

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 Arimoto¹ (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 Bell², *Brooks Hanson¹ (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 SHIMAMURA¹, Yasuhiro Yamanaka², Kiyoshi Suyehiro¹, Brooks Hanson³ (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 Silva¹ (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 Kuze¹, David Crisp², Carol Bruegge², Laura Iraci³, Florian Schwandner³, Fumie Kataoka⁴, Kei Shiomi¹, Nobuhiro Kikuchi¹, Hiroshi Suto¹ (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 Masunaga¹, Riko Oki², Moeka Yamaji², Kosuke Yamamoto² (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 Moeka¹ (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 Sekine¹, Maya Nakamura¹, Davaasuren Davaadorj², Daigo Shoji¹, Koki Morida³, Keisuke Fukushi³, Noriko Hasebe³, Shawn E McGlynn¹ (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 Suzuki¹ (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 Shinnosuke¹ (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 Graham¹, Vlada Stamenkovic², Shino Suzuki³, Ken Takai³, Tomohiro Usui⁴ (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] Understanding the Earth's deep interior with geo-neutrino measurements

★Invited Papers

*Hiroko Watanabe¹ (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 Araki¹, Taichi Sakai², Hiroko Watanabe², Takashi Yokobiki¹ (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 Kuramoto¹ (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 Cottrell¹, Francis Nimmo³, Hirokuni Oda⁴, Axel Hofmann⁵ (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 Kawai¹, Anselme F. E. Borgeaud^{1,2}, Yuki Suzuki¹, Robert J. Geller¹ (1.Department of Earth and Planetary Science, School of Science, University of Tokyo, 2.Academia Sinica)

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[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 Arimoto¹ (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 Bell², *Brooks Hanson¹ (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 SHIMAMURA¹, Yasuhiro Yamanaka², Kiyoshi Suyehiro¹, Brooks Hanson³ (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 Arimoto¹

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

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

Robin Elizabeth Bell², *Brooks Hanson¹

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

Panel Discussion of the Session

*Michiyo SHIMAMURA¹, Yasuhiro Yamanaka², Kiyoshi Suyehiro¹, Brooks Hanson³

1. Japan Agency for Marine-Earth Science and Technology, 2. Hokkaido University, 3. AGU

This session will be consisted from presentations 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

[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

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

★Invited Papers

*Arlindo da Silva¹ (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 Kuze¹, David Crisp², Carol Bruegge², Laura Iraci³, Florian Schwandner³, Fumie Kataoka⁴, Kei Shiomi¹, Nobuhiro Kikuchi¹, Hiroshi Suto¹ (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 Masunaga¹, Riko Oki², Moeka Yamaji², Kosuke Yamamoto² (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 Moeka¹ (1.Japan Aerospace Exploration Agency)

Past, Current and Future NASA-JAXA Partnership in Earth System Observations from Space

*Arlindo da Silva¹

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 AMSR-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

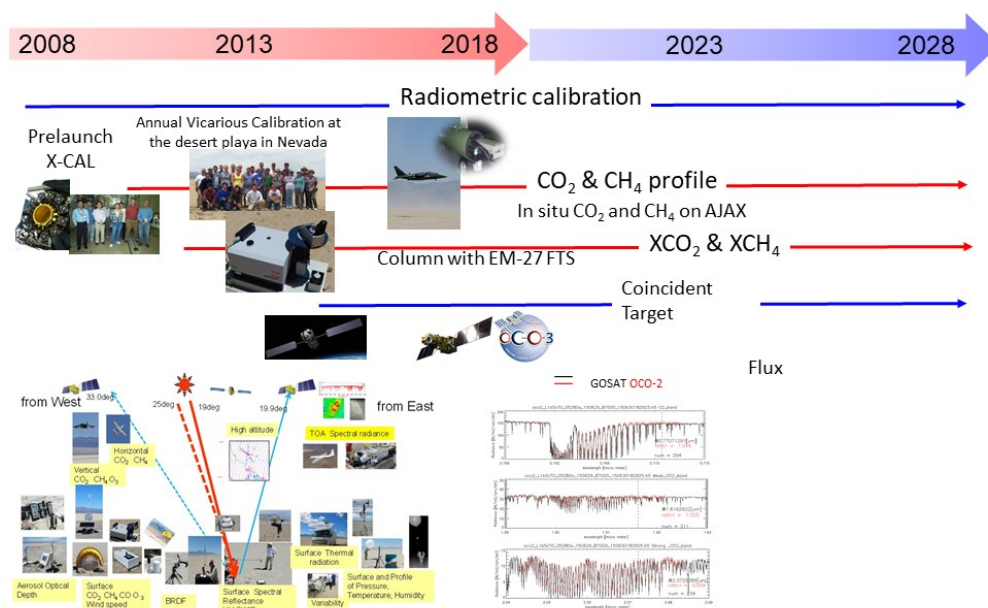
US-Japan collaboration toward accurate flux estimation of greenhouse gases from space: Intercomparison between US OCO and Japanese GOSAT

*Akihiko Kuze¹, David Crisp², Carol Bruegge², Laura Iraci³, Florian Schwandner³, Fumie Kataoka⁴, Kei Shiomi¹, Nobuhiro Kikuchi¹, Hiroshi Suto¹

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 CO₂ 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



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

*Hirohiko Masunaga¹, Riko Oki², Moeka Yamaji², Kosuke Yamamoto²

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

Open Discussion

*Yamaji Moeka¹

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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[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 Sekine¹, Maya Nakamura¹, Davaasuren Davaadorj², Daigo Shoji¹, Koki Morida³, Keisuke Fukushima³, Noriko Hasebe³, Shawn E McGlynn¹ (1.Tokyo Institute of Technology, 2.National University of Mongolia, 3.Kanazawa University)

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[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)

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

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*Shino Suzuki¹ (1.Japan Agency for Marine-Earth Science and Technology)

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*Aoyama Shinnosuke¹ (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 Graham¹, Vlada Stamenkovic², Shino Suzuki³, Ken Takai³, Tomohiro Usui⁴ (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 Sekine¹, Maya Nakamura¹, Davaasuren Davaadorj², Daigo Shoji¹, Koki Morida³, Keisuke Fukushi³, Noriko Hasebe³, Shawn E McGlynn¹

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 $\sim 10^4$ m³. 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

Prospects for Subsurface Energy, Water, and Life on Mars

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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 volcanoclastic 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 H₂O. 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

Life on serpentinized setting on the Earth and beyond

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Almost all the microbial ecosystems on present-day Earth are supported by photosynthesis including the subsurface biosphere. Organic carbons from the photosynthesis have been accumulated 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

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 ($\delta\text{-S-34}$) because MSR is characterized by large sulfur isotopic fractionation up to -65% (Sim et al., 2011). Microbial cultivation studies reported not only the traditional $\delta\text{-S-34}$ but also minor sulfur isotopes ($\delta\text{-S-33}$ & $\delta\text{-S-36}$) 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) $\delta\text{-S-33}$ 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 $\delta\text{-S-34}$ 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

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 **International Center for Deep Life Investigation (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

Opportunities and Exploration: A Panel Discussion on Planetary Subsurface Science

*Heather Valeah Graham¹, Vlada Stamenkovic², Shino Suzuki³, Ken Takai³, Tomohiro Usui⁴

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 encompasses 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

[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] Understanding the Earth's deep interior with geo-neutrino measurements

★Invited Papers

*Hiroko Watanabe¹ (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 Araki¹, Taichi Sakai², Hiroko Watanabe², Takashi Yokobiki¹ (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 Kuramoto¹ (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 Cottrell¹, Francis Nimmo³, Hirokuni Oda⁴, Axel Hofmann⁵ (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 Kawai¹, Anselme F. E. Borgeaud^{1,2}, Yuki Suzuki¹, Robert J. Geller¹ (1.Department of Earth and Planetary Science, School of Science, University of Tokyo, 2.Academia Sinica)

Understanding the Earth's deep interior with geo-neutrino measurements

*Hiroko Watanabe¹

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 dicssussed.

Keywords: geo-neutrinos, understanding Earth's deep interior, Radiogenic heat in mantle

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 hungry 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

planned 1-10 tons class detector, we also estimated the level of expected neutron background for different structure of the detector vessel.

Direct sampling and measurement at deep crust through scientific ocean drilling

*Shin'ichi Kuramoto¹

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 located 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°C 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

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 Eoarchean, 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

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

Imaging subducted slabs in the mantle through inversion of seismic waveforms

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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

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