Al, Automation & Optimization

Thu. Nov 12, 2026 4:00 PM - 5:30 PM JST | Thu. Nov 12, 2026 7:00 AM - 8:30 AM UTC | Room C (201) (2F)

Oral C3 Al, Automation & Optimization

Chair: Di Wan, Justin Buck, Yosuke Fujii

4:00 PM - 4:15 PM JST | 7:00 AM - 7:15 AM UTC

[GW9BIT7e-01] How ocean reanalysis are used to train Machine Learning Emulators

Yann Drillet (1. Mercator Ocean International (France))

4:15 PM - 4:30 PM JST | 7:15 AM - 7:30 AM UTC

[GW9BIT7e-02] Uncertainty-Aware Satellite-to-Profile Mapping for Ocean Data Assimilation

*Geon-Min Lee (1. Hanyang University (Korea))

4:30 PM - 4:45 PM JST | 7:30 AM - 7:45 AM UTC

[GW9BIT7e-03] BlueMath: An Open-Source and Modular Python Framework with Interactive Notebooks for the Development of Digital Twins of Coastal Climate Hazards in a Changing Climate

*Fernando Mendez[1] (1. University of Cantabria (Spain))

4:45 PM - 5:00 PM JST | 7:45 AM - 8:00 AM UTC

[GW9BIT7e-04] Automation of shadowgraph imaging analysis: detecting species and characterizing their preferred environments

*Mehul N. Sangekar (1. JAMSTEC (Japan))

5:00 PM - 5:15 PM JST | 8:00 AM - 8:15 AM UTC

[GW9BIT7e-05] Causal Operator Learning for Marine Heatwave Prediction

*Dong Eun Lee (1. Chungnam National University (Korea))

5:15 PM - 5:30 PM JST | 8:15 AM - 8:30 AM UTC

[GW9BIT7e-06] Enhanced Tropical Cyclone Track Prediction Using Ocean–Atmosphere Coupled Model Simulations and Hybrid Ensemble Deep Learning Approaches

*Amit Kumar Jena[1] (1. Japan Agency for Marine-Earth Science and Technology (Japan))

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[GW9BIT7e-01] How ocean reanalysis are used to train Machine Learning Emulators

Yann Drillet (1. Mercator Ocean International (France))

Mercator Ocean International operates the Copernicus Marine Service and develops some of the world's most comprehensive ocean reanalysis systems, providing consistent reconstructions of the past ocean state by combining numerical modelling, observations, and data assimilation. These long-term, quality-controlled datasets include the global physical ocean reanalysis GLORYS, the global biogeochemical reanalysis BIORYS, the global wave reanalysis WAVERYS, the regional Iberia–Biscay–Ireland physical and biogeochemical reanalysis IBIRYS, and the global mid-trophic ecosystem reanalysis MICRORYS. Together, these products describe the evolution of the ocean circulation, temperature, salinity, sea level, biogeochemistry, waves, and marine ecosystems over several decades, providing an unparalleled digital representation of the ocean system. Beyond their traditional applications in ocean monitoring, climate assessment, marine ecosystem studies, and operational forecasting, these reanalyses constitute a unique foundation for the development of machine learning (ML) and artificial intelligence (AI) models. Their global coverage, long temporal extent, physical consistency, and multidimensional nature make them ideal training datasets for data-driven ocean prediction systems. Within the EDITO ecosystem, several AI models available through the AI Gallery are already leveraging Copernicus Marine datasets to demonstrate new approaches for ocean forecasting. Current developments include emulators of the global and regional physical forecasting system, emulator of the biogeochemistry and micronekton. These approaches aim to significantly reduce computational costs while preserving the predictive skill of physics-based models, opening new opportunities for rapid scenario exploration, uncertainty quantification, data assimilation, and Digital Twin Ocean applications. By combining decades of Copernicus Marine reanalyses with advanced AI methods, Mercator Ocean is building a new generation of hybrid ocean prediction systems where numerical modelling and machine learning work together to enhance ocean monitoring, forecasting, and decision support for marine services

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[GW9BIT7e-02] Uncertainty-Aware Satellite-to-Profile Mapping for Ocean Data Assimilation

*Geon-Min Lee (1. Hanyang University (Korea))

Satellite-derived surface observations provide broad constraints on ocean variability, but inferring subsurface temperature and salinity (T/S) remains challenging because the surface-to-subsurface relationship is nonlinear and non-unique. This study proposes the Temperature–Salinity Transformer (TST), an uncertainty-aware framework that generates subsurface T/S pseudo-profiles and depth-dependent uncertainty directly at observation locations from satellite-derived SSH, SST, and SSS. Unlike full-field reconstruction approaches, TST produces profile-type pseudo-observations designed for direct use in profile-based ocean data assimilation. TST was trained using GLORYS12V1 reanalysis and evaluated over the northwestern Pacific and adjacent marginal seas. Against independent in situ observations, TST achieved basin-mean RMSEs of 0.80 °C and 0.11 psu, with correlations of 0.98 and 0.90 for temperature and salinity, respectively. Empirical uncertainty calibration aligned predicted uncertainty with realized errors, providing depth-dependent observation-error estimates for uncertainty-aware assimilation. In a MOM5-based assimilation experiment, TST-only assimilation reduced both temperature and salinity RMSE relative to the control and SST-only experiments. When combined with conventional T/S profile assimilation, the TST-based experiment further improved the subsurface state and achieved lower RMSE than the K-ORA22 regional reanalysis reference in WOD-based validation. The improvements were especially clear for salinity and extended through the upper and intermediate layers, indicating that TST provides thermohaline constraints beyond surface thermal correction. These results demonstrate the potential of uncertainty-aware TST pseudo-profiles to bridge satellite surface observations and profile-based ocean data assimilation.

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[GW9BIT7e-03] BlueMath: An Open-Source and Modular Python Framework with Interactive Notebooks for the Development of Digital Twins of Coastal Climate Hazards in a Changing Climate

*Fernando Mendez[1] (1. University of Cantabria (Spain))

In the face of increasing global challenges such as coastal hazards and climate change, the use of robust statistical and numerical analysis tools is essential. Tools that facilitate the analysis of multivariate met-oceanic climatic drivers (e.g., waves, storm surges, tropical and extratropical tropical cyclones) acting at multiple spatial and temporal scales are key for predicting flooding events, producing risk assessments or planning for adaptation measures.

Within this context, BlueMath emerges as a collaborative platform of many research groups and universities around the world working together to democratize the access to advanced models and services, empowering both researchers and non-specialists to generate customized, complex solutions. BlueMath (https://gitlab.com/geoocean/bluemath) is an innovative, open-source repository of Python-coded tools. The repository is also accessible from the muti-user cloud-based Jupyter Hub environment, leveraging shared computational resources and the user-friendly interface of Jupyter Notebooks. BlueMath integrates state-of-the art statistical techniques and high-fidelity numerical model wrappers in a system framework that includes from standalone models with straightforward applications to hybrid model-tool combinations that produce comprehensive climate services. The individual modules of BlueMath are designed to be highly adaptable to a wide range of needs and applications:

a) BlueMath-Toolkit: Provides fundamental tools including data mining, interpolation, and wrappers for numerical models such as SWAN, SWASH, Delft3D, and SCHISM. It also supports statistical analyses of waves, tides, and tropical cyclones.
b) BlueMath-Hybrid Downscaling: Integrates statistical and numerical models to optimize computational efficiency. It includes the implementation of hybrid models like metamodels (e.g., HySwash (Ricondo et al., 2024)) and additive approaches (e.g., Binwaves (Cagigal et al., 2024)).
c) BlueMath-Climate Services: Enables the creation of integrated applications by combining functionalities from previous modules, such as coastal digital twins of high resolution waves and storm surge levels, due to extratropical or to tropical cyclones.

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[GW9BIT7e-04] Automation of shadowgraph imaging analysis: detecting species and characterizing their preferred environments

*Mehul N. Sangekar (1. JAMSTEC (Japan))

Detecting marine animals in their natural environments and characterising the habitat they are found in is essential for ocean science. Especially in the age of climate change, real-time in-situ detection of new and invasive species and any information of the environment they occur in, can provide valuable insights for future predictions and mitigations. At JAMSTEC, we have developed a shadowgraphic imaging system that can observe marine animals and other marine particles in-situ with high resolution. Because the system uses parallel light for imaging, sizes of animals can be accurately estimated. This optical technique also allows us to see density mixing layers, hydrothermal plumes, particle plumes etc, which can provide useful information for characterizing marine environments. The shadowgraph camera records video at high frame rates, producing a large volume of data, which is difficult to analyze manually. Also for future use of this system for long-term in-situ autonomous monitoring, automatic semi-real-time detection of plankton and the environmental conditions is essential. For this, we have been developing an automated image analysis pipeline that uses AI and other image processing techniques to perform the task of species detection and extract environmental information from shadowgraph videos. The analysis pipeline goes through videos automatically to separate objects from the background, mainly marine particles and marine animals. Object classification is performed to identify animal species using a trained model that is further improved by adding the new detections and previously untrained labels. The particle information, combined with CTD data, is used to make particle profiles and obtain information about the environmental conditions. We have also designed an algorithm to detect patterns in shadowgraph images representing mixing layers, hydrothermal plumes, particle plumes etc using unsupervised image feature extraction and clustering. This, combined with the species detection, could provide comprehensive information about the preferred environments of marine animals.

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[GW9BIT7e-05] Causal Operator Learning for Marine Heatwave Prediction

*Dong Eun Lee (1. Chungnam National University (Korea))

Predicting Marine Heatwaves (MHWs) remains challenging for data-driven approaches, because they are rare, often unprecedentedly intense, persistent, and shaped by nonlinear upper-ocean processes. A prediction model trained solely on observational realizations may not capture the underlying physics unless explicitly constrained, limiting its ability to anticipate extreme MHW conditions not represented in the observational record. Here, using a Laplace Neural Operator (LNO) surrogate of a numerical model, we show that training on physically contrasting sensitivity experiments promotes generalization to unobserved MHWs.

An LNO is trained to emulate the numerically integrated upper-ocean temperature profile in a controllable virtual environment governed by surface heat flux, wind, and precipitation forcing through nonlinear, Richardson-number-dependent mixing. The optimal hyperparameter configuration is selected through systematic grid search. In 32-day hindcasts, the surrogate outperforms a damped-persistence baseline. We then use controlled forcing experiments to test whether it learns physical response operators rather than experiment-specific Sea Surface Temperature (SST) patterns. Models trained separately on control and modified-forcing simulations exhibit limited cross-experiment generalization, indicating that conventional training primarily captures forcing-dependent statistical patterns. In contrast, a surrogate trained on a balanced combination of control and weakened-wind simulations retains high skill in both environments. An SST-distribution-matched dataset randomly sampled across sensitivity experiments yields substantially lower predictive skill, despite broader coverage of temperature outcomes.

These results show that surrogate training on physically controlled simulations can promote learning of forcing-dependent oceanic response sensitivities, providing a pathway toward predicting MHW extremes beyond those observed historically.

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[GW9BIT7e-06] Enhanced Tropical Cyclone Track Prediction Using Ocean–Atmosphere Coupled Model Simulations and Hybrid Ensemble Deep Learning Approaches

*Amit Kumar Jena[1] (1. Japan Agency for Marine-Earth Science and Technology (Japan))

Accurate prediction of tropical cyclone trajectories remains a significant challenge due to the complex and nonlinear ocean–atmosphere interactions governing cyclone evolution, while conventional numerical weather prediction models are computationally intensive and often inadequate for real-time forecasting. In this study, Cyclone Amphan (2020) is simulated using both an ocean-atmosphere coupled WRF model and an uncoupled WRF model to investigate the impact of air–sea interactions on track prediction. The coupled model exhibits substantially improved performance over the uncoupled configuration by more realistically representing upper-ocean feedbacks, thereby reducing track errors. To further enhance prediction accuracy, a comprehensive deep learning framework is developed by implementing and systematically comparing CNN, LSTM, CNN-GRU, MLP, and Temporal Fusion Transformer (TFT) models using the outputs from both numerical simulations. The novelty of this study lies in integrating coupled model simulations with hybrid deep learning architectures that combine spatial feature extraction and temporal sequence learning, together with a dual evaluation framework based on RMSE and spatial track alignment. Results demonstrate that hybrid models, particularly CNN-GRU, achieve the highest prediction accuracy, while the coupled model consistently outperforms the uncoupled model by providing more realistic environmental conditions. The proposed framework offers a computationally efficient and accurate approach for tropical cyclone track prediction, with significant potential for improving operational forecasting, early warning systems, and disaster risk management.

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