, we should realize that offshore real-time monitoring systems are very important and effective for early warning.
The Japanese offshore real-time monitoring system such as DONET and S-net are used for earthquake early warning (EEW) and tsunami warning, and they have contributed to understanding of seismic activities in the region. At the same time, we could examine the *in-situ* data acquired by the system for the purpose of scientific studies.
In the presentation, we introduce the Japanese offshore real-time monitoring system and the utilization of their data.

Keywords: real-time monitoring system, Nankai Trough, early warning, resilience

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Beyond the antipode: Hydroacoustic detection of earthquake activity along the Middle America Trench

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Earthquakes occur regularly along the northern Middle America Trench, a major subduction zone located offshore the Pacific coast of Mexico. Results from phased array beamforming suggest that low-frequency acoustic phases generated by these events couple into the Sound Fixing and Ranging (SOFAR) channel and can be recorded as far as Diego Garcia, Indian Ocean, where a hydrophone triplet station is operated as part of the International Monitoring System (IMS). At more than ~21,300 km, source-receiver ranges exceed antipodal distances (‘suprapodal propagation’), marking the furthest hydroacoustic transmissions to have ever been observed on Earth. Transmission loss modeling indicates that hydroacoustic propagation between the epicenter region and the IMS station is feasible and matches observed travel times. Implications for test-ban monitoring and the potential of the Diego Garcia station for further studying seismic activity along the Middle America subduction system will be discussed.

Keywords: CTBT, IMS, Hydroacoustics, Earthquake, Indian Ocean, Diego Garcia

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Tremendous damage of I30JP by typhoon “FAXAI”

Takanari Fujii[1], Takayuki Otsu[1], Toyomi Sakamoto[1], Soshi Iwata[1], RYOHEI EMURA[1], Mami Nogami[1], Makiko Iwakuni[1], *Masashi Motohashi[1]

1. Japan Weather Association

Typhoon No.15 “FAXAI” attacked around Tokyo area (including Isumi city where I30JP was installed) which brought strong wind and rainfall widely on 08-09/Sep./2019. The barometric pressure when it landed in Chiba prefecture (08/Sep. 19:00UTC) was 960hPa. It caused tremendous damage by strong wind at Tokyo and Chiba. Because so many electric poles and towers were toppled, power outage continued for more than 2 weeks in the vast area of Chiba prefecture.

In I30JP, IMS infrasound station in Japan, observation data of I30H1 –I30H6 are normally transmitted to IDC miraculously, however, in each site so many cedars were fallen and observation facilities were heavily damaged.
Here, it is shown about analysis results during the typhoon passed through Tokyo area. Infrasound waveform data are compared at the damaged site (I30H6) before and after the typhoon. Furthermore, the surrounding environment has been quite changed at I30H6 after the typhoon, the future remedial action plan for maintenance is also introduced.

Keywords: CTBT, National Data Centre, infrasound, waveform analysis, typhoon

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Observation results of the Fukushima Daiichi accident at CTBT radionuclide monitoring stations

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1. Japan Atomic Energy Agency

After the Great East Japan Earthquake in 2011, the Fukushima Daiichi Nuclear Power Plant accident happened and large amounts of radioactive materials were released into the environment and spread globally. The National Data Center-2 (NDC-2) in the Japan Atomic Energy Agency received observation data every day sent from the radionuclide monitoring network of the CTBT International Monitoring System and analyzed the data. The radionuclides released by the accident generally circulated around the northern hemisphere in about 12 days. The activity concentration of Xenon-133 around each radionuclide station in the northern hemisphere almost became uniformed by diffusion in early April, 2011, and after that, the activity concentration at each station decreased with the half-life of Xe-133 and returned to the normal level before the accident in early June. NDC-2 also estimated the timing of first arrival of the radioactive plume at the CTBT Takasaki radionuclide station using the observation data of the station. Consistent results were found between the estimated timing and the time when the spatial gamma-ray dose rate at the monitoring post neat the station rose suddenly.

Keywords: CTBT, Takasaki radionuclide monitoring station, Fukushima Daiichi Nuclear Power Plant accident

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A synthesis of worldwide sediment source tracing research including fallout radiocesium (^{137}Cs)

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Quantifying the main sources delivering harmful sediment loads to river systems is required to improve our knowledge of soil erosion processes. Among these potential sources, quantifying the contributions of surface (e.g. cultivated topsoil) and subsurface (e.g. channel bank, gully, landslide) material to sediment transiting river systems is of particular interest. Radiocesium (^{137}Cs) that was emitted during the atmospheric bomb tests that took mainly place in the 1960s and nuclear accidents provides an effective tracer to distinguish between topsoil material exposed to the fallout and subsoil sheltered from this fallout. A global synthesis of research articles (n=123) that used radiocesium to fingerprint sediment sources indicated that the largest number of publications (~55% of the total) were found in the United Kingdom, Australia and the United States. On the contrary, very few studies (~9% of the total) were published for catchments located in Africa or South America. Given the low proportion of fallout recorded in regions located between 0-20°N and 0-20°S, the potential of this technique for quantifying sediment source contributions may be limited in this part of the world. A similar conclusion may be drawn for applying this method in agricultural areas exposed to several soil erosion during the last several decades, such as Chinese Loess Plateau and South Africa. Overall, 94% of studies incorporating ^{137}Cs as a potential tracer included this property in mixing models. In the future, given the continuous decay of the initial radiocesium fallout that peaked in the 1960s, the access to ultra-low background gamma-ray spectrometry facilities will be increasingly necessary to measure this important sediment tracing property. In addition, more research should be devoted to develop surrogate tracers providing discrimination between surface and subsurface material. Based on this extensive study review, researchers are also recommended to systematically include basic catchment information, details on the soil/sediment sampling design and access to raw data to facilitate the dissemination of this information among the communities of scientists and catchment managers.

Keywords: soil erosion, sediment tracing, sediment fingerprinting, radiocesium, geomorphology

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[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-SD Space Development & Earth Observation from Space

[M-SD46] Effects of lightning, severe weather and tropical storms

convener:Mitsuteru Sato(Department of Cosmoscience, Hokkaido University), Yoav Yair(Interdisciplinary Center Herzliya), Xiushu Qie(Institute of Atmospheric Physics, Chinese Academy of Sciences), Yukihiro Takahashi(Department of Cosmosciences, Graduate School of Science, Hokkaido University)

Thunderstorms are markers of deep convection and severe weather, producing heavy precipitation, hail and strong winds that lead to significant natural hazards, especially in coastal and urban areas. Huge economic damages and loss of human lives often result from such events. As the intensity and frequency of thunderstorms is projected to increase in the future - when the atmosphere and oceans become warmer - the need for detecting and nowcasting thunderstorms and lightning on local and regional scales becomes crucial.
We invite contributions dealing with thunderstorms and lightning and their atmospheric effects. We seek contributions focusing on convective storm evolution, forecasting of thunderstorms and lightning using regional and global detection networks as well as other sensors. Also, works on global lightning patterns in an era of climate change, satellite-based studies of thunderstorms and other remote-sensing technologies, as well as urban effects on lightning and public safety from lightning danger.

[MSD46-01] Is there a "weekend effect" in precipitation and lightning activity during winter thunderstorms over the Tel-Aviv, Israel metropolitan area?

*Yoav Yair[1], Mordecai Yaffe[1] (1.Interdisciplinary Center (IDC) Herzliya, Israel)

[MSD46-02] An unusual multiple-stroke positive cloud-to-ground lightning flash with different terminations

*Xiushu Qie[1], Shanfeng Yuan[1], Rubin Jiang[1] (1.Institute of Atmospheric Physics, Chinese Academy of Sciences)

[MSD46-03] **Cell-Scale Analysis of Convective Cloud Merging in a Squall Line and the Associated Lightning Behaviour**

★Invited Papers

*Jingyu Lu[1,2], Xiushu Qie[1,2], Rubin Jiang[1], Dongxia Liu[1], Dongfang Wang[1], Shanfeng Yuan[1], Zhixiong Chen[1,2], Jinliang Li[3], Xian Xiao[4,5], Xiaoyuan Yi[6] (1.Key Laboratory of Middle Atmosphere and Global Environment Observation (LAGEO), Institute of Atmospheric Physics, Chinese Academy of Science, Beijing, China., 2.College of Earth and Planetary Science, University of Chinese Academy of Science, Beijing, China., 3.Key Laboratory of Semi-Arid Climate Change, Ministry of Education, College of Atmospheric Sciences, Lanzhou University, Lanzhou, China., 4.Institute of Urban Meteorology, China Meteorological Administration, Beijing, China., 5.Beijing Urban Meteorological Engineering Research Center, Beijing, China., 6.Tianjin Meteorological Observatory, Tianjin, China.)

[MSD46-04] On-going development of ground observation system for typhoon and thunderstorm activities connected to real-time micro-satellite operation

*Yukihiro Takahashi[1,2], Mitsuteru Sato[1,2], Hisayuki Kubota[1,2], Tetsuro Ishida[1,2], Kozo Yamashita[4], Ellison Caparas Castro[3], Loren Jay Estrebillo[1], Purwadi Purwadi[1], Gay Perez[3], Joel Marciano[3], Jun Matsumoto[5], Jun-Ichi Hamada[5] (1.Department of Cosmosciences, Graduate School of Science, Hokkaido University, 2.Faculty of Science, Hokkaido University, 3.University of the Philippines, Diliman, 4.Ashikaga University, 5.Tokyo Metropolitan UNniversity)

[MSD46-05] **Summer monsoon experiment in Metro Manila of Philippines in 2019**

*Hisayuki Kubota[1], Yukihiro Takahashi[1], Mitsuteru Sato[1], Glenn Vincent Lopez[2], Joel Marciano[2] (1.Hokkaido University, 2.Advanced Science and Technology Institute)

[MSD46-06] Implementation of the ULAT Project : Quasi-Real Time Monitoring of Lightning and Weather in the Philippines

*Mitsuteru Sato[1], Glenn Vincent C. Lopez[2], Yukihiro Takahashi[1], Hisayuki Kubota[1] (1.Department of Cosmoscience, Hokkaido University, 2.Advanced Science and Technology Institute, DOST)

Is there a "weekend effect" in precipitation and lightning activity during winter thunderstorms over the Tel-Aviv, Israel metropolitan area?

*Yoav Yair[1], Mordecai Yaffe[1]

1. Interdisciplinary Center (IDC) Herzliya, Israel

There is numerous evidence that show changes of lightning frequency above and around (especially downwind of-) major urban areas compared with their rural surroundings. For example, Bell et al. (2009) reported a weekly cycle in lightning frequency in the south-east of the USA, but only a weak signal over major cities. There was a clear midweek increase in storm intensity, indicating that increases in aerosol levels lead to invigoration of storms in regions where convective instability and humidity are high. A similar weekday-weekend difference was reported for the Atlanta, Georgia metropolitan area by Stallins et al. (2012) and by Farias et al. (2009) in Sao-Paulo, Brazil.

We report the analysis of 10 years of winter-time (DJF) pollution, precipitation and lightning data over the Tel-Aviv metropolitan area, Israel's largest and densest urban environment. The region has an area of 2291 km^2 and a population of 3.854 million people, and hosts 1 million cars per day during weekdays (Sunday-Thursday) and the overflights of hundreds of airplanes landing at the Ben-Gurion international airport. Hourly aerosol concentrations (PM2.5 and PM10) were obtained from several automatic air-quality stations operated by the Ministry for Environmental Protection. The daily precipitation amounts at the Bet-Dagan Meteorological Center were analyzed on a decadal basis and exhibit a weekend effect with a varying maximum during weekdays. Lightning data obtained from the Israeli Lightning Detection Network (ILDN) for the period showed a similar pattern with enhanced activity during mid-week, with maximum on Wednesday and Thursday. These results suggest that increased activity of lightning during week-days (as compared with the weekend) is caused by increased levels of pollution due to traffic and economic activity. The increased amounts of particles tend to prolong the life-time of storms and their total lightning amounts and change their intracloud/cloud-to-ground flash ratios.

Keywords: Lightning, Urban Effect, Winter thunderstorms

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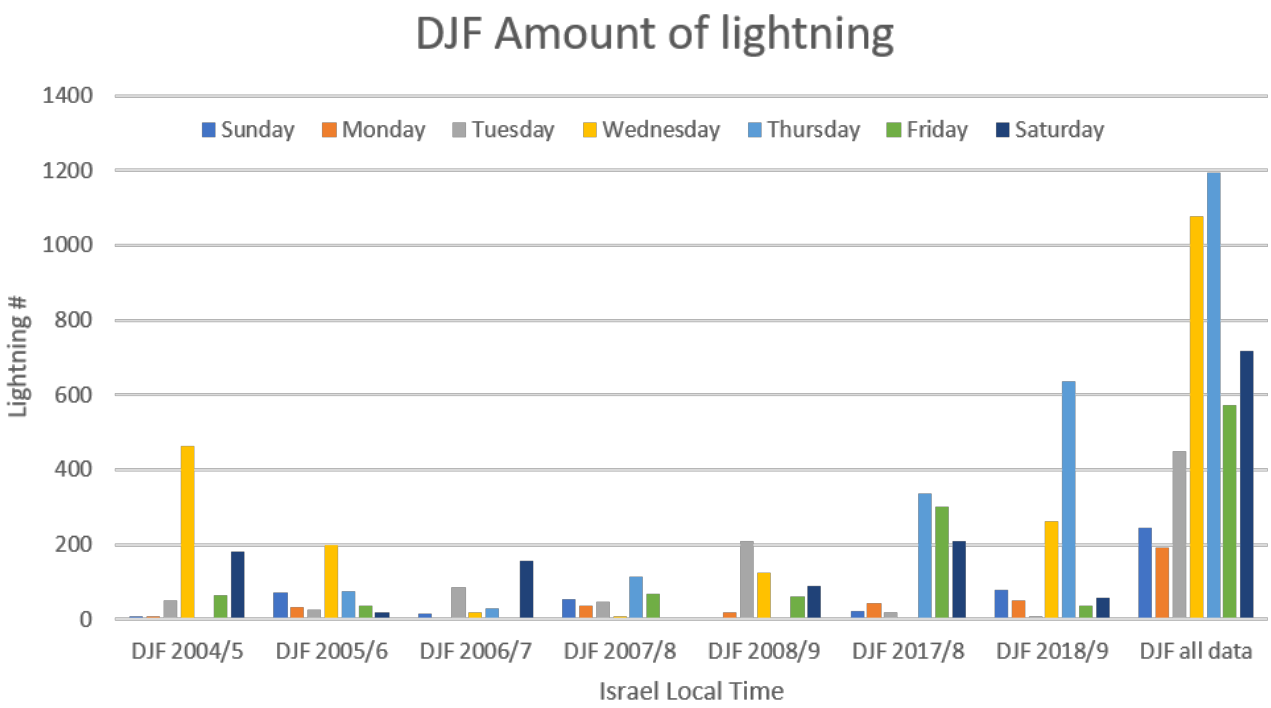

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An unusual multiple-stroke positive cloud-to-ground lightning flash with different terminations

*Xiushu Qie[1], Shanfeng Yuan[1], Rubin Jiang[1]

1. Institute of Atmospheric Physics, Chinese Academy of Sciences

An unusual positive cloud-to-ground (CG) lightning flash with three-stroke was observed by synchronous multifrequency radiation sensors. Its 3D channel development was carefully mapped. The results show that three positive strokes grounded at different points approximately 4-8 km apart and time intervals between neighboring CGs were 85 ms and 222 ms. This +CG flash was preceded by an intracloud (IC) discharge. The locations of the termination points on the ground were just below the pre-established horizontal IC discharge channels, and the 3 strokes, associated with shared horizontal negative leader channels inside the cloud, were linked with each other. There were stepping pulses less than 0.4 ms before the first and second return-stroke (RS), and their location results were distributed nearby the following RS, which suggests that might be associated with the attachment process. The first and second positive strokes occurred when the horizontal in-cloud negative channel stopped extending, while the third positive stroke occurred below the opposite end of an advancing negative leader in the cloud. The above results suggest that the downward positive leader preceding the strokes developed either from different decayed leader channels or from the opposite end of an advancing leader channel.

Keywords: positive cloud-to-ground (CG) lightning flash , Three positive return strokes, Channel mapping, Decayed leader channels , Advancing leader channel

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Cell-Scale Analysis of Convective Cloud Merging in a Squall Line and the Associated Lightning Behaviour

*Jingyu Lu[1,2], Xiushu Qie[1,2], Rubin Jiang[1], Dongxia Liu[1], Dongfang Wang[1], Shanfeng Yuan[1], Zhixiong Chen[1,2], Jinliang Li[3], Xian Xiao[4,5], Xiaoyuan Yi[6]

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The merging process of convective cells in a severe squall line and its impact on lightning behaviour is analysed in detail, by using the observations from the Beijing Lightning Network (BLNET), Doppler weather radar, and other meteorological data. The vertical profiles of the radar reflectivity indicate that the convective cells connected each other through cloud bridges at heights of 3~7 km during the merging process. The lightning data with high spatiotemporal resolution show that the total flash rate dropped immediately at the beginning of the cloud merger, then increased sharply and eventually peaked when the merger finished. A Similar feature was also involved in the cloud-to-ground (CG) lightning activity. At the later stage of the merger, the lightning activity of the cells in the front seemed to be more consistent. It is found that the cell-merging process had significantly different effects on different cells. The cells at the rear of the storm tended to be weakened by the merging and they dissipated thereafter, while the front cells were enhanced substantially with rapid growth in scale and intensity, termed as a rear-cell feeding merger. The dynamic field inferred from the VDRAS (Variational Doppler Radar Analysis System) shows that the updraft was dominant at the front cells of the storm, while downdraft was dominant in the middle and in the lower layers at the rear cells during the merger, as combined with strong low-level wind shear. The inflow contains both the humid air in the lower layer ahead of the cell and the outflow of the rear cells, providing abundant water vapour which favoured the development of the front cells.

Keywords: squall line, convective cloud merger, cloud bridge, lightning activity, radar reflectivity

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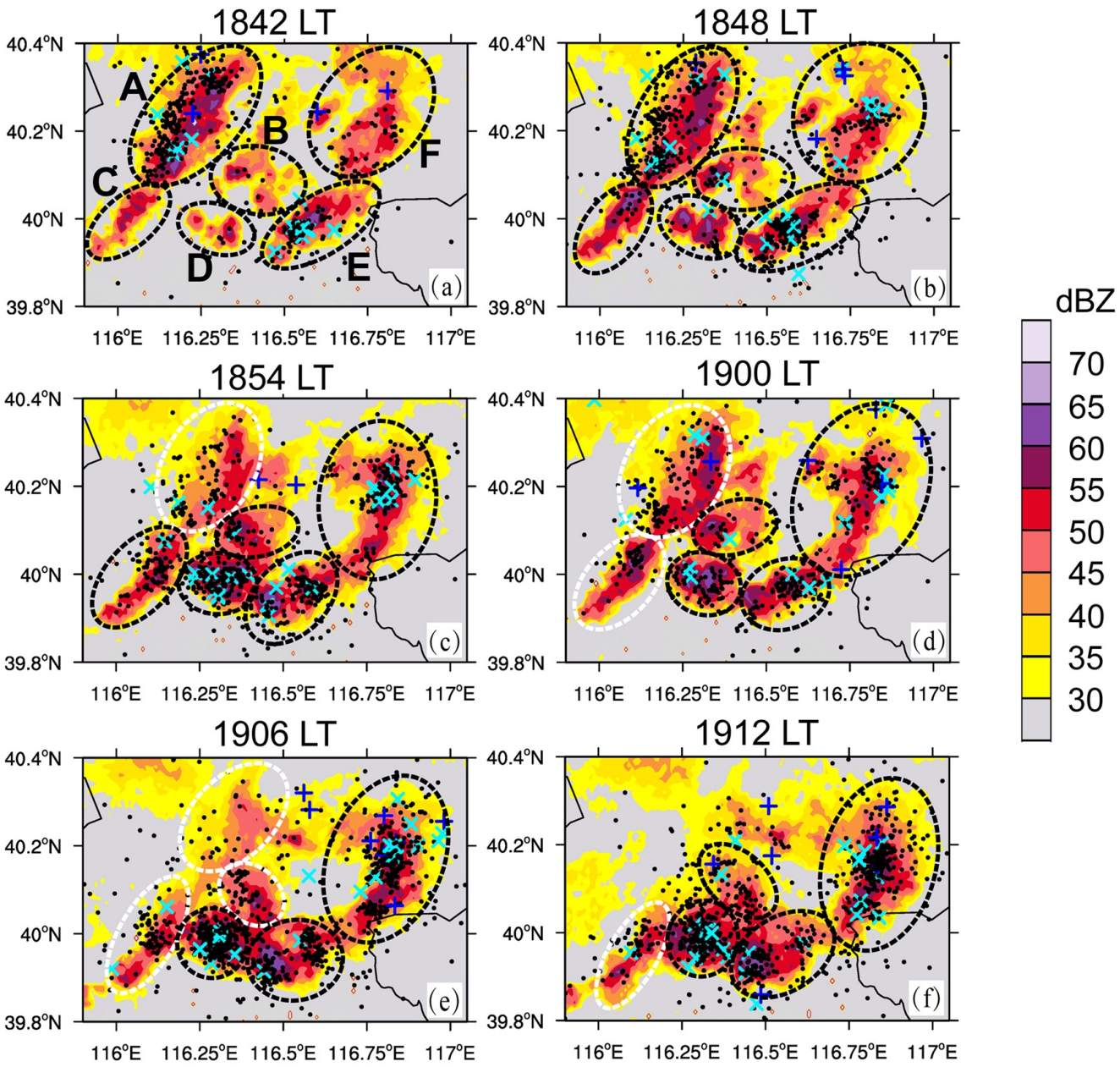

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On-going development of ground observation system for typhoon and thunderstorm activities connected to real-time micro-satellite operation

*Yukihiro Takahashi[1,2], Mitsuteru Sato[1,2], Hisayuki Kubota[1,2], Tetsuro Ishida[1,2], Kozo Yamashita[4], Ellison Caparas Castro[3], Loren Jay Estrebillo[1], Purwadi Purwadi[1], Gay Perez[3], Joel Marciano[3], Jun Matsumoto[5], Jun-Ichi Hamada[5]

1. Department of Cosmosciences, Graduate School of Science, Hokkaido University, 2. Faculty of Science, Hokkaido University, 3. University of the Philippines, Diliman, 4. Ashikaga University, 5. Tokyo Metropolitan UNniversity

In order to realize precise real-time monitoring and issuing alert for extreme weather, such as torrential rainfall or typhoon, we have been developing a ground observation network with lightning sensors under the projects of a SATREPS “ULAT” and e-ASIA under international cooperation among Japan, Philippines, Indonesia and other SE-Asian countries.

It is pointed out that intensification of lightning activity is precursor of typhoon growth as well as an indicator of individual thunderstorm activity. In these projects, we apply two new technologies, that is, the lightning activity estimated by the ground-based lightning networks with 12 sites for VLF radio wave measurement in nation-wide of Philippines and with 50 sites for electrostatic field measurement in Metro Manila together with infrasound sensor and automated weather station, and the 3 dimensional capturing of thunderstorms by the on-demand operation of 50-kg micro-satellites, including the Philippine-developed satellites. Also few more lightning stations installed in Indonesia and Japan are used. Based on these new observations we try to construct the cutting-edge observation system to monitor the development of typhoons and thunderstorms, which may greatly contribute to the prediction of disasters and the public alerting system. We started ULAT project in 2017 and completed the installation of the ground lightning observation station with automated weather station about half of the original plan and started continuous recording of the data. As for the satellite observation, we succeeded in reconstructing 3-D cloud structure with cameras onboard DIWATA-1at high resolution of ten to several meters. In this presentation we update the recent progress of the projects.

Keywords: remote sensing, lightning, micro-satellite

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Summer monsoon experiment in Metro Manila of Philippines in 2019

*Hisayuki Kubota[1], Yukihiro Takahashi[1], Mitsuteru Sato[1], Glenn Vincent Lopez[2], Joel Marciano[2]

1. Hokkaido University, 2. Advanced Science and Technology Institute

The Philippines is an archipelago country which is located in the western side of tropical western Pacific. There is a distinct summer monsoon in the western side of the country. This study focuses on the mature stage of summer monsoon in the western Philippines during July to August in 2019. We conducted four times a day upper-air observation at Tanay PAGASA weather station and installed 23 automatic weather and lightning observation systems called P-POTEKA in Metro Manila under the ULAT (Understanding Lightning and Thunderstorm) of SATREPS (Science and Technology Research Partnership for Sustainable Development) in the Philippines.
When the low-level southwesterly wind was intensified moistening air was induced in the Philippines and convection became active in the western side of the Philippines. Strong low-level southwesterly wind was observed every few days to 14 days in interval and continued from few days to two weeks during July and August in 2019. It was strongly influenced by the activities of tropical cyclones in the Philippine Sea. Continuous rainfall was observed widely in Metro Manila when the low-level southwesterly wind was intensified. Heavy rainfall tends to observe from nighttime to early morning. Many stations reached more than 100 mm/day on 1st and 2nd Aug. 2019. On the other hand, when the low-level wind was weak, rainfall was limited in a small area and tends observe during the afternoon.

Keywords: Monsoon, Heavy rainfall, Manila, Philippines

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Implementation of the ULAT Project : Quasi-Real Time Monitoring of Lightning and Weather in the Philippines

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Monitoring and understanding thunderstorms are key components for mitigating the disasters by torrential rainfall and typhoons. The integration of lightning data has the potential to provide short term forecasts of thunderstorms, further meteorological studies, and supplement disaster risk response strategies. This presents the activities and updates on the Understanding Lightning and Thunderstorm for Extreme Weather Monitoring and Information Sharing in the Philippines (ULAT) Project, which is led by Hokkaido University and other Japanese institutes and ASTI/DOST in the Philippines supported by the Japan International Cooperation Agency (JICA) and Japan Science and Technology Agency (JST). The ULAT Project is aimed at the following: a) establishment of a dense network of lightning and weather detectors in Metro Manila and nearby municipalities in order to provide thunderstorm “now-casting” and supplement weather-related research and disaster response studies and strategies; b) establishment of a ground receiving station for the direct reception of the satellite imagery and utilization of existing ground receiving facilities in order to develop effective observation methods by comparing 3D structures of thunderclouds from satellite images with lightning/precipitation data; c) establishment of a methodology for short term forecasts; and d) development of software for sharing information on short term forecast weather to concerned agencies. At the presentation, we will show the updated status of this project and will show the initial results derived from this project.

Keywords: lightning, thunderstorm, severe weather

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[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-SD Space Development & Earth Observation from Space

[M-SD46] Effects of lightning, severe weather and tropical storms

convener:Mitsuteru Sato(Department of Cosmoscience, Hokkaido University), Yoav Yair(Interdisciplinary Center Herzliya), Xiushu Qie(Institute of Atmospheric Physics, Chinese Academy of Sciences), Yukihiro Takahashi(Department of Cosmosciences, Graduate School of Science, Hokkaido University)

Thunderstorms are markers of deep convection and severe weather, producing heavy precipitation, hail and strong winds that lead to significant natural hazards, especially in coastal and urban areas. Huge economic damages and loss of human lives often result from such events. As the intensity and frequency of thunderstorms is projected to increase in the future - when the atmosphere and oceans become warmer - the need for detecting and nowcasting thunderstorms and lightning on local and regional scales becomes crucial.
We invite contributions dealing with thunderstorms and lightning and their atmospheric effects. We seek contributions focusing on convective storm evolution, forecasting of thunderstorms and lightning using regional and global detection networks as well as other sensors. Also, works on global lightning patterns in an era of climate change, satellite-based studies of thunderstorms and other remote-sensing technologies, as well as urban effects on lightning and public safety from lightning danger.

[MSD46-07] Lightning Geolocation using a Ground-based Lightning Observation Network in the Western North Pacific

*Loren Joy De Vera Estrebillo[1], Mitsuteru Sato[1], Yukihiro Takahashi[1], Hisayuki Kubota[1] (1.Hokkaido University)

[MSD46-08] **Typhoon energy input estimation using lightning data and backtracing technique**

★Invited Papers

*Purwadi Purwadi[1,2], Yukihiro Takahashi[1], Mitsuteru Sato[1], Hisayuki Kubota[1], Kozo Yamashita[3] (1.Department of Cosmosciences, Hokkaido University, Sapporo 0600810, Japan, 2.National Laboratory for Weather Modification Technology, Agency for Assessment and Application of Technology, Jakarta 10340, Indonesia, 3.Division of Electrical and Electronic Engineering, Dept. of Innovative engineering, Ashikaga University, Tochigi 3268558, Japan)

[MSD46-09] Estimation of relationship between tropical cyclone intensity and electrical properties of lightning

*Shunsuke Niwa[1], Mitsuteru Sato[1], Yukihiro Takahashi[1], Hisayuki Kubota[1] (1.Department of Cosmoscience, Hokkaido University)

[MSD46-10] Infrasound multi-site observation of thunders 4: regional testing process for SATREPS

*Masa-yuki Yamamoto[1], Taisei Yamamoto[1] (1.Department of systems engineering, Kochi University of Technology)

[MSD46-12] **3D Reconstruction of Typhoon and Thunderstorm Cloud Top Using Airborne and Satellite-borne Camera**

★Invited Papers

*Meryl Regine Llenaresas Algodon[1], Yukihiro Takahashi[1], Hisayuki Kubota[1], Joel Joseph Marciano[2] (1.Hokkaido University, 2.DOST - Advanced Science and Technology Institute)

Lightning Geolocation using a Ground-based Lightning Observation Network in the Western North Pacific

*Loren Joy De Vera Estrebillo[1], Mitsuteru Sato[1], Yukihiro Takahashi[1], Hisayuki Kubota[1]

1. Hokkaido University

The Philippines sits in the western North Pacific (WNP), which is the region where most of the strongest typhoons originate. An average of 20 tropical cyclones (TC) crosses and/or makes landfall in the Philippines each year. This makes the archipelago susceptible to the damages brought about by TCs. There has been a significant development in the accuracy of TC track forecast within the Philippine Area of Responsibility (PAR) over the years with the use of ground-based synoptic observations, weather radars, and meteorological satellites. However, prediction of TC intensity remains a significant challenge. Lightning activity is the indicator of the dynamics and microphysics in thunderstorms, TCs and torrential rainfall. Recent studies suggest that lightning activity in tropical cyclones can give predictive information about its intensity development. Thus, a ground-based lightning observation system (V-POTEKA) has been developed, and it has been installed at four stations in the Philippines, Guam, Palau and Okinawa. The V-POTEKA system uses the event-trigger method and can detect radio wave pulses from lightning discharges in the very low frequency (VLF) range of 1-50 kHz. It also consists of the automatic weather station (AWS), the VLF sensors, and the automatic data-processing unit. The V-POTEKA system analyzes lightning data, extracts pertinent information, i.e., peak amplitude and time of the triggered waveform, and transmits data to a server in Japan and the Philippines through 3G communication. Lightning locations from the V-POTEKA data are calculated using the difference in time-of-arrival (TOA) method. Lightning activity in TCs along the WNP region was investigated using the V-POTEKA lightning locations. In comparison with blitzortung.org, an open-access collaborative lightning detection network, a geolocation error of 48 km was computed for V-POTEKA network. Select TCs in 2019 were examined using NASA Cyclone Global Navigation Satellite System (CYGNSS) ocean winds and best track data from the Japan Meteorological Agency and Joint Typhoon Warning Center. Correlation analyses among lightning activity and maximum winds in TCs showed a 30-hour lag time, calculated using lightning and TC data of Typhoon Fengshen in 2019.

Keywords: geolocation, V-POTEKA, tropical cyclone, lightning

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Typhoon energy input estimation using lightning data and backtracing technique

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Price et al., 2009 analyzed the evolution of maximum winds and total lightning frequency every six hours. They found that in all of the hurricanes classified into category 4 and 5, lightning frequency and maximum sustainable wind speed are significantly correlated with a correlation coefficient of 0.82 with the lag time ~30h. Whittaker et al., 2015, enhance the Price work by increasing the number of tropical cyclones and changing the lightning collection window. Using radial lightning collection windows of < 500 km, theyfound broadly similar result to Price et al. Their work shows that lightning is good proxy to estimate the maximum wind speed of typhoon. In the present work, we are going to estimate the energy input of the typhoon by counting the number lightning swept by wind which enter into the typhoon cycle. We assume that the lightning activity is proportional to the energy input from the ocean. We use the lightning data detected by AVON supported by ULAT project of SATREPS and e-ASIA program or Blitzortung, and back-tracing of the wind. We did back-tracing using the wind data of ERA5 reanalysis at the pressure level 1000 to 400 mb with the interval 100 mb and typhoon data from the Joint Typhoon Warning Center (JTWC). First, we make symmetrical of 60 initial points in the radius of 100 km surrounding the center. Then we trace the points with the speed and opposite direction of the wind. The new position is calculated using the 30-min interval time and up to 48 hours before. Every 2 points and new locations of it in interval time 6 hours is connected and will form the polygon area as our lightning collection window. We estimate the time lag by making cross-correlation of our result to the typhoon maximum wind speed data.

Keywords: typhoon, maximum wind speed, lightning, back-tracing

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Estimation of relationship between tropical cyclone intensity and electrical properties of lightning

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1. Department of Cosmoscience, Hokkaido University

Tropical cyclone (TC) causes serious damage to human society every year. For reduction of its risk, TC forecast is important. TC track forecast is improving year by year but intensity forecast is not improving. Prediction of TC intensity is a big problem. Lightning is an good indicator of updraft intensity and TC is intensified by strong updraft. Thus lightning can be use to monitoring TC intensity. Previous studies suggested that lightning activity in TC can be a predictor of TC intensity. All previous studies used only frequency as an indicator of lightning activity. Electrical properties (EP) of lightning should be also related to updraft intensity, so using EP will help us to get more understand the relationship between TC intensity and lightning activity. Using ELF (1-100 Hz) magnetic field, we can estimate EP such as Peak current, Charge moment change and Charge amount. In this study, World Wide Lightning Location Network (WWLLN) and Global ELF Observation Network (GEON) were used to analyze lightning activity and the relationship between maximum sustained wind and EP in 4 TCs over the North Western Pacific Ocean in 2013. By comparison the relationship between each EP and TC intensity, it was found that Charge amount was the most likely to be a predictor of TC intensity. In this presentation, we will show result of this analysis more in detail.

Keywords: Typhoon, Lightning, ELF, CMC, intensity forcast

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Infrasound multi-site observation of thunders 4: regional testing process for SATREPS

*Masa-yuki Yamamoto[1], Taisei Yamamoto[1]

1. Department of systems engineering, Kochi University of Technology

Here we will introduce current status for the SATREPS/ULAT project in infrasound observation aspect for thunder remote-sensing. Infrasound, low-frequency sound of 20 Hz or less, is considered as one of the possible method for estimating lightning/thunder energy. The infrasound sensors have been and/or now are to be deployed for the SATREPS/ULAT project in Philippine, especially in Manila region since early 2019. We use two types of infrasound sensors: Small but impulsive pressure changes caused by the rapid expansion of the heated plasma along the path of lightning strikes can be detected by infrasound sensors with higher sensitivity range of 1 mPa. Thus, we will use multiple film type (DC type) infrasound sensor for low frequency measurements. But for the thunder infrasound signals, lower-cost microphone type (AC type) sensors can be also applied for measurements. Thus, we will mainly use many microphone type infrasound sensors in Metro Manila region.
It is expected that the multi-site infrasound observation can reveal the lightning activities as close as 100 m scale when the infrasound sensors can be installed with a mesh of 10 km scale or less by using the speed of sound as a precise remote-sensing scale. Recently, we tried regional testing with 6 AC-type sensors for checking the capability of remote-sensing in Kochi area by using real thunder signals with some other methods to compare. At present, we have several results for energy estimation with comparing dataset obtained by JLDN electro-magnetic wave remote-sensing results.
In this talk, we will introduce a possibility of infrasonic remote-sensing and its field testing phase, in order to realize future disaster-mitigation studies and applications.

Keywords: Infrasound, Thunder, Energy estimation

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3D Reconstruction of Typhoon and Thunderstorm Cloud Top Using Airborne and Satellite-borne Camera

*Meryl Regine Llenaresas Algodon[1], Yukihiro Takahashi[1], Hisayuki Kubota[1], Joel Joseph Marciano[2]

1. Hokkaido University, 2. DOST - Advanced Science and Technology Institute

Typhoons or individual thunderstorms are natural disasters which cause deaths and damaged properties to several countries. Consequently, it is important to analyze this meteorological phenomenon to allow researchers to understand its behavior, and properly deal with the hazards that go with it. A standard mode of visualization of typhoons involves the use of three-dimensional representations of a typhoon cloud top. This could help meteorologists determine the typhoon’ s height and estimate the amount of its precipitation. Creating a three-dimensional model requires visible distinct features or landmarks in the cloud’ s stereo images. This is difficult as clouds does not normally have rigid structures like points and corners to serve as landmarks. In this study, an experiment under the ULAT project (ULAT: Understanding Lightning and Thunderstorm) was conducted where images of Typhoon Trami were taken from an aircraft and by DIWATA-1 satellite last September 26, 2018. A 3D model of Typhoon Trami’ s cloud top was reconstructed from the images using a commercially available software. Aircraft or low-altitude satellite images provide closer views of the typhoon cloud top than that of geostationary satellite images making it easier to reconstruct a 3D model. This allows for the manual adjustment of the camera to capture images ideal for 3D reconstructions. From the result, an estimate of the cloud top dimension can be derived.

Keywords: 3D Reconstruction, Typhoon Monitoring

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[E] Oral | M (Multidisciplinary and Interdisciplinary) : M-TT Technology & Techniques

[M-TT48] Cryoseismology - A new proxy for detecting surface environmental variations of the Earth -

convener:Masaki Kanao(National Institute of Polar Research), Seiji Tsuboi(JAMSTEC, Center for Earth Information Science and Technology), Genti Toyokuni(Research Center for Prediction of Earthquakes and Volcanic Eruptions, Graduate School of Science, Tohoku University), Yoshihiro Hiramatsu(School of Geosciences and Civil Engineering, College of Science and Engineering, Kanazawa University)

In high latitude and elevation regions, the Earth's glaciers, ice sheets, sea ice, permafrost, and snowpacks are undergoing rapid change. Fortunately, many of the cryospheric processes of interest produce ground vibrations. Analysis of these seismic signals can yield insight into the relationship between environmental forcing and the response of ocean-cryosphere-solid earth system.
Ice-related seismic motions for small magnitude events are generally named ice-quakes and can be generated by glacially related dynamics. Such kinds of cryoseismic sources are classified into the movements of ice sheets, sea-ice, oceanic tide-cracks, icebergs and the calving fronts of ice caps. Cryoseismic waves are likely to be influenced by variations in environmental conditions, and the continuous study of their time-space variability provides indirect evidence of climate change. As glacial earthquakes are the most prominent phenomena found recently in polar regions particularly around Greenland, the new innovative studies from seismology are expected by long-term monitoring under extreme conditions in the Earth's environment.
Taking these issues into account, the conveners are willing to invite many contributions to a special session on "Cryoseismology", which cover recent topics on glacial related seismic events and associated phenomenon. It is particularly encouraged to have contributions based on seismic signals involving the dynamics of ice sheets, sea-ice, icebergs and glaciers. Although the glacial earthquakes are the most prominent evidence found recently in polar regions, all related topics involving polar seismology are welcome, such as studies of crust and mantle structure, comparison of tectonic and glacier-related seismicity, recent triggered earthquakes and active volcanoes, glacial isostatic adjustment (GIA), harmonic tremor associated with cryoseismic events.

[MTT48-01] Seismic tremors and their candidate origins in relation to cryosphere dynamics in Lützow-Holm Bay, Antarctica

*Masaki Kanao[1], Yoshihiro Hiramatsu[2] (1.National Institute of Polar Research, 2.Kanazawa University)

[MTT48-02] An effort to utilize the infrasound monitoring network data for understanding surface environment of Antarctica

*Takahiko Murayama[1], Masaki Kanao[2], Masa-yuki Yamamoto[3], Yoshiaki Ishihara[4], Takeshi Matsushima[5], Yoshihiro Kakinami[6] (1.Japan Weather Association, 2.National Institute of Polar Research, 3.Kochi University of Technology, 4.National Institute for Environmental Studies, 5.Kyushu University, 6.Hokkaido Information University)

[MTT48-03] Locating earthquakes around Antarctica by using neural networks based on deep learning

*Seiji Tsuboi[1], Daisuke Sugiyama[1], Masaki Kanao[2], Yoshiaki Ishihara[3], Takahiko Murayama[4] (1.JAMSTEC, Center for Earth Information Science and Technology, 2.National Institute of Polar Research, 3.National Institute of Environmental Studies, 4.Japan Weather Service)

[MTT48-04] Ice dynamics inferred from the detection of icequake seismicity near the Princess Elisabeth base, eastern Dronning Maud Land, East-Antarctica

★Invited Papers

*Denis Lombardi, Guilhem Barruol[1], Lionel Benoit[2], Thierry Camelbeeck[3], Irina Gorodetskaya[4], Olivier Martin[5], Christophe Meynard[5], Christian Thom[5] (1.Institut de Physique du Globe, Paris, France, 2.Université de Lausanne, Lausanne, Switzerland, 3.Royal Observatory of Belgium, Brussels, Belgium, 4.Centre for Environmental and Marine Studies,University of Aveiro, Portugal, 5.Institut National de l'Information Géographique et Forestière, St-Mandé, France)

[MTT48-05] P-wave tomography beneath Greenland and surrounding regions

*Genti Toyokuni[1], Takaya Matsuno[1], Dapeng Zhao[1] (1.Research Center for Prediction of Earthquakes and Volcanic Eruptions, Graduate School of Science, Tohoku University)

Discussion

Seismic tremors and their candidate origins in relation to cryosphere dynamics in Lützow-Holm Bay, Antarctica

*Masaki Kanao[1], Yoshihiro Hiramatsu[2]

1. National Institute of Polar Research, 2. Kanazawa University

Characteristics of seismic tremors occurring during April 2015 were investigated by seismographs at Syowa Station, in the Lützow-Holm Bay (LHB), East Antarctica. In order to examine a relationship between surface environment in particular cryosphere variation, the MODIS satellite images were utilized for comparison with the detected tremor events. Since a large volume of sea-ice was discharged during the April 2015, along with a few numbers of large icebergs passed through the northern edge of the fast sea-ice of LHB, it was supposed to detect characteristic seismic tremors involving cryospehre dynamics at the local region. During the month, a total number of 49 tremor events including short duration ice shocks were identified (Kanao et al., 2017). Majority of the events had their duration times more than 15 minutes, which were divided into both tremors and ice shocks. Cryospheric sources recorded by seismic tremors were classified by their origins; “crevassing events” along the large cracks inside the fast sea-ice, “discharge events” of fast sea-ice from the bay, “collision events” between iceberg and the edge of fast sea-ice, “crashing movement” between fragmentation of fast sea-ice and packed sea-ice, etc.. Particularly, strong amplitude tremors with harmonic overtones (classified as “type C” by Tanaka et al., 2019) were assumed to be occurred independently from meteorological condition, along with episodic events in the cryosphere. The most plausible candidate of the source origins could be collision events between the bottom of drifting icebergs with the top of sea-bedding sediments/crystalline rocks at the places where the northern edges of continental shelf of LHB in which the depths of the ocean-floor could be less than 300 m from mean sea level (Moriwaki and Yoshida, 2002). Further investigation of ocean-floor topography at the edge of continental shelf will be expected by using multi-narrow beam system equipped by icebreaker vessel “Shirase”.

Keywords: Seismic tremors, Cryosphere dynamics, Antarctica

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An effort to utilize the infrasound monitoring network data for understanding surface environment of Antarctica

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1. Japan Weather Association, 2. National Institute of Polar Research, 3. Kochi University of Technology, 4. National Institute for Environmental Studies, 5. Kyushu University, 6. Hokkaido Information University

Characteristic features of infrasound waves observed in the Antarctic reflect the physical interaction between the surface environment along the continental margin and the surrounding Southern Ocean. In April 2008, infrasound observation started at the Japanese main station; Syowa (SYO; 69.0S, 39.6E), in the Lützow–Holm Bay (LHB) of East Antarctica, as one of the projects of the International Polar Year (IPY2007-2008). In austral summer in 2013 and 2014, several field stations by infrasound sensors were established along the eastern coast of LHB. In particular, two infrasound arrays with different diameters were deployed on the outcrop site at SYO as well as the second array on the continental ice sheet near the eastern coast of LHB. The infrasound arrays clearly detected temporal variations in frequency content and propagation direction during this period. Until now, by using the array configuration deployed at the LHB and other sites, moreover, identification of infrasound sources was tried to detect identical events. A number of infrasound sources were identified, many located north of the arrays. Many of the events had a predominant frequency content of a few Hz, higher than microbaroms from the ocean. Many of the sources were assumed to be cryoseismic origins; the ice-quakes associated with calving of glaciers, discharge of sea-ice, collision between sea-ice and icebergs around the LHB. Continuous measurements of infrasound in the Antarctic may serve as a proxy for monitoring the regional surface environment in terms of climate change at high southern latitudes.

Keywords: Infrasound, Seismic waves, Antarctica, Microbaroms, Icequake, Sensor array

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Locating earthquakes around Antarctica by using neural networks based on deep learning

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1. JAMSTEC, Center for Earth Information Science and Technology, 2. National Institute of Polar Research, 3. National Institute of Environmental Studies, 4. Japan Weather Service

Seismic activity inside Antarctic plate is low but there also exists unusual large earthquakes, such as 1998 Balleny Islands earthquake (Figures 1). The traditional method of locating earthquakes may not be adequate to those earthquakes, which occur where the seismic activity is low and seismic network is sparse. We propose a new approach combining numerically computed theoretical seismograms and deep machine learning. Theoretical seismograms for a realistic three-dimensional Earth model are calculated, and these seismograms are used to create snapshots of spatial images for seismic wave propagation at the surface of the Earth. Subsequently, these snapshots are used as a training dataset for a convolutional neural network. Neural networks are established for the determination of hypocentral parameters such as the epicenter, depth, origin time, and magnitude, and these networks are applied to actual seismograms to demonstrate the feasibility of this procedure to locate earthquakes. The advantages of using the proposed approach to locate earthquakes are as follows: The accuracy of determining the hypocenter parameters can be increased by accumulating theoretical seismograms for various locations and sizes of earthquakes as the learning dataset of deep machine learning; a three-dimensional Earth structure can be incorporated without additional computational cost to locate earthquakes; and seismologically rare but inevitable cases, such as earthquakes that occur where the seismic activity is low, can be included in the learning dataset.

Keywords: icequakes, hypocenter determination, synthetic seismograms

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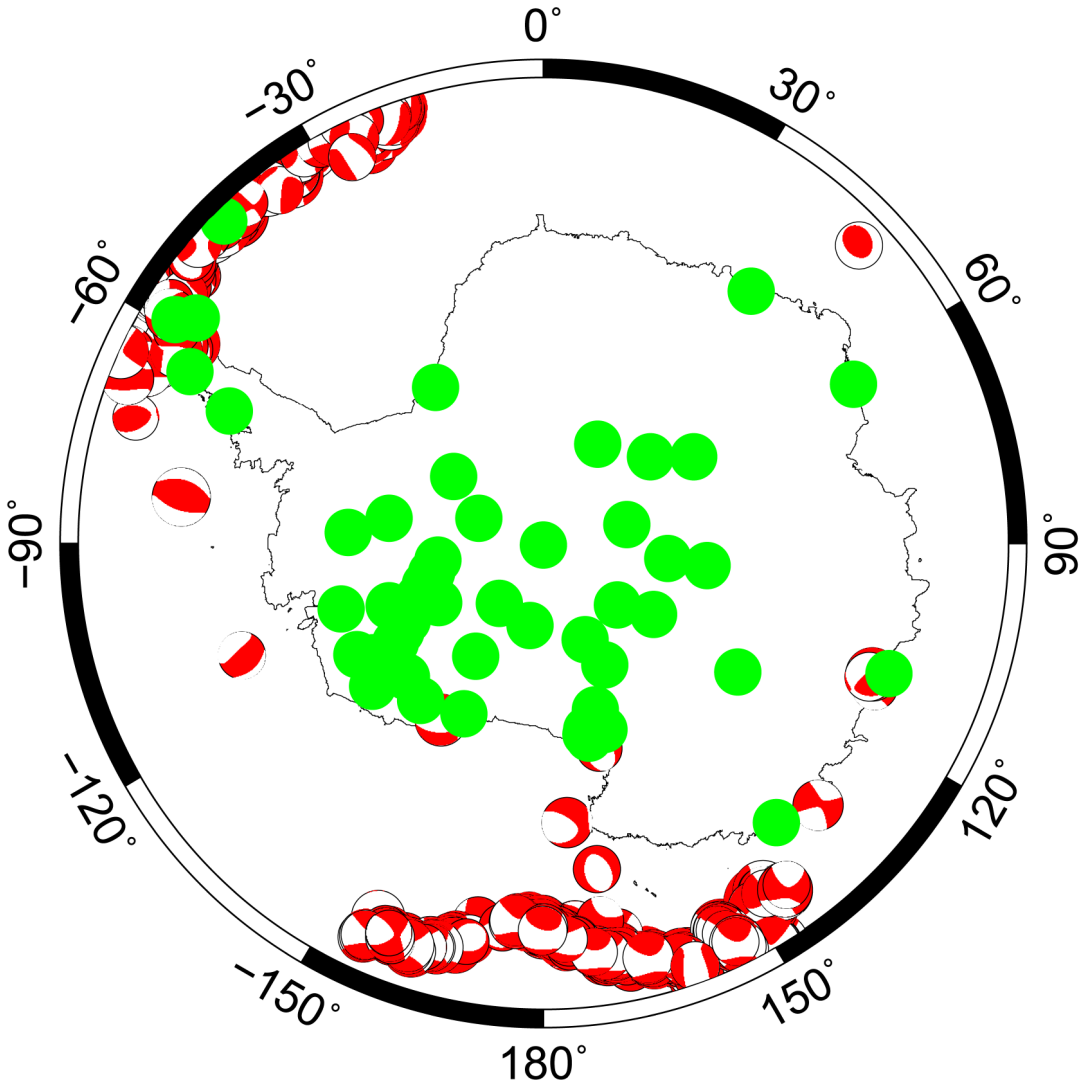
Earthquakes in Antarctica 1976 – 2018



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Ice dynamics inferred from the detection of icequake seismicity near the Princess Elisabeth base, eastern Dronning Maud Land, East-Antarctica

*Denis Lombardi, Guilhem Barruol[1], Lionel Benoit[2], Thierry Camelbeeck[3], Irina Gorodetskaya[4], Olivier Martin[5], Christophe Meynard[5], Christian Thom[5]

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In a world threatened by a “climate crisis”, the polar regions have now become the center of attention of everyone, and in particular of the science community which developed new tools to investigate the cryosphere evolution. Here, we use “cryoseismology” to investigate the dynamics of the East Antarctic ice sheet near the Belgian Princess Elisabeth base (PEA) in the eastern Dronning Maud Land. Filling a ca. 1000 km wide gap between Novo and Syowa and located 200 km from the coast, PEA provides an incredibly balanced situation to study both the inland plateau and the coastal margin of the continent. In this study, we present the results of three passive seismic experiments conducted over the past 10 years inland and at the coast, in the vicinity of PEA.

Inland, the permanent seismic station allows the detection of thousands of surface waves dominated icequakes. Their occurrence is anti-correlated with surface temperatures which are modulated by diurnal solar radiation variations in summer and by episodes of cold katabatic regimes in winter. The locations of these icequakes point towards nearby blue ice areas suggesting these events are related to thermal contraction of the blue ice areas, creating thin surface crevasses. These thermally induced icequakes can be regarded as a proxy for monitoring the thermal state of ablation surface. To study the ice-related seismicity on a wider region, five additional temporary broadband seismic stations separated by 25-30 km were deployed for a 3 month duration allowing for the detection of nearly one thousand seismic events, one third being reliably located. Most of these events occur in areas where the ice sheet meets the mountains outcrops at the edge of the polar plateau, at the initiation of narrow and thin outlet glaciers and characterized by intense ice deformation. Only one event cluster departs from this observation and hypothetical sliding of thick ice layer may be evoked.

At the coast, the dynamics of ice shelves is dominated by its shear margin and its interactions with the ocean. To monitor this sensitive zone, two temporary experiments were conducted with light weight seismic and GPS devices for about 1 month each. Our study indicated that this zone experiences periodic seismic activity resulting from surface crevassing during oceanic tide-induced flexure of the ice shelf. Furthermore, apparent fortnightly tide-modulated low-frequency, long-duration seismic events are originating near the ice shelf rifting characterizing the seaward front of an ice rise promontory. A basal origin for these events may be postulated explained by ocean water surge at each new spring tide triggering basal crevassing. In addition, other low-frequency seismic events are also found upstream of the grounding line and their clustered location and occurrence at low tide may suggest the presence of a subglacial topography such as an esker, a glacial deposit feature, as it has been suggested by a previous ground penetrating radar study. We acknowledge detection and monitoring of such seismicity may help identifying the characteristics of ice shelves sensitive to external forcing.

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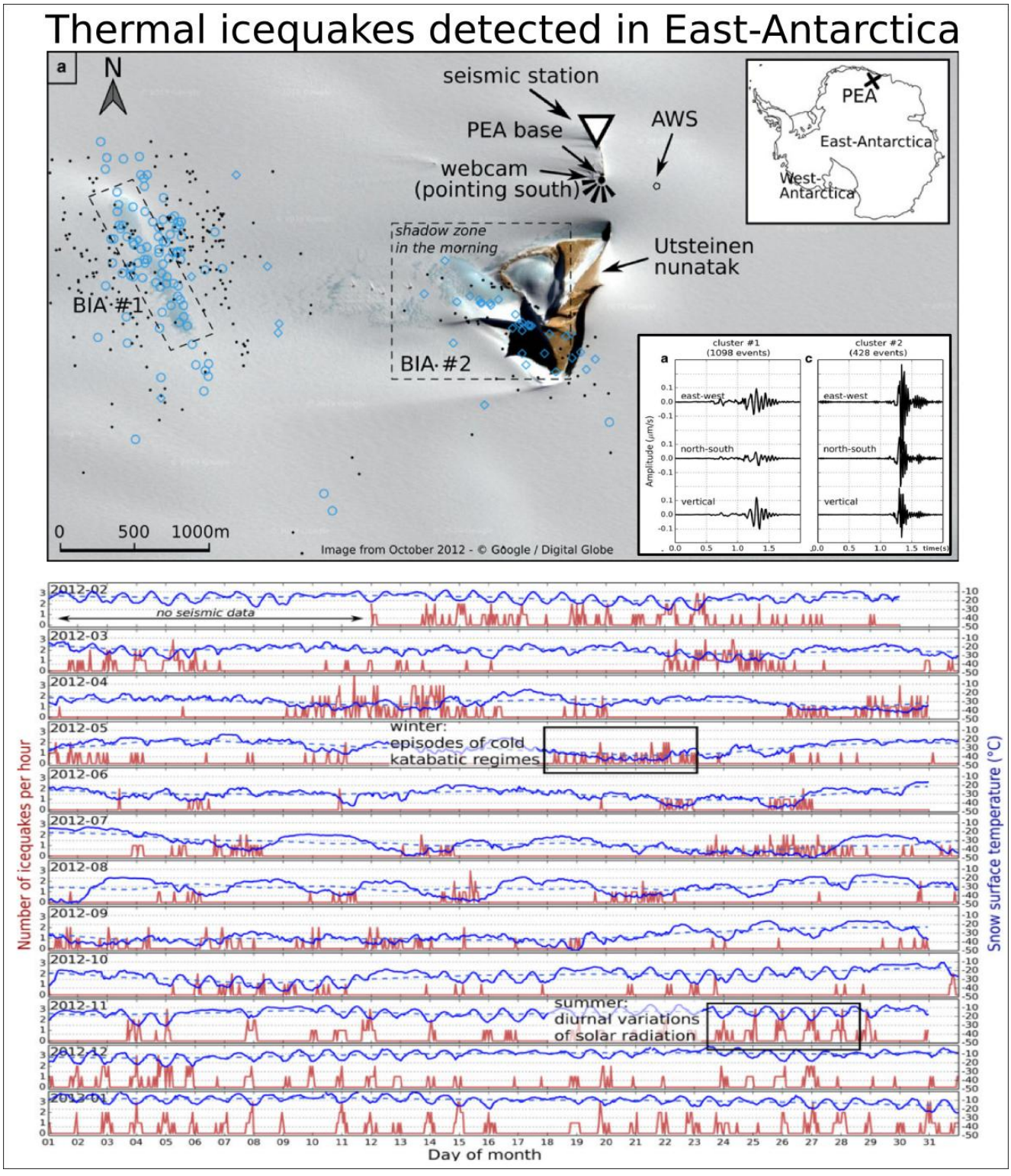
Keywords: cryoseismology, icequake, ice sheet, antarctica, ice shelf



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P-wave tomography beneath Greenland and surrounding regions

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1. Research Center for Prediction of Earthquakes and Volcanic Eruptions, Graduate School of Science, Tohoku University

Greenland is a stable land mass and has preserved ~4 billion years of Earth's history. In the vicinity of the island, there are the Mid-Atlantic Ridge, the Iceland and Jan Mayen hotspot volcanos, and a geothermal area of western Svalbard, which indicate importance of these regions for understanding the global-scale tectonics. The Greenland Ice Sheet Monitoring Network (GLISN), initiated in 2009, is an international project for seismic observation in these regions, and currently is operating 35 seismic stations. The purpose of this work is to study the detailed 3-D P-wave velocity (Vp) structure beneath Greenland and surrounding regions using the latest data recorded by the GLISN network. We use a method of regional tomography to investigate the 3-D crust and upper mantle structure, and apply a global tomography method to study the deep structure from the mantle-transition zone to the core-mantle boundary.

In the regional tomography, we used the method of Zhao et al. (1994, 2012) to simultaneously invert both P-wave arrival-time data from local events and P-wave relative travel-time residuals from teleseismic events recorded at 34 GLISN stations. We used 1,508 P-wave arrival time data from 934 local earthquakes extracted from the ISC-EHB catalog. For teleseismic events, we integrated two sets of arrival-time data. The first data set was selected from the EHB catalog, which includes 35,871 arrival times from 5,399 teleseismic events. The second data set was newly picked from seismograms by ourselves using the cross-correlation technique (Liu & Zhao, 2016), which includes 7,573 relative travel-time residuals from 347 events.

In the global tomography, we used a multi-scale tomography method (Zhao et al., 2017), which sets 3-D grid nodes densely in the target area. We inverted ~5.8 million arrival times of P, pP and PP waves from 16,257 earthquakes extracted from the EHB catalog, which were recorded at 12,549 stations in the world. Since the grid intervals in the longitudinal direction depend on the latitude in the polar regions, we applied the coordinate transformation that moves the target area to the equator in both the regional and global tomographic studies.

Our results reveal the following features.

(1) A remarkable low-Vp anomaly elongated in the NW-SE direction is revealed at depths <= 250 km beneath the center of Greenland, which may reflect the residual heat when the plate with Greenland passed over the Iceland plume at ~80–20 Ma. Although previous studies have suggested this feature, our results first show that the low-Vp zone is within the Greenlandic lithosphere and its spatial distribution agrees very well with the high crustal heat-flow regions.

(2) The Iceland plume has been considered to be a single plume, but it could be a composite of a plume rising from a depth of 1,500 km beneath Iceland and a plume rising from the core-mantle boundary beneath Greenland. Here the latter one is called the "Greenland plume". We deem that, after the two plumes are joined together in the mantle transition zone, they supply magmas to the active volcanoes in Iceland, Jan Mayen, and Svalbard.

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(3) A high-Vp anomaly is imaged at depths <= 500 km off the northeast coast of Greenland. Iceland and Jan Mayen volcanoes are located south of the high-Vp anomaly, while Svalbard is located to the north. There is no volcano in Svalbard but it exhibits a high heat flow. The high-Vp body is also located at the bend of the Mid-Atlantic Ridge, suggesting that it might be an obstacle for plume flow to provide sufficient magma to Svalbard, and it might have caused changes in the plate-spreading direction at the Mid-Atlantic Ridge.

Keywords: Greenland, Seismic tomography, Iceland plume

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[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-TT Technology & Techniques

[M-TT49] GEOSCIENTIFIC APPLICATIONS OF HIGH-DEFINITION TOPOGRAPHY AND GEOPHYSICAL DATA IN THE ANTHROPOCENE

convener:Yuichi S. Hayakawa(Faculty of Environmental Earth Science, Hokkaido University), Shigekazu Kusumoto(Graduate School of Science and Engineering for Research, University of Toyama), Christopher A Gomez(Kobe University Faculty of Maritime Sciences Volcanic Risk at Sea Research Group)

Recent technical developments have enabled us to acquire high-definition topographic and geophysical data for geoscientific research, including land surface processes, subsurface structures, submarine and aerial environments, and geo-ecological interactions. Such high-definition or high-resolution data are particularly useful for studies on relatively short-term, i.e., decadal to millennial time scales, and for future predictions using numerical modelings. In this session, we expect submissions on topics challenging the issues in the Anthropocene, the most recent geological era of the Earth considerably affected by human activities. A range of topics would fit the session framework, such as theoretical works, improvements in the data acquisition, extensive data preservation and archiving, pre- and post-processing, statistical analysis, physical modeling, and numerical simulation for any kind of geoscientific research in the Anthropocene. The methodological approaches may include, but not limited to, laser scanning, SfM-MVS photogrammetry, GNSS precise positioning, SAR interferometry, multi-beam sonar, ground-penetrating radar, geomagnetic and electromagnetic sensors, based on terrestrial (fixed or mobile) and aerial (UAV or manned airborne) platforms.

Introduction

[MTT49-01] Assessing topographical change of peatland using drones

*Kotaro Iizuka[1], Tsuyoshi Kato[2], Asep Andi Yusup[2], Sisva Silsigia[2], Alifia Yuni Soufiningrum[2] (1.Center for Spatial Information Science, University of Tokyo, 2.PT Mayangkara Tanaman Industri / PT Wana Subur Lestari)

[MTT49-02] Monitoring of topographic changes using RTK-UAV in landslide area caused by 2018 Hokkaido Eastern Iburi Earthquake

★Invited Papers

*Yasutaka Nakata[1], Masato Hayamizu[1], Satoshi Hasui[1], Hajime Sato[1] (1.Hokkaido Research Organization, Forest Research Institute, Forest Environment Division)

[MTT49-03] Comparison of LiDAR data using three platforms (Aerial-LiDAR, UAV-LiDAR, Terrestrial-LiDAR) in evergreen coniferous forest

*Ebina Masuto[1], Akira Kato[2], Fumio Takeuchi[1], Shouichi Kondou[3] (1.Forestry Research Institute, Hokkaido Research Organization, 2.Graduate School of Horticulture, Chiba University, 3.Industrial Research Institute, Hokkaido Research Organization)

[MTT49-04] Ground Penetrating Radar Imaging of Pro-glacial Landforms in the upper Waimakariri River (New Zealand)

*Christopher A Gomez[1], Heather Purdie, Justin Harrison, Paul Bealing, Nicholas Key (1.Kobe University Faculty of Maritime Sediment Hazards and Disaster Risk Laboratory)

[MTT49-05] A New Method for Gully Detection on High-Resolution Digital Elevation Models

*Jun-Ping Zhao[1], Shen Yu Hsiao[1] (1.National Chung Hsing University)

Discussion

Discussion

Assessing topographical change of peatland using drones

*Kotaro Iizuka[1], Tsuyoshi Kato[2], Asep Andi Yusup[2], Sisva Silsigia[2], Alifia Yuni Soufiningrum[2]

1. Center for Spatial Information Science, University of Tokyo, 2. PT Mayangkara Tanaman Industri / PT Wana Subur Lestari

Peatland ecosystem store large amounts of soil carbon and constitute an important component of the global carbon cycle, which not only plays a role in the storage of carbon in forest and peat, but also in controlling water resources and in preserving bio-resources and biodiversity. In the past decade, the use and development of peatland in Indonesia have been more extensive because of conversion of peatland to agricultural land. The drainage of peatlands without any well-planned management causes irreversible lowering of the surface (subsidence) as a consequence of peat shrinkage and biological oxidation. The conventional approaches utilize such as poles for observing the subsidence rate of the peat, which lacks in knowledge for the spatial distribution of the subsidizing event. This work focus on utilizing the emerging trends of the Unmanned Aerial Vehicles (UAVs) for collecting high definition terrain information of the peat environment through the Structure from Motion photogrammetry method. The observed terrain data was compared with the past data to see the topographical changes of the peats. The results represents the heterogeneity of the subsidence at a spatial scale. The mean subsidence was shown -26 cm, although there are fluctuations in the phenomenon. The amount of CO_2 possibly emitted from the subsiding event is computed and we will further investigate its trend together with other relating data to understand the characteristics of the subsiding areas.

Keywords: UAV, Drone, Remote Sensing, Peatland, Indonesia, Digital Elevation Model

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Monitoring of topographic changes using RTK-UAV in landslide area caused by 2018 Hokkaido Eastern Iburi Earthquake

*Yasutaka Nakata[1], Masato Hayamizu[1], Satoshi Hasui[1], Hajime Sato[1]

1. Hokkaido Research Organization, Forest Research Institute, Forest Environment Division

The Hokkaido Eastern Iburi Earthquake occurred in September 2018, causing a large-scale landslides in about 4,300 ha of the forest area, which is currently in need of immediate forest restoration. However, forest restoration of large-scale landslide areas is a field lacking in knowledge of applicable methods. On the slopes of the landslide area, soil erosion due to rainfall, freezing, and thawing is a driving force moving the surface soil layer of several tens of centimeters depth, inhibiting seed settlement, germination, and growth of seedlings. Therefore, it is necessary to quickly and accurately assess the topographic changes of the landslide surface, which is the base for plant growth. We started monitoring topographic changes using real-time kinematic unmanned aerial vehicles (RTK-UAV) and structure-from-motion multi-view stereo (SfM-MVS) photogrammetry in April 2019.
First, we investigated topographic changes in a landslide area caused by the Hokkaido Eastern Iburi Earthquake in 2018. To verify our measurement accuracy, the position coordinates of 11 validation points in the 4-ha assessment area were obtained using a ZED-F9P, dual-frequency RTK global navigation satellite system (GNSS) on March 12th, 2019. The maximum height difference between verification points was approximately 28 m. We moreover extracted position coordinates of validation points from a digital surface model (DSM), and an orthomosaic image was created from aerial images obtained by the RTK-UAV. Subsequently, the position coordinates of validation points were compared. The analysis of topographic changes was performed on two DSMs created from the aerial images acquired on March 12th and April 23rd, 2019.
The average position between each validation point and the model was 0.060 m~0.064 m in both horizontal and vertical directions. The maximum vertical error was 0.108m. The result of topographical changes analysis indicates a change of -0.1 m to +0.1 in 86.86% of the total assessment area. A change of -0.5 m to -0.1 m was the next most frequent at 11.36%. In particular, the erosion area was confirmed at the boundary between the forest and the landslide area, as well as around the channels. These results demonstrate that monitoring using RTK-UAV the dynamics and stability of surface soil is important in the forest and the landslide area, where it is difficult to set ground control points.

Keywords: Hokkaido Eastern Iburi Earthquake, RTK-UAV, SfM-MVS, Landslide, Monitoring

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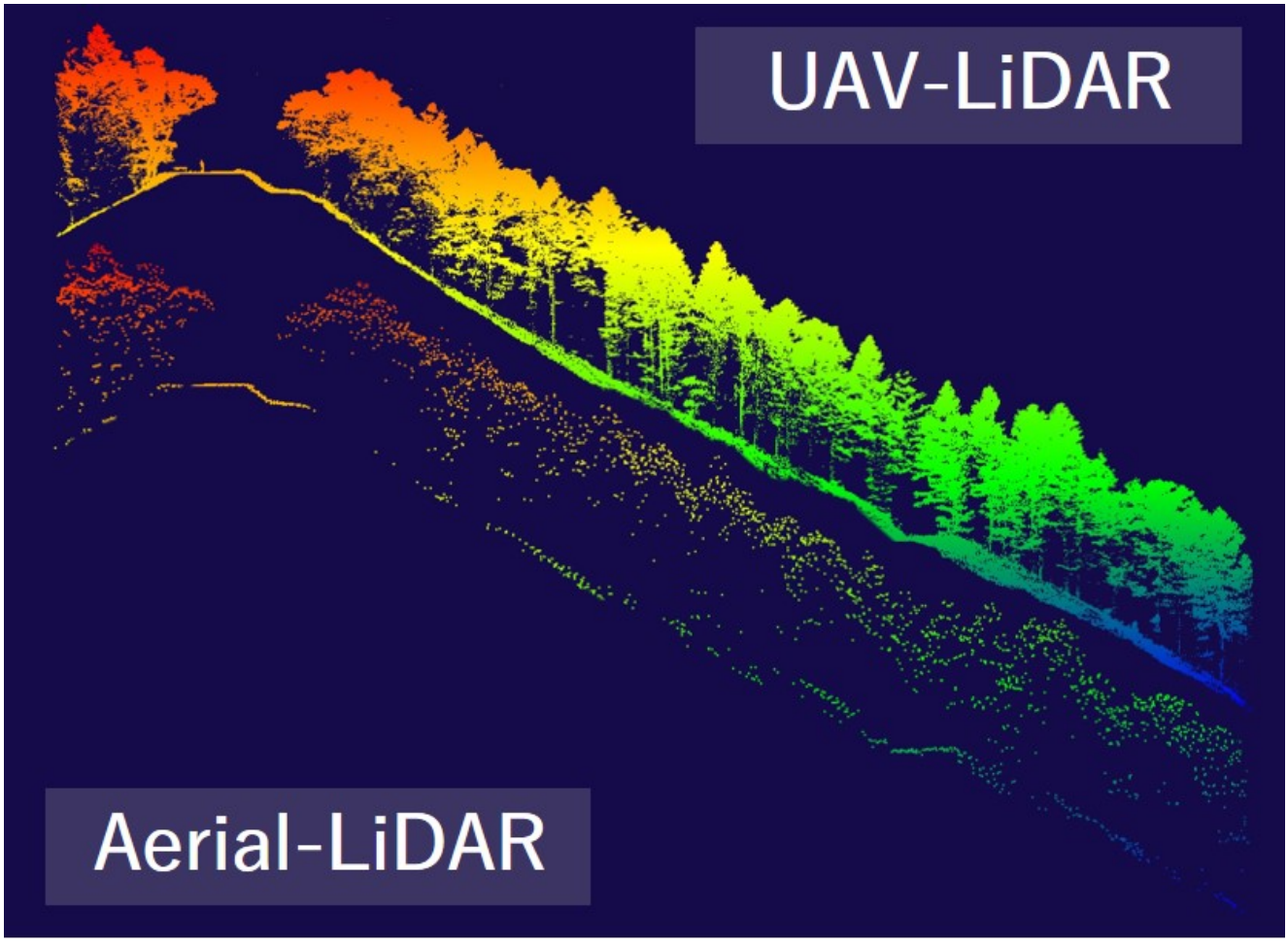
Comparison of LiDAR data using three platforms (Aerial-LiDAR, UAV-LiDAR, Terrestrial-LiDAR) in evergreen coniferous forest

*Ebina Masuto[1], Akira Kato[2], Fumio Takeuchi[1], Shouichi Kondou[3]

1. Forestry Research Institute, Hokkaido Research Organization, 2. Graduate School of Horticulture, Chiba University, 3. Industrial Research Institute, Hokkaido Research Organization

LIDAR based forest measurement becomes popular in forest inventory field. LIDAR provides three-dimensional data of terrain and vegetation by aerial and terrestrial platforms. The data has been used to estimate amount of biomass from above ground data and design forest roads from terrain data created from ground data. In this study, we compare three different platforms LiDAR data acquired over evergreen coniferous forest in Urahorocho, Hokkaido. The three platforms are airborne-, UAV-, and terrestrial-LiDAR. The tree height measurement was influenced by the data quality of terrain and canopy surface model created from the three different platforms. The result shows the differences reflected by different point density of terrain and vegetation. The UAV-LIDAR provides high quality point density and gives more solid model improves an accuracy for tree species classification using deep learning and reduces computational cost to estimate accurate tree height measurement. The higher point density from UAV has potential to improve data collection efficiency of forest inventory.

Keywords: LiDAR, Evergreen coniferous forest, Terrain, Tree height



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Ground Penetrating Radar Imaging of Pro-glacial Landforms in the upper Waimakariri River (New Zealand)

*Christopher A Gomez[1], Heather Purdie, Justin Harrison, Paul Bealing, Nicholas Key

1. Kobe University Faculty of Maritime Sediment Hazards and Disaster Risk Laboratory

The Waimakariri River catchment is the product of Quaternary glaciation and deglaciations as attested by the geomorphologic features left during and after the last glaciations in the Waimakariri River bend, behind the Cass basin. Several of those features that now connect the braided river floodplain and the mountain slopes have the shapes of truncated fans, but the top surface displays slopes that can also apparent them to paleo-terraces or are the product of reorganization of original features.
In the absence of topographically determining features, the question of understanding the origin and formation of those landforms remains unanswered. For this purpose, the authors have used a series of Ground Penetrating Radar (GPR) investigations across the now vegetated floodplain and the geomorphologic features creating the contact-areas with the slopes. The GPR used for the present investigation is the PulseEkko Pro mounted with a set of 50 Mhz, 100 Mhz and 500 Mhz antennas, depending on the locations.
The transects have revealed that the visibly similar features that make the connections between the valley floor and the slopes were actually a set of variable elements that encompassed (a) mixture of sediments without any apparent structure to (b) horizontally and sub-horizontally structured GPR layers, with various degrees of structure. The topographically lower locations, close to the present Waimakariri River level presented GPR structures that present the patterns of foresets and backsets typically of riverine environments.
In details, the higher-subhorizontal features that were supposed to be lateral fans are actually a mixture of elements, but interestingly the surface slopes do not correspond to the subsurface layers, suggesting that the layers must have been truncated to recreate smooth and sub-horizontal features, while the original deposits must have been deposit.
In the discussion, this set of data would point towards a "small" readvance of a glacier on top of frozen deposits, that were scalped on top, but without modifying the internal structure of the deposits. These process then left the place to more "water-borne" processes, that could be evidenced from surface rills in the topography and subsurface layers showing finer-material with a structure typical of small-scale streams.

Keywords: Ground Penetrating Radar, Waimakariri River, New Zealand, Pro-glacial geomorphology

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A New Method for Gully Detection on High-Resolution Digital Elevation Models

*Jun-Ping Zhao[1], Shen Yu Hsiao[1]

1. National Chung Hsing University

This research focuses on detecting exact gully locations on high-resolution terrains using a new method -- Gully Identifying Method (GIM). The high-resolution terrains tested in this study include: (1) a simulated Digital Elevation Model (DEM), and (2) a real DEM produced by airborne LiDAR system. The spatial resolutions of two DEMs are both 1 m. The study area is located at the watershed of Deji Reservoir, Taichung, Taiwan. The GIM is used to test the ability of detecting gullies both on the simulated and real DEMs, and the results are compared to those from the traditional method --Topographic Position Index (TPI). Both results are verified with aerial photographs, remote sensing images, red-relief maps and field inspections. This research shows that the GIM is more advantageous than the TPI in gully detection.

Keywords: Gully-Identifying Method, Topographic Position Index, Gully, LiDAR

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[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-TT Technology & Techniques

[M-TT50] Distributed Fiber Optic Sensing for Geophysical Applications

convener:Matthew Becker(California State University Long Beach), Xiangfang Zeng(Institute of Geodesy and Geophysics, Chinese Academy of Sciences), Ziqiu Xue(Research Institute of Innovative Tech for the Earth), Herbert F Wang(University of Wisconsin Madison)

Distributed fiber optic sensing has generated tremendous excitement with applications including seismology, seismic imaging, hydrology, petroleum development, carbon dioxide sequestration, and geothermal energy. Distributed Temperature Sensing (DTS) became widely accessible about a decade ago. DTS can measure temperature along a fiber optic cable at sub-meter intervals, over distances of kilometers, and at sampling frequencies of 0.1 Hz or less. Distributed Acoustic Sensing (DAS) is a more nascent technology that is only now being tested for geophysical applications. DAS can acquire dynamic strain at sub-meter intervals, over distances of kilometers, and at sampling frequencies of 100 kHz or less. Both technologies can use standard telecommunication fiber optic cables for measurement. DAS, for example, has been used to sense earthquake movements in unused (dark) buried fiber optic communication networks. We invite presentations that discuss novel applications of distributed fiber optic sensing, interpretation of results of monitoring, and advancements in processing of data streams. This session will bring together practitioners from many disciplines to discuss opportunities, share experience, and suggest solutions to technical challenges.

[MTT50-01] On the broadband instrument response of fiber-optic DAS arrays

★Invited Papers

*Nate Lindsey[1,2], Horst Rademacher[3], Jonathan Ajo-Franklin[4,2] (1.Stanford University, 2.Lawrence Berkeley National Laboratory, 3.University of California, Berkeley, 4.Rice University)

[MTT50-02] Importance of using optimum gauge length for DAS measurement to observe geophysical events

*Tsunehisa KIMURA[1] (1.Schlumberger)

[MTT50-03] Surface-wave dispersion spectrum inversion method applied to Love and Rayleigh waves recorded by DAS

*Zhenghong Song[1,2], Xiangfang Zeng[1], Clifford Thurber[3] (1.State Key Laboratory of Geodesy and Earth's Dynamics, Innovation Academy for Precision Measurement Science and Technology, Chinese Academy of Science, 2.School of Earth and Space Sciences, University of Science and Technology of China, 3.Department of Geoscience, University of Wisconsin-Madison)

[MTT50-04] Recent Advances in Fiber-optic Distributed Acoustic Sensor (DAS) Based on Time-gated Digital Optical Frequency Domain Reflectometry

★Invited Papers

*Qingwen Liu[1], Zuyuan He[1], Dian Chen[1] (1.Shanghai Jiao Tong University)

[MTT50-05] A Field Test in Preparation for Long-Range Distributed Acoustic Sensing in Subsea Applications

*Martin Horst Karrenbach[1], Carson Laing[1] (1.OptaSense Inc.)

[MTT50-06] Hydroacoustic Field Lake Trial Using High Performance Fiber Distributed Acoustic Sensing System

*Hao Li[1], Cunzheng Fan[1], Tao Liu[1], Zhijun Yan[1], Deming Liu[1], Qizhen Sun[1] (1.Huazhong University of Science and Technology, Wuhan, Hubei, China)

On the broadband instrument response of fiber-optic DAS arrays

*Nate Lindsey[1,2], Horst Rademacher[3], Jonathan Ajo-Franklin[4,2]

1. Stanford University, 2. Lawrence Berkeley National Laboratory, 3. University of California, Berkeley, 4. Rice University

Distributed Acoustic Sensing,DAS, is a novel tool in array seismology that measures the phase of backscattered laser pulses traveling in a fiber-optic cable, and relates this measurement to the axial strain induced on the cable by a propagating seismic wavefield. Combining DAS with telecommunications optical fiber networks has begun to address a range of earth science questions where cost and field logistics have historically hindered observations. Unlike classic inertial seismometers, DAS instrument response is presently unquantified. This topic includes a variable sensing element, the fiber, including packaging and installation, which changes between experiments. Ignoring this element, one DAS record should approximate a fixed-length strain gauge, which exactly measures Earth's motion down to quasi-static frequencies relevant to geodesy. In this paper, we test this hypothesis using seismological observations of teleseismic earthquakes and microseism noise spanning the 1 to 120 s period range. We use a commercial DAS interrogator unit connected to an optical fiber previously used for telecommunication and a colocated broadband seismometer to estimate the DAS transfer function. We find a direct correspondence with actual ground motion from 10-120 s. At shorter periods, 1-10 s, DAS amplitude response is enhanced by 3-11 dB. Phase response is flat over this range of periods. We interpret the recovered DAS response function in terms of hypothesized fiber coupling and photonic effects. We propose this calibration methodology for future DAS experiments where seismic amplitude information is desired.

Keywords: fiber-optic, distributed acoustic sensing, instrumentation

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Importance of using optimum gauge length for DAS measurement to observe geophysical events

*Tsunehisa KIMURA[1]

1. Schlumberger

DAS (Distributed Acoustic Sensing) technology has been introduced to the oil and gas industry since the beginning of the century for the purpose of monitoring pipelines and detecting intruders. However, its application to geophysical exploration only began around 2011. Conventional DAS are able to measure measures the change in the amplitude of backscatter, but it has been confirmed that there is a problem with linearity[1)]. The latest optical fiber sensing technology which uses differential phase data named "heterodyne Distributed Vibration Sensing" (hDVS) solved this problem which led to its use from around 2014. This system can record high-quality seismic data, including the Vertical Seismic Profile (VSP)[2)]. Three-dimensional imaging can be performed using the 3DVSP method, and it has already come to be used in Japan[3)]. It has been reported in recent years at occasions such as SEG and the Seismological Society of Japan conferences, that the natural earthquake data recorded using optical fiber and hDVS have been confirmed to be similar to data recorded using seismometers[4) 5)].

There are some differences between DAS and conventional sensors. One significant difference is that DAS provides distributed measurement, while the spatial resolution of the DAS data is determined by the gauge length (GL). GL is a measurement distance, equivalent to moving average filter.

For conventional DAS system, GL is set in an optical domain, so that one system provides only one GL value or maybe few variations by changing laser pulse width. On the other hand, hDVS does phase differentiation over a GL in digital domain instead of optical domain, allowing different or optimal GL processing after data acquisition, which is an ability that is unique to hDVS amongst the available DAS techniques.

When GL becomes a parameter, the bigger the GL gains, the higher the SNR of the data will be, but along with sacrificing the resolution generally. When seismic waves were considered using Ricker wavelet with a center frequency of 40 Hz and a velocity of 1,000 m/s, the equation below was obtained[6)].

GL_{opt} = ratio V / f_p

Where ratio is GL/spatial wavelength with values of between 0.4 and 0.54 as optimum value considering SNR and resolution, V is the velocity, and f_p is the peak frequency. This means that changing GL from one value to the other value with significant difference, the hDVS data would show or enhance different events in the same data set.

From 2017, demonstration tests of hDVS including earthquake observations using various different optical fiber cables have been conducted in Japan. Some data sets contained different Geophysical events recorded, so that event separation was performed using different GL against raw data. Different images were obtained from the same data set enhancing different events.

For DAS data acquisition, it is important to select optimal GL for the event expected prior to acquire the data, which would be challenging in most of cases.

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Keywords: DAS, hDVS, optical fiber, gauge length, seismic monitoring, event separation

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Surface-wave dispersion spectrum inversion method applied to Love and Rayleigh waves recorded by DAS

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Recently, a new seismic acquisition technique, Distributed Acoustic Sensing (DAS), has been applied to shallow seismic structure imaging, providing dense spatial sampling at a relatively low cost. DAS on a standard fiber-optic cable mostly records axial dynamic strain, which makes it difficult to separate Rayleigh and Love wavefields via particle motion as in the case of a three-component geophone record. As a result, the mixed Rayleigh and Love wave signals cannot be used in the surface-wave dispersion inversion method. Therefore, it is often ensured that the source and the cable are in-line and only Rayleigh wave dispersion is used, which limits constraints on structure and model resolution.
We propose to invert surface-wave dispersion spectra instead of dispersion curves. This inversion method can use mixed Rayleigh and Love waves recorded by DAS, even when the source and receiver array are not aligned. The new method not only improves the flexibility of the acquisition system design, but the Love wave data also provide additional constraints on the inversion. Our method is applied to active source and ambient noise datasets acquired at a geothermal site, providing consistent results for different datasets and acquisition geometries. The sensitivity of the data to layer thickness, density, and Vp are also discussed. Our method extends the usefulness of DAS datasets and improves data constraints that help to construct higher resolution models in practice.

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Recent Advances in Fiber-optic Distributed Acoustic Sensor (DAS) Based on Time-gated Digital Optical Frequency Domain Reflectometry

*Qingwen Liu[1], Zuyuan He[1], Dian Chen[1]

1. Shanghai Jiao Tong University

The fiber-optic distributed acoustic sensor (DAS) can detect vibrations along the whole sensing fiber and quantitatively retrieve the amplitude, frequency and phase information. To overcome the trade-off between spatial resolution and sensing distance in the common phase-sensitive optical time domain reflectometry technology, a novel DAS based on time-gated digital optical frequency domain reflectometry (TGD-OFDR) is developed. The recent advances in high performance TGD-OFDR based DAS are reviewed, including the fading-free phase demodulation method with enhanced spatial resolution, response bandwidth, long sensing distance, and the intensity demodulation method using non-matched filter and interference pattern. The field experiment of pipeline leak detection is also introduced.

Keywords: fiber-optic sensor, distributed acoustic sensor, time-gated digital optical frequency domain reflectometry

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A Field Test in Preparation for Long-Range Distributed Acoustic Sensing in Subsea Applications

*Martin Horst Karrenbach[1], Carson Laing[1]

1. OptaSense Inc.

Over the past several years distributed fiber-optic sensing (DAS) has been to a variety of seismic and seismological applications. Many particular optical and acquisition parameters can be optimized but practically the ultimate signal quality is determined by a combination of effective sensing extent and required sensitivity. Industrial seismic applications perform measurements on distances on the order of a few km with signal frequencies as high as many kHz, while seismological applications tend to measure signals on the order of 40-50 km distance with lower frequency content.

Due to having many active or passive optical components subsea installations are often non-optimal for sensing purposes. A series of built-in losses at connectors, splices, penetrators, as well as other optical components, leads to typical light propagation loss-budgets of 8-11 dB. For seismological applications these budgets are suitable for the larger gauge lengths due to the lower frequency waves of interest. However, for higher frequency applications, smaller gauge lengths and pulse widths are required, while still overcoming the light propagation losses
To demonstrate that we can properly interrogate, we acquired field test data on-shore utilizing boreholes and surface layouts with a 5 km section of fiber after a 30 km lossy lead-ins, which is a typical scenario for industrial seismic applications. The data acquisition utilized standard telecom and borehole fiber cables permanently deployed at an on-shore field site. A low-energy vibrator with sweep frequencies from 8-150 Hz was used. High SNR seismic wave fields containing direct arrivals, refractions and reflections in all active sensing sections. The results show that state-of-the-art DAS interrogators can be used efficiently in a practical field setting for various subsea sensing applications. Future applications include long-reach subsea surface and borehole-based sensing for seismic imaging purposes, and opportunistic interrogation of active or abandoned boreholes.

Keywords: Distributed Fiber-optic Sensing, Seismic, Subsea

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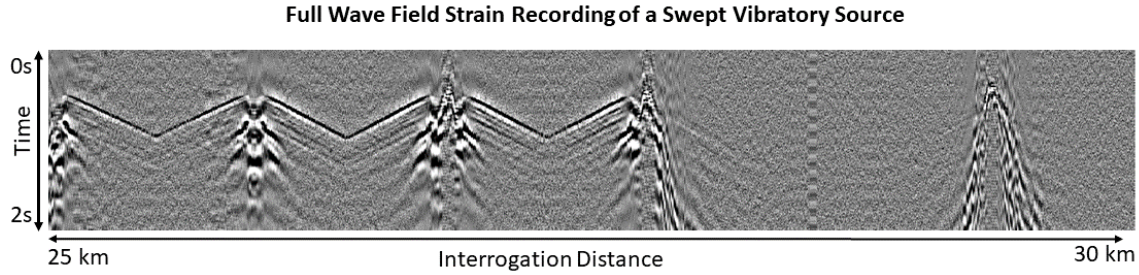

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Hydroacoustic Field Lake Trial Using High Performance Fiber Distributed Acoustic Sensing System

*Hao Li[1], Cunzheng Fan[1], Tao Liu[1], Zhijun Yan[1], Deming Liu[1], Qizhen Sun[1]

1. Huazhong University of Science and Technology, Wuhan, Hubei, China

The exploration of marine oil resources has gained great attentions in recent years. Among several methods, the acoustic detection is a relatively common method for offshore oil logging. Consequently, it is important to set up underwater acoustic sensors with high reliability and sensitivity. Owing to the advantages of great convenience, low cost and distributed detection, fiber distributed acoustic sensing (DAS) has been served as an attractive means for large-scale detection. In this work, a high sensitive fiber DAS system based on the distributed microstructured optical fiber (DMOF) and coherent detection is proposed to perform the hydroacoustic sensing. The calibration experiment of acoustic pressure sensitivity is conducted, in which the fiber is demonstrated with a high sensitivity of -140.22dB (*re* 1rad/ μPa). Besides, the hydroacoustic field lake trial is carried out successfully, including source directivity tracking, long-distance direct wave test and underwater target location, which fully indicated that our fiber DAS has great potential for applications in the underwater hydrophone network.

Several experiments are performed to demonstrate the underwater sensing performance of our fiber DAS. As illustrated in Fig. 1(a), the acoustic pressure sensitivity of -140.22dB (*re* 1rad/ μPa) is linear fitted through the calibration between the standard hydrophone and optical fiber. Then the lake trial is carried out to verify the underwater performance of our DAS system. In the field test, the direct waves respectively emitted by monopole and dipole sources are detected successfully, which verifies the practicability of our system. Specifically, the hydroacoustic signal of the monopole source as far as 2.3km away can be detected, demonstrating an excellent sensitivity of the DAS system. And the directionality of the hydroacoustic source is also tested, which appears a good “8” shape as shown in Figs. 1(c) and 1(d). Moreover, the direct wave and reflected wave can be obtained simultaneously. As illustrated in Fig. 1(e), by calculating the time difference between the direct wave and reflected wave, the location of the underwater target can be obtained. As the hydroacoustic velocity is 1500m/s, the distance between the reflector and fiber sensor is calculated to be 54.75m, which is basically consistent with the actual installation (55m). Besides, the propagation of the hydroacoustic signal is tracked by six fiber sensors composed of different DMOF segments as shown in Fig. 1(f), which demonstrates the distributed detection ability of the sensor system. Benefiting from the convenient deployment, high sensitivity and large-scale detection, our fiber DAS system could be further applied in the area of underwater geological and resource exploration, such as the remote cross-hole seismic tomography.

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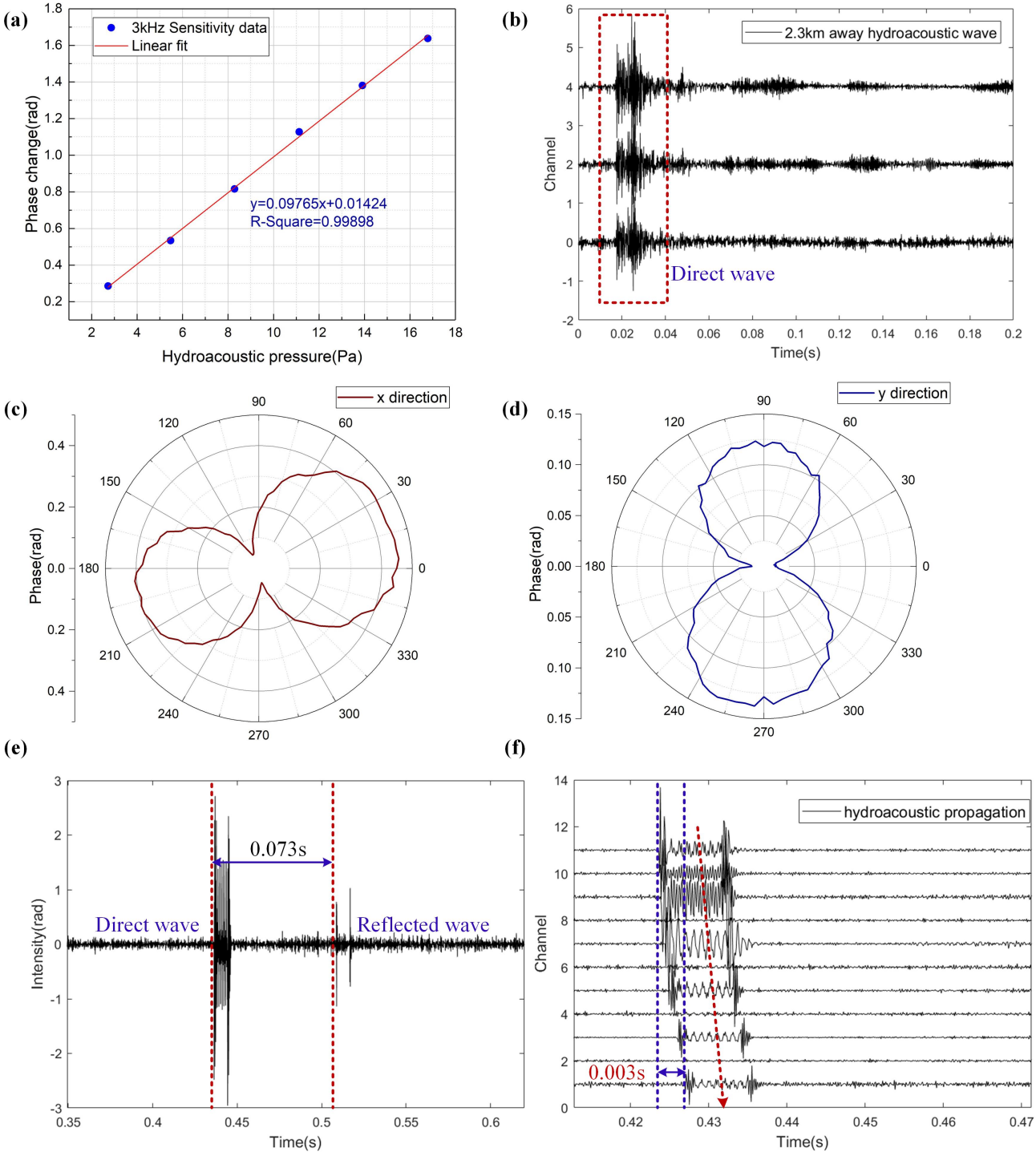

Fig.1. Experimental results; (a). Sensitivity at 3kHz; (b). 2.3km away direct wave; (c). X direction tracking of dipole source; (d). Y direction tracking of dipole source; (e). Direct wave and reflected wave detected by the fiber sensor; (f). Distributed detection of hydroacoustic wave.

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[E] Oral | M (Multidisciplinary and Interdisciplinary)：M-ZZ Others

[M-ZZ53] Availability of earth science data in renewable energy field

convener:Hideaki Ohtake(National Institute of Advanced Industrial Science and Technology), Fumichika Uno(Nihon University, College of Humanities and Sciences), Teruhisa Shimada(Graduate School of Science and Technology, Hirosaki University), Daisuke Nohara(Central Research Institute of Electric Power Industry)

Renewable energy penetration is increasing dramatically in the world. Renewable energy power generations have become a strong presence in grid operations. However, it is a challenge for renewable energy to be stable power sources due in part to natural variability of renewable energy and its uneven distribution. For effective use of renewable energy, a combinational use of various power resources and energy storage technologies (e.g., pumped-storage power generation, storage battery system, electric vehicles) should be desired. Therefore, we need to understand the amount of renewable resources, causes of variation, and the predictability of power output. Then, observation and forecast information from earth science field should be analyzed and applied to power energy field to achieve easy use of earth science databases.
 Recently, observation databases from remote sensing technology and/or forecasts from numerical models have become essential for both renewable energy and electric power system fields. Impacts of both earth science data and optimization are essential to economic evaluation of grid operations.
This proposed session needs your presentation from the whole of renewable energy fields (such as, wind power, solar power, geothermal power, tidal power, wave power and biomass power generations). Our goal of this session is to exchange views with various researchers between renewable energy field and earth science field (e.g., usage-trends of earth science datasets for renewable energy field, earth science datasets availability, integrated studies, renewable energy resources in future climate system, and a request from renewable energy field to earth science field).
The proposed session features contribution of general interest within earth sciences community.

[MZZ53-01] Study on effective use of incidental gas from hot spring waters: a case study in Toyotomi town, Hokkaido

Takumi Takahashi[2], *Masahiko Fujii[1,2], Maki Ikegami[3] (1.Faculty of Environmental Earth Science, Hokkaido University, 2.Graduate School of Environmental Science, Hokkaido University, 3.Hokkaido University Sustainable Campus Management Office)

[MZZ53-02] **Investigation of Offshore Wind Climate in the Southeast Asia**

*Inovasita Alifdini[1], Teruhisa Shimada [1], Anindya Wirasatriya [2] (1.Graduate School of Science and Technology, Hirosaki University, Japan, 2.Department of Oceanography, Faculty of Fisheries and Marine Sciences, Diponegoro University, Indonesia)

[MZZ53-03] A webGIS-based application of solar radiation data and related information

*Ken T. Murata[1], Atsushi Higuchi[2], Hideaki Takenaka[3], Yohei Yamaguchi[4], Shinya Yoshizawa[5], Takashi Nakajima[6] (1.National Institute of Information and Communications Technology, 2.Center for Environmental Remote Sensing (CEReS), Chiba University, 3.JAXA/EORC, 4.Osaka University, 5.Waseda University, 6.Research and Information Center, Tokai University)

[MZZ53-04] Harmonised global datasets of wind and solar farm locations and power

*Sebastian Lionel Dunnett[1], Alessandro Sorichetta[2,1], Gail Taylor[3], Felix Eigenbrod[1] (1.University of Southampton, 2.WorldPop, 3.University of California)

[MZZ53-05] **General issues of Photovoltaic power forecasts for energy management in Japan**

*Hideaki Ohtake[1], Takashi Oozeki[1] (1.National Institute of Advanced Industrial Science and Technology)

[MZZ53-06] Predictability Assessment of Photovoltaic Solar Energy Production with Analog Ensemble

*Weiming Hu[1], Guido Cervone[1], Matteo Turilli[2], Andre Merzky[2], Shantenu Jha[2] (1.Pennsylvania State University Main Campus, 2.Rutgers, The State University of New Jersey)

Study on effective use of incidental gas from hot spring waters: a case study in Toyotomi town, Hokkaido

Takumi Takahashi[2], *Masahiko Fujii[1,2], Maki Ikegami[3]

1. Faculty of Environmental Earth Science, Hokkaido University, 2. Graduate School of Environmental Science, Hokkaido University, 3. Hokkaido University Sustainable Campus Management Office

In order to examine the value of utilizing hot spring incident gas, we evaluated the environmental performance and economic efficiency by comparing cases of utilizing the incidental gas and liquefied petroleum gas (LPG) as fuels. Our results show that when co-generation system (CGS) is newly introduced in the hot spring incident gas emission area, both greenhouse gas (GHG) emissions and costs can be significantly reduced. In addition, it was found that by switching fuels from LPG to the hot spring incident gas in LPG use areas, both GHG emissions and costs could be significantly reduced. Furthermore, it was found that GHG emissions and costs were significantly reduced even when CGS was introduced to the maximum extent. In order to promote the effective use of the hot spring incident gas in the future, in addition to relaxing laws and regulations, it is important to promote government-led initiatives and to add added value such as self-sustaining energy for disasters.

Keywords: Incidental gas from hot spring waters, Ambience, Economical efficiency, Life cycle assessment

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Investigation of Offshore Wind Climate in the Southeast Asia

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1. Graduate School of Science and Technology, Hirosaki University, Japan, 2. Department of Oceanography, Faculty of Fisheries and Marine Sciences, Diponegoro University, Indonesia

Offshore winds in the Southeast Asia were analyzed using satellite observations and reanalysis data. Since the Southeast Asian region are passed by the East Asian monsoon and Australian monsoon, it is promising for the development of offshore wind energy. Therefore, detail information of wind distribution and variability associated with monsoon are needed to be identified. In this study, we analyzed wind measurements acquired by ASCAT onboard MetOP-A and MetOP-B satellites for 2010–2018 and ERA5 reanalysis data for 2003–2018. The ASCAT wind measurements has a spatial resolution of 12.5 km providing observational evidence of surface winds in the island-studded seas. On the other hand, the ERA5 reanalysis data provide hourly wind fields at a spatial resolution of 0.25˚ and allow to analyze temporal variations from monsoon variations to diurnal variations. Hence, we obtain these following results.

The monsoon in the Southeast Asian region pass the Indonesian seas consisting of a main route and secondary routes. The wind routes are composed of small seas and straits. The main route of the northwest monsoon (East Asian monsoon) extends from the South China Sea to the northern Australian continent through the Arafura Sea, Banda Sea, Java Sea, and Karimata Strait. Small seas and straits adjacent to the main route work as the secondary routes of the monsoons. Meanwhile, the main route of the southeast monsoon (Australian monsoon) extends from the northern Australian continent to the Halmahera Sea and the Molucca Sea. The Java Sea and Karimata Strait work as secondary monsoon route. These monsoon routes align with the coastlines and are well represented by the major-axis directions of variance ellipses of wind velocities. Moreover, the velocity variance ellipses are highly anisotropic in the Indonesian seas.

We investigate the seasonal variations of monsoons in the Indonesian seas. The peak of monthly climatology of vector wind during the Australian monsoon is in August and during the East Asian monsoon is in January. Along the main monsoon route, the monsoon changes its direction from northwest to southeast in April and vice versa in November. The periods of southeast monsoon are longer than those of northwest monsoon. In addition, wind speeds during southeast monsoon are greater than those during northwest monsoon. In the lee of island (around Sulawesi), the wind is consistently weak.

Wind variabilities along the main monsoon routes in the Indonesian seas are induced by the variabilities of SLP. Two key regions were identified using the correlation analyses between the major-axis wind component and SLP. One is a region fully covering northern Australian continent and the other region covers the South China Sea. The result shows that monsoon systems in the South China Sea and northern Australian continent induce the offshore wind variability in Indonesia.

We analyzed the diurnal variations of the wind. Near the coast, diurnal wind variation dominates throughout the year. Moreover, the wind fields show divergent and convergent patterns along the main monsoon routes during daytime and night-time, respectively. The seasonal variation of diurnal wind is consistent with the daily maximum of surface temperature difference between land and sea. The diurnal variations are roughly separated into southern and northern region. In the southern region, the peak is in

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September while in the northern region, two peaks are in February and September.

Keywords: offshore wind, surface wind, wind climatology, monsoon, wind energy

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A webGIS-based application of solar radiation data and related information

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1. National Institute of Information and Communications Technology, 2. Center for Environmental Remote Sensing (CEReS), Chiba University, 3. JAXA/EORC, 4. Osaka University, 5. Waseda University, 6. Research and Information Center, Tokai University

We are introducing a WebGIS-based visualization application of solar radiation data delivered from Himawari satellite data. This WebGIS application is a part of results in "Development of a geoscientific data analysis system for harmonized utilization of the terrestrial renewable energy" in "Creation of Fundamental Theory and Technology to Establish a Cooperative Distributed Energy Management System and Integration of Technologies Across Broad Disciplines Toward Social Application" project in CREST/JST. The objective of the WebGIS application is to visualize solar radiation data in real time with other related data, such as human activity data or electric power line data. The spatial scale of the visualized data is smaller than city size. We present the WebGIS application and discuss how we can extend this technique to other subjects in Earth science.

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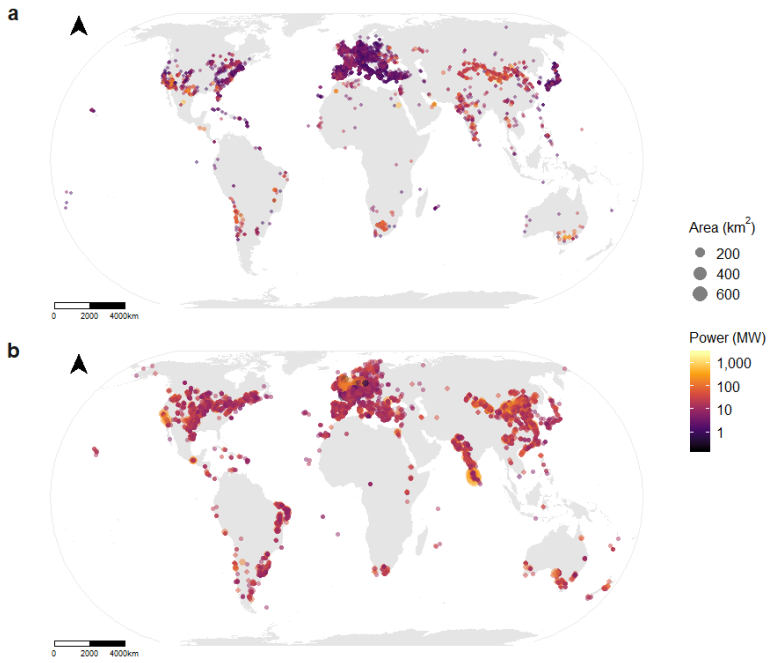
Harmonised global datasets of wind and solar farm locations and power

*Sebastian Lionel Dunnett[1], Alessandro Sorichetta[2,1], Gail Taylor[3], Felix Eigenbrod[1]

1. University of Southampton, 2. WorldPop, 3. University of California

Energy systems need decarbonisation in order to limit global warming to within safe limits. While global land planners are promising more of the planet’ s limited space to wind and solar photovoltaic, there is little information on where current infrastructure is located. The majority of recent studies use land suitability for wind and solar based on earth science data, coupled with technical and socioeconomic constraints, as a proxy for actual location data. Here, we address this shortcoming. Using readily accessible OpenStreetMap data we present, to our knowledge, the first global, open-access, harmonised spatial datasets of wind and solar installations and include first order estimates of power capacities. We anticipate this data will be of widespread interest within global studies of the future potential and trade-offs associated with the global decarbonisation of energy systems, as well as those interested in the relationship between installations and improving earth science data.

Keywords: solar, wind, open data



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General issues of Photovoltaic power forecasts for energy management in Japan

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1. National Institute of Advanced Industrial Science and Technology

A large amount of photovoltaics (PV) power systems (approximately 52 GW as of 2019) have been connected to a power grid in Japan. For safety control of an energy manage system (EMS) with renewable power generation, optimal use of other power plants (thermal power plants etc) and battery systems (include electric vehicles in future) will be required in a future energy network.

However, PV power forecasts data include forecast errors of various types (e.g., forecast errors of low level clouds, snow cover, ..). In December, 2018, Tokyo Electric Power Company Holdings, Inc. (TEPCO) and Hokkaido Electric Power Co., Inc. jointly launched the “PV in HOKKAIDO” contest to find outstanding new models for predicting the power output of solar power plants in Hokkaido (URL: https://cuusoo.com/projects/50369/challenges/result). After the competition, their general discussion on PV power forecast errors has been done through the Japan Solar Energy Society. In this presentation, we summarized the forecast technologies and various technical issues in order to improve PV power forecasts in Japan area.

Keywords: Photovoltaic power generation, PV power forecasts, forecast errors

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Predictability Assessment of Photovoltaic Solar Energy Production with Analog Ensemble

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Photovoltaic solar energy production is highly subjective to weather-dependent conditions such as ambient temperature changes and cloud formations. Therefore, predictions of the actual power generation from solar farms and panels can be volatile due to its intermittent nature. Furthermore, aside from the meteorological factors, the anthropogenic climate change and conditions of the power facilities are making the prediction even harder. This is challenging when integrating such a form of renewable energy source to the operation power grid as the power supply is not fully controlled and its high variability increases the operational cost of the power grid.

Ensemble simulations are usually carried out to better understand the predictability of meteorological factors. Run at high resolutions, ensemble simulations provide a range of possible scenarios with increased prediction accuracy but at a higher computational cost. However, the missing linking lies between the modeled global horizontal irradiance and the actual power generation. As mentioned above, other factors such as conditions of the facilities and the setup of the panels can differ greatly from place to place which also impacts the ultimate power generation. To improve the status quo of integrating renewable energy into the operational power grid, the missing link should be made to understand how meteorological and non-meteorological factors, as a whole, affect the predictability of solar power generation.

This interdisciplinary work focuses on assessing the predictability of photovoltaic solar energy production over the continental US. Meteorological forecasts are collected from WRF-NAM and then fed into Analog Ensemble, which is a technique to transform a deterministic model simulation into a simulation ensemble purely based on archived historical forecasts and the corresponding observations. Analog Ensemble does not require extra model simulations, and therefore, it is efficient and highly desired when the weather model is computationally expensive. The photovoltaic energy system is modeled using the System Advisor Model from National Renewable Energy Laboratory. It facilitates a wide range of solar panel setup and decision-making processes. The goal of this work is to gain insights into how predictable different regions in the US are and how to optimize the predictability and the power generation using state-of-the-art technologies.

Keywords: Solar Energy, Ensemble Modelling, Predictability, Renewable Energy, Analog Ensemble

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