Joint workshop of the OS-Eval TT and CP-TT and SynObs Kick-Off

Observing System Evaluations Task Team (OS-Eval TT)

Coupled Prediction Task Team (CP-TT)

Workshop Summary

15 – 18 November 2022

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1 Background

OceanPredict is a research program on ocean predictions contributing to UNESCO-IOC and has six task teams. Among them, the Observing System Evaluation Task Team (OS-Eval TT) promotes evaluation of the impact of ocean observational data on ocean predictions (including coupled atmosphere-ocean predictions), and aims to make proposals for ocean observing network improvement. The Coupled Prediction Task Team (CP-TT) promotes development and use of coupled atmosphere-ocean prediction systems based on the knowledge of ocean prediction science.

The OS-Eval TT, as a task team of the predecessor program of OceanPredict, GODAE OceanView, held task team meetings every two to three years until 2018. Then, after being taken over by OceanPredict, the OS-Eval TT had decided to hold a joint meeting with the CP-TT in 2020 in order to focus on the impacts of the ocean observing network in coupled atmosphere-ocean predictions, and preparations for the workshop had begun with the support of two Japanese Institutes, JMA/MRI and JAMSTEC. However, the workshop was postponed due to the spread of COVID-19.

Meanwhile, the United Nations (UN) designated the period 2021-2030 as the UN Decade of Ocean Science for Sustainable Development (UN Ocean Decade) following the recommendation of UNESCO-IOC, and UNESCO-IOC issued a call for research programs and projects to participate in the UN Ocean Decade. In response to this call, OceanPredict proposed the research program “Ocean Prediction Capacity of the Future” (ForeSea), which aims to strengthen the ocean prediction value chain from ocean observing systems to end-users through ocean prediction systems, and was approved as an UN Decade Program in June 2021. In addition, the OS-Eval TT proposed the research project “Synergistic Observing Network for Ocean predictions” (SynObs), which aims to evaluate and design ocean observing network and develop assimilation methods to achieve synergy among various observing systems, typically between satellite and in-situ observation data of the ocean, and was approved as an UN Decade Project under ForeSea in June 2022.

It became necessary for the OS-Eval TT to invite many concerned scientists to participate in SynObs and to discuss its activity plan. Thus, the OS-Eval TT, with the agreement of the CP-TT and in cooperation with JMA/MRI and JAMSTEC, decided to hold the postponed joint meeting of the OS-Eval TT and the CP-TT in conjunction with the SynObs Kick-off Workshop.

2 The purpose and themes of the workshop

The purpose of this workshop was to publicize the start of SynObs to the international community on marine science and to discuss future SynObs activities. In order to achieve the purpose, the following four themes are set.

1. Co-design and evaluation of ocean observing systems: their needs and achievements
    a. Expectation of co-design/evaluation from observational communities
        - ✓ What observing systems need co-design/evaluation
        - ✓ What are the benefits from co-design/evaluation
    b. Observing System Evaluation showcase
        - ✓ Evaluation of large swath sea level anomaly data (SWOT, COMPIRA, …)
        - ✓ Evaluation of the global Argo Array and its evolution (Including Core Argo, BGC Argo, Deep Argo, etc.)
        - ✓ Evaluation of tropical buoys (TPOS2020 design etc.)
        - ✓ Other ocean observing systems and platforms
    c. Methodology
        - ✓ Strategy for Multi-System OSE/OSSE and Nature Run
        - ✓ New methods for designing and evaluating the observation network
        - ✓ Evaluation of societal and economical impacts
        - ✓ Best practices for observing system evaluation
2. Data assimilation development for better use of observation data
    a. Observation operators
        - ✓ For new-type observations (Lagrangian trajectories, Ocean current velocities, etc.)
        - ✓ For coupled data assimilation systems (Radiance, Scatterometer, etc.)
    b. Modeling of the background errors across multi-physics/domains
        - ✓ Across the atmosphere-ocean boundary
        - ✓ Across the open ocean-coastal sea boundary
        - ✓ Across physical and biogeochemical parameters
    c. Methods for dealing with correlated observation errors
        - ✓ Data Thinning and modeling of observation errors
3. Ocean modeling and initialization in earth system predictions
    a. Modeling, and data assimilation of the ocean-atmosphere boundary layers
        - ✓ Impact of Wind waves
        - ✓ Vertical mixing process at the boundary
        - ✓ Variation of Skin-SST
        - ✓ Exchange of momentum, heat, and fresh-water flux
    b. Best practices for earth system predictions
        - ✓ Coupled data assimilation for earth system predictions
        - ✓ Initialization technique to reduce the coupled shock
        - ✓ Oceanic perturbation for ensemble member generation
        - ✓ Operational design for earth system predictions

  - ✓ Metrics to assess the oceanic impacts
  c. Roles of ocean observation data in earth system predictions
    - ✓ Ocean Observation impacts
    - ✓ Ocean observation timeliness requirements
4. Discussion on the future activities of OS-Eval TT, CP-TT, and SynObs
    - ✓ Setup of SynObs activities
    - ✓ CP-TT contribution to UN Decade of Ocean Science (ForeSea and SynObs)
    - ✓ Enhancing communication across ocean and coupled predictions and observational communities for more effective use of the ocean observation data

3 Overall summary

The workshop invited registrations and presentations from both domestic and overseas participants. Midway through the application period, we announced that online participation was recommended for participants from outside Japan, and the program was organized mainly for the convenience of both domestic on-site participants and overseas online participants. (See the Appendix 1 for program details.)

Specifically, the International Conference Room of the Tsukuba Center for Institutes, which has a capacity for 170 people, was used only for the sessions in the morning and afternoon of November 15 and in the morning of November 16 to encourage domestic scientists to participate in the workshop in person during this period. As a result, a total of 38 participants (4 from abroad and 34 from Japan) attended those sessions, and a total of 26 presentations were made: 12 on-site oral presentations (including 3 invited talks), 7 online oral presentations (including 3 invited talks), and 7 poster presentations. In consideration of the prevention of coronavirus infection, a reception was held in the early afternoon of November 16, which also served as a lunch without alcoholic beverages. A total of 16 people were invited to the reception, including participants from outside Japan and participants from Japan who gave opening remarks or oral research presentations.

Meanwhile, on the morning of November 17 and 18, research presentations and summary sessions were held in a meeting room of JMA/MRI, with the participation of international participants and online participants mainly from North and South America. In addition, on the evening of November 16 and 17, sessions for research presentations were held online mainly for participants from Europe, Africa, and South and West Asia. Two discussion sessions were also held in the late evening (21:20-22:50 JST) following the evening sessions, in anticipation of participation not only from Europe, Africa and Asia but also from North and South America. In addition to the above, two discussion sessions were also held in the morning of the 16th. Online poster presentations were avoided for this workshop, and all applications for poster presentations from outside of Japan were accepted as online oral presentations. As a result, together with the sessions at Tsukuba Center for Institutes, 84 people from overseas (80 of them online) and 62 from Japan (28 of them online) participated, and a total of 53 presentations (6 invited talks, 40 oral presentations, and 7 poster presentations) were made.

Although the content of each session was organized as much as possible to group presentations by the four themes listed above, many of the sessions had a mixture of presentations on multiple topics due to the time difference between Japan and foreign countries. The opening session was held on the morning of the 15th, with opening remarks by Takayuki Matsumura, Director General of the Meteorological Research Institute, representing the host, Shuhei Masuda, Director General of RICG, JAMSTEC, representing the co-host, and Yutaka Michida (University of Tokyo), representing the Japanese domestic committee for the UN Ocean Decade. After a brief explanation of the venue, Yosuke Fujii (JMA/MRI) gave a brief overview of SynObs. This was followed by an invited talk on the real-time ocean reanalysis intercomparison project by Dr. Chaihong Wen (NOAA/NCEP), followed by five presentations on simulations and predictions using coupled atmosphere-ocean models. This was followed by a flash talk by poster presenters, and after a lunch break, local poster presentations were given. This was followed by six presentations on the development of assimilation methods and efforts to evaluate observing systems. In particular, Marilaure Gregoire (Liege University) introduced the activity of reviewing observation requirements for earth system predictions conducted by the WMO's Joint Expert Team on Earth Observation System Design and Evolution (JET-OSDE), and requested future collaboration between JET-OSDE and SynObs.

On the morning of the 16th, three research presentations on observation system evaluation were first presented, followed by a discussion session on observation systems and OSE/OSSE chaired by Lidia Cucurull, NOAA Quantitative Observing System Assessment Program (QOSAP) representative. This was followed by three presentations on the use of observation data acquired by fishery people, and a discussion session on the use of fishery and coastal data, chaired by Naoki Hirose (Kyushu University). In the evening, an online session featured seven presentations on the development of assimilation methods and Earth system predictions, mainly by participants from Europe. This was followed by a discussion session on the future activities of the CP-TT, chaired by one of the CP-TT co-chairs, Santha Akella (NASA).

In the morning session on the 17th, seven research presentations, mainly from the U.S., were made on the development of data assimilation systems, the use of observation data, and coupled atmosphere-ocean predictions. In the evening, six research presentations were given on observation systems and their evaluation, mainly from European research. After a dinner break, two research presentations related to future activities of SynObs were given, followed by a discussion session chaired by Yosuke Fujii

(JMA/MRI) on future activities of SynObs, especially research collaboration on Observing System Experiments (OSEs).

In the morning of the 18th, there were five presentations on Observing System Simulation Experiments (OSSEs), an UN Decade Program “Ocean Observing Co-Design” with which SynObs is collaborating, and future satellite missions. In the summary session, international participants and Yosuke Fujii summarized the results of the workshop for each of the themes listed in Section 2. The workshop was closed with a final remark by Goro Yamanaka (JMA/MRI), as the Japan representative of OceanPredict.

4 Workshop Outcomes

This section summarizes the workshop outcomes for each of the themes listed in Section 2.

4.1 Codesign and evaluation of Ocean Observing Systems: their needs and achievements

As new satellite and in-situ observing systems for ocean applications are proposed, a rigorous evaluation of their potential impact in ocean prediction models is necessary, so that a quantitative cost-benefit assessment can be developed for better planning and decision making. A primary quantitative assessment tool is an observing system simulation experiment (OSSE). Results from OSSEs help prioritize mission designs and configurations in a cost-effective way by analyzing tradeoffs of proposed designs. In order for the results of an OSSE to be realistic, there are a few criteria that need to be met to avoid overestimating or underestimating observing system impacts. A rigorous ocean OSSE system consists of 1) a Nature Run (NR) that represents the true ocean, 2) a second, different ocean model (the ‘‘forecast model’’) coupled to a data assimilation system, and 3) software to simulate current and proposed observations from the NR with realistic spatial and temporal coverage as well as observation error characteristics. . Rigorous evaluation of the OSSE system requires performing Observing System Experiments (OSEs) that evaluate one or more existing observing systems, and then performing OSSEs that are identical to these OSEs except for the assimilation of synthetic observations from the NR. Forecast accuracy and the impact of existing observing systems in an OSSE should be comparable to the impacts in the OSE (the real world). Furthermore, the differences (errors) between the forecast model and the NR need to be comparable to the errors between state-of-the-art ocean models and the true ocean, to ensure that the OSSE system has realistic performance.

This theme consisted of a total of 28 presentations, with five invited oral presentations. The sessions covered a wide spectrum of topics, including existing and planned observation designs, and impact of observations in global, regional, subseasonal to seasonal and reanalysis efforts. Different quantitative assessments (OSEs and FSOI) were used to evaluate the impact of current observations, while some proposed observing capabilities were discussed under the OSSE framework. The nature run is a critical component of any OSSE experiment. Nature runs are expensive to generate, as they require significant computer resources, as well as scientific and technical support staff. A recently generated global nature run was proposed for potential evaluation of impact of observations. In addition, the adjoint method was used to investigate areas of larger sensitivity. Finally, updates on ongoing projects/programmes were discussed. Specific details on some of the presentations are provided below.

Caihong Wen (NOAA/NWS/Climate Prediction Center, abstract 1.18) provided an update of the Real-time Ocean Reanalyses Intercomparison Project (RT-ORA-IP). The project focuses on how the variations in the Tropical Pacific Observing System (TPOS) influence the ocean reanalysis and ENSO predictions. It was shown how an estimate of the climate signal can be obtained from the mean of an ensemble of ocean reanalyses, while uncertainties can be estimated from the ensemble spread. The impact of observations was investigated by quantifying their impact in reducing the ensemble spread. While this investigation has focused on the Tropical pacific region, plans exist to extend the work to other regions and SynObs supports the plan.

Dimitris Menemenlis (JPL, abstract 1.17) presented a new global, atmosphere-ocean simulation with km-scale horizontal grid spacing for air-sea exchange studies and climate-observing system design. The nature run is a critical component of any OSSE experiment. Thus, having this long-term simulation to be used as the nature run offers the possibility to conduct ocean OSSEs. The simulation has been integrated for 14 months starting from January 20, 2020, initial conditions, Hourly atmospheric and oceanic model output of all prognostic and some diagnostic variables has been saved and is being made available to the scientific community. This nature run simulation provides a unique synthetic data set for atmospheric and oceanic boundary layer studies and for satellite and in-situ observing system design. Preliminary evaluation of the output files was presented, and results were very encouraging to use it for the SynObs collaborative OSSEs.

Marilaure Gregoire (Liege University, abstract 1.8) reviewed the WMO High-Level Guidance Document, with emphasis on the ocean topics. This document describes the evolution of global observing systems during the period 2023-3027 in response to the Vision for WIGOS (i.e. WMO Integrated Global Observing System) in 2024. It relies on information gathered through the Rolling Requirements Review (RRR), the process used by WMO to collect, vet and record user requirements for all WMO application areas and match them against observational capabilities. Some of the ocean topics include the ocean surface (integrating satellite and in-situ observations), sea-ice, the river-ocean interface, the subsurface ocean, and the green ocean. It was confirmed that a future collaboration between WMO and SynObs for the RRR will be necessary.

Lidia Cucurull (NOAA, abstract 1.2) introduced the NOAA QOSAP program, including its efforts on conducting OSEs and OSSEs. The program was established in 2014 to address NOAA's capability gap for conducting quantitative assessments for proposed changes to the global observing system. Since then, QOSAP has coordinated NOAA assessments of the impact of current and new observing technologies for atmospheric applications. Plans towards developing an ocean OSSE capability with national and international partnership, including the generation of a global ocean nature run, were discussed during the presentation. It was confirmed that QOSAP will contribute to SynObs.

Andy Moore (University of California Santa Cruz, abstract 1.18) showed the impact of different observations in terms of Forecast Sensitivity-Based Observation Impact (FSOI) in an Analysis-Forecast System of the California Current System (abstract 1.18). It was found that only ~40-50% of in situ observations improved the forecast skill, while this percentage was higher for remote sensing observations (~60%). These numbers are similar to those found in numerical weather prediction systems. When comparing local versus remote impacts, results showed significant remote influence on forecast skill of SST observations upstream along the coast of Northern California, Oregon, and Washington. Local SST observations had the largest impact on central California SST forecast skill.

Matthieu Le Henaff (University of Miami/CIMAS, abstract 1.13) first showed the OSE/OSSE experiments using the Gulf of Mexico OSSE system. Four experiments of OSEs were performed, OSE1–assimilate all data (3 altimeters, MCSST+SST, in-situ SST, ship XBT profiles, airborne profiles; OSE2–deny airborne profiles; OSE3–also deny 2 of 3 altimeters; OSE4–DA free (unconstrained simulation with DA model). Three OSSE experiments identical to OSE1, 2, 3 were also performed, except they assimilated synthetic data instead of real observations. The key findings are that evaluations of an OSSE system necessitate: separate evaluation of each model (NR + forecast model); errors growing in the forecast model due to model differences, they need to be comparable to errors between state-of-the-art models and real ocean; evaluation of the diagnostics from OSSE system, similar to that from equivalent OSEs using real observations. Only after these criteria have been validated, can the OSSE system be used to quantify the performance of alternative or new observing systems.

David Legler (NOAA, abstract 1.16) from NOAA introduced the Ocean Observing Co-Design Programme. A contribution to the UN Decade for Ocean Science, Co-Design aims to transform the ocean observing system assessment and design process, creating a new framework with observing, modeling, operational services (from weather predictions to climate projections) and key user stakeholders. The goal is to provide readily available, and actionable, ocean information from a more integrated ocean observing system. Cheyenne Stienbarger (NOAA/GOMO Program, abstract 1.21) also introduced the effort of the Tropical Cyclone Ocean Observations and Forecasts Exemplar of the Ocean Observing Co-Design Programme. She stressed the importance of timely forecasting of TC in saving lives and the needs of co-designing an observing system for improved tropical cyclone forecasts and the overarching goal of providing recommendations for designing an ocean observing system to improve TC intensity forecasts that is co-developed among the global observing and modeling communities. The Ocean Observing Co-Design Programme expects contributions from SynObs for the evaluation of ocean observation impacts using ocean prediction systems.

Tony Lee (JPL, abstract 1.15) presented a satellite mission concept to unravel small-scale ocean dynamics and air-sea interactions: Ocean Dynamics and Surface Exchange with the Atmosphere (ODYSEA). It is yet to be proposed to NASA's Earth System Explorers by June 2023, will provide the first ever, simultaneous measurements of ocean-surface winds and currents with 5-km data postings. The ODYSEA effort needs broader community collaboration, including with OceanPredict in general (the OSEval Task Team and Coupled Prediction Task Team) and with the UN Decade Project SynObs in particular.

4.2 Data assimilation development for better use of observation data

The second theme of the meeting concerned the development of data assimilation for effective use of ocean observation data. Theme 2 comprised one invited talk by Prof. Naoki Hirose (Kyushu University, Japan; abstract 2.6), nine oral presentations (abstracts 2.1–2.5, 2.8, and 2.11–2.13), and two posters (abstracts 2.7 and 2.9) for a total of 12 presentations with authors from seven countries (New Zealand, France, South Korea, Japan, USA, Saudi Arabia, and UK). Half of the presentations concerned regional ocean data assimilation systems (near New Zealand, Japan, and South Korea; and in Red Sea, North Pacific, and North Atlantic) and the other half concerned global or quasi-global domains.

Most of the presentations discussed ocean analysis (or reanalysis) systems, except for the presentation of Dr. Mounir Benkiran (from Mercator Ocean, France), which pertained to a Surface Waters and Ocean Topography (SWOT) Observation System Simulation Experiment (OSSE), and that of Mr. Olivier Goux (from CERFACS, France), which pertained to the representation of correlated errors in simulated SWOT observations. Three of the ocean analyses (two regional and one global) were carried out using four-dimensional variational (4DVAR) data assimilation (a.k.a. the adjoint method). The remaining analyses were based on sequential (e.g., nudging, optimal interpolation, 3DVAR, or Kalman filter) approaches.

On the one hand, the adjoint method permits the utilization of "future" observations to inform the state estimates and it enables property-conserving estimates that can satisfy ocean model evolution equations exactly. On the other hand, sequential methods are, in general, more computationally efficient to implement and better suited for operational analyses and predictions. In fact, it can be shown that, if fully implemented with the same cost function in a linear system, the adjoint method and the Kalman filter will produce exactly the same solution at the end of the estimation period, which makes sequential methods especially well-suited for operational predictions. Indeed, five of the eight sequential ocean analysis systems were also used for carrying-out ocean forecasts.

With the exception of the 4DVAR global analysis produced by the Estimating the Circulation and Climate of the Ocean (ECCO) project, whose central production estimate currently resides on a grid with nominal 1° horizontal spacing (except at the Equator where meridional spacing is 1/3° and in the Arctic Ocean where horizontal spacing is ~50 km), all other regional and global analyses and forecast system discussed had horizontal grid spacing of 1/4° or finer.

In addition to ocean circulation: (1) the ECCO (abstract 2.8) and European Centre for Medium-Range Weather Forecasts (ECMWF; abstract 2.12) analyses include estimates of sea ice; (2) the ECCO and Marine Ecosystem Analysis and Prediction (MEAP) task team (abstract 2.4) analyses include estimates of ocean ecology and biogeochemistry; and (3) the ECCO analysis includes circulation estimates and melt rates under Antarctic ice-shelves.

There were two presentations (abstracts 2.5 and 2.13) that considered the impact of correlated errors (one (abstracts 2.5) is on observation errors and the other (abstract 2.13) is on background errors) and the use of diffusion operators to represent these errors. The ECCO analysis and perhaps others, not discussed, also use diffusion operators and other techniques, e.g., superobing or subsampling, to deal with correlated errors. Presentation 2.12 by Dr. Nozomi Sugiura (JAMSTEC, Japan) explored the use of a new observation operator for vertical-profile observations based on a functional representation of the profiles that uses path signatures.

Last but not least, two of the presentations (abstracts 2.1 and 2.6) discussed crowd-sourced ocean observations for ocean data assimilation in, respectively, New Zealand and Japanese coastal waters. In these two presentations, the stakeholders of the coastal circulation estimates themselves, in this case fishing vessels, become the data collectors through the deployment of inexpensive temperature-depth or conductivity-temperature-depth sensors.

As summarized in this section, the workshop featured presentations on various ocean data assimilation methods that have been developed in recent years and that will contribute to more efficient use of ocean observation data in the future. SynObs will continue to share the latest findings on the development of such ocean data assimilation methods and promote the effective use of ocean observation data.

4.3 Ocean Modeling and Initialization in Earth System Predictions

This workshop has led us to the following discussions on the third theme: "ocean initialization and modeling in earth system predictions".

For ocean initialization, ocean observations should be taken full advantage of to produce reliable analysis products with data assimilation (e.g., abstracts 3.8 and 3.10). For this purpose, we should keep following the practice of using OSE to evaluate the existing ocean observations and using OSSE to design the future observing system network. When designing the observing network, it is not only the location or the type of the observations we should care about, but also potentially the spatial resolution of the data and the sampling frequency of the data (e.g., abstract 3.9). We encourage more physical evaluation of increments to trace the bias source in data assimilation, which can offer guidance to further improve the reanalysis system (e.g., abstract 3.9). Initialization shock in some ocean states has been found in coupled forecasts that are initialized from uncoupled ocean data assimilation, which highlights the need of the coupled data assimilation for ocean initialization (e.g., abstracts 3.1 and 3.3). The coupled data assimilation framework further offers an opportunity to more comprehensively investigate the importance of the existing ocean in-situ observations that measure both atmospheric variables and oceanic variables such as the TAO array (e.g., abstract 3.5), and can potentially inspire new types of observations. Another aspect of the ocean initialization is the ensemble method. We need a better strategy to generate ensembles, so that the initial difference among ensembles can match the analysis errors, and the forecast spread can match the uncertainty of the ocean variables (e.g., abstracts 3.10 and 3.7).

For ocean modeling, we look forward to the high-resolution models, a better representation of the biogeochemistry variables and their interaction with other earth system components (e.g., abstract 3.4), and parameter adjustment via machine learning methods. We would also like to encourage a reconsideration of the target variables in prediction, to better accommodate the key impact of the phenomenon of our interest as well as its nature of predictability (e.g., abstract 3.6). Furthermore, for coupled forecasts initialized from different ocean conditions, the atmospheric variables are worthy of investigation as well, from which we can learn how information from the ocean is propagated into the earth systems (e.g., abstract 3.1). Such investigations will provide specific guidance on the calibration of the coupled models, as well as illustrate the key role played by the ocean in the earth system prediction.

The above findings shared at this workshop are very useful for the continued development and improvement of coupled prediction systems in the future, and are also essential for evaluating the impact of ocean observation data on earth system predictions at SynObs.

4.4 Discussion on the future activities of OS-Eval TT, CP-TT, SynObs

4.4.1 Presentations

There are two oral presentations submitted for this theme. Magdalena Balmaseda (ECMWF, abstract 4.1) introduced the plan of OSE collaborations for subseasonal-to-seasonal (S2S) forecasts among operational centers. They plan to generate oceanic initial conditions by ocean reanalysis OSEs between 2000 and 2022 and to perform coupled atmosphere-ocean model prediction runs from them. It is confirmed that SynObs should design the flagship OSEs like that the S2S OSEs and the flagship OSEs are complementary to each other, and that the ocean reanalyses of the S2S OSEs can also be used for the flagship OSEs.

Meanwhile, Clemente Tanajura (UFBA/REMO, abstract 4.2) indicated some difficulty of OSSEs. He used ROM to create NR in the South Atlantic, and HYCOM + RODAS to assimilate with and without SWOT. Diagnostics of these experiments were performed and correlations with the “truth” showed strong influence of SSH and SST, but the impact of SWOT was not as big as expected, possibly due to the six expected mean errors. New experiments are underway, better NR, sub-meso scale features, and in depth data (e.g. ARGO), would help improve the future impact of SWOT data. His experience should be considered in order to make the flagship OSE and OSSEs more effective.

4.4.2 Discussion for future activities of CP-TT

Discussion in this session was centered around following three points:

A. Collaborations synergies across Task Teams (CP, OS-Eval, IV, DA, …) and SynObs.
B. Modeling (ocean, coupled) initiatives that advance SynObs and coordination with other TTs.
C. Recommendations/requirements for high resolution modeling, data assimilation in the context of OSEs, OSSEs, Nature Run.

It is to be first noted that CP-TT and its activities are in a revival phase.

Following points were noted to be of common interest for above item A:

- What is the impact of observations in coupled data assimilation (DA) and it was emphasized that connections to DA-TT will be helpful. Particular focus on tests with single observations and their impacts was noted to be potentially beneficial for all. It was also discussed whether collocated observations will help better determine the coupled state?

- We would like to promote exchange of information across different oceanPredict TTs in the context of WCRP coupled initialization exercise. Also the exchange of initial conditions and increments will help inter-comparisons and possible portability of initial conditions across systems.
- Coordinate projects on coupled forecasting at different time horizons: short-, medium- and long-range. CP-TT is actively engaged in determining its focus. Tropical cyclone exemplar in coordination with GOOS are being taken up by CP-TT. Another suggestion is to promote collocated satellite and Argo measurements.

For above item B, it was suggested that:

- Study of ocean model biases and their consideration on SST and mixed layers is important.
- Study initialization shocks in coupled DA with skin temperature variability/resolution.
- Focus should be sharing tools to improve models and predictability.

Finally, for above item C:

- We noted that coupled nature runs and at *high* resolutions will be developed in future.
- Efforts should be devoted to considering models with BGC components and data.
- There should be coordination between seasonal prediction (S2S) and Observation System Evaluation (OSE) groups.

Based on the above discussion, the CP-TT will consider future activities and at the same time, will contribute to the activities of SynObs.

4.4.3 Discussion for future activities of OS-Eval TT and SynObs

During the discussion on future SynObs and OS-Eval TT activities, different points were raised by the participants on the following aspects:

- ✓ How to collaborate efficiently with the observing networks,
- ✓ How to collaborate with the ORA / S2S OSE project,
- ✓ On the specific design and communication of outcomes from the flagship OSEs.

It was suggested to discuss more closely with the different observing networks when designing and evaluating the OSEs and OSSEs. This will allow targeting more precisely the processes of interests and the questions to answer related to the present network or their planned evolution. A suggestion was, for example, to test the impact of doubling Argo in WBC by subsampling regions where the floats density is already increased compared to the “reference” historical coverage.

It was mentioned also the question of how to improve the sampling strategy with an optimized integrated array of diverse already existing platforms regionally, for example the Agulhas region.

To analyze the experiments, relevant physical diagnostics should be discussed with the Observing networks but also programs such as the ObsCoDe UN decade program focusing on few exemplars. The Intercomparison and Validation Task Team may also help on the validation aspect of the OSE/OSSEs.

OceanGliders will set up a data assimilation team to discuss the role of gliders and how the DA efficiency could be improved.

Many OceanPredict centers are preparing their system to assimilate SWOT observations, SWOT OSEs can be planned for the second SynObs phase since no calibrated real data time will be available before mid-2023.

Since the flagship OSEs are looking at observation impact on multi-year simulations, a collaboration with the ORA / S2S project presented by Magdalena Balmaseda will be welcome. The ensemble of simulations will inform on the sensitivity of different systems to observations.

Conversely, the proposed multi-year flagship OSE may not be reachable for high resolution ocean and regional prediction systems. The question of having a less strict OSE framework was raised to include more participants but this may limit the results interpretation. Having regional diagnostics may help to include more systems.

Based on the above discussion, more specific plans of SynObs flagship OSEs and the showcase activity will be decided by the SynObs Steering Team with contribution from all SynObs participants.

5 Acknowledgements

First of all, on behalf of the Japan Representative of OceanPredict, the local organizing committee would like to express our sincere appreciation for all the participants for joining this workshop, which was held in a hybrid format due to the extraordinary conditions in Japan, generated by COVID-19. We would like to thank all the guests for their positive participation. We believe during the workshop, we have all had insightful, interactive discussion and a great opportunity to share a common understanding.

The primary goal of this workshop was to emphasize the importance of international collaboration on ocean observing co-design and evaluation as well as data assimilation development for more effective use of ocean observation data. By listening to the excellent presentations and discussions, we are sure we have gained a deeper understanding on the vital role of the ocean observing co-design and evaluation as well as data assimilation development. Operational ocean prediction systems can draw

effective information synergistically from both in-situ and satellite ocean observing systems with limited cost, which eventually can provide societal benefit through the ocean information value-chain. We will continue to make efforts to enhance the international collaboration of ocean observation evaluation to obtain better and meaningful research results.

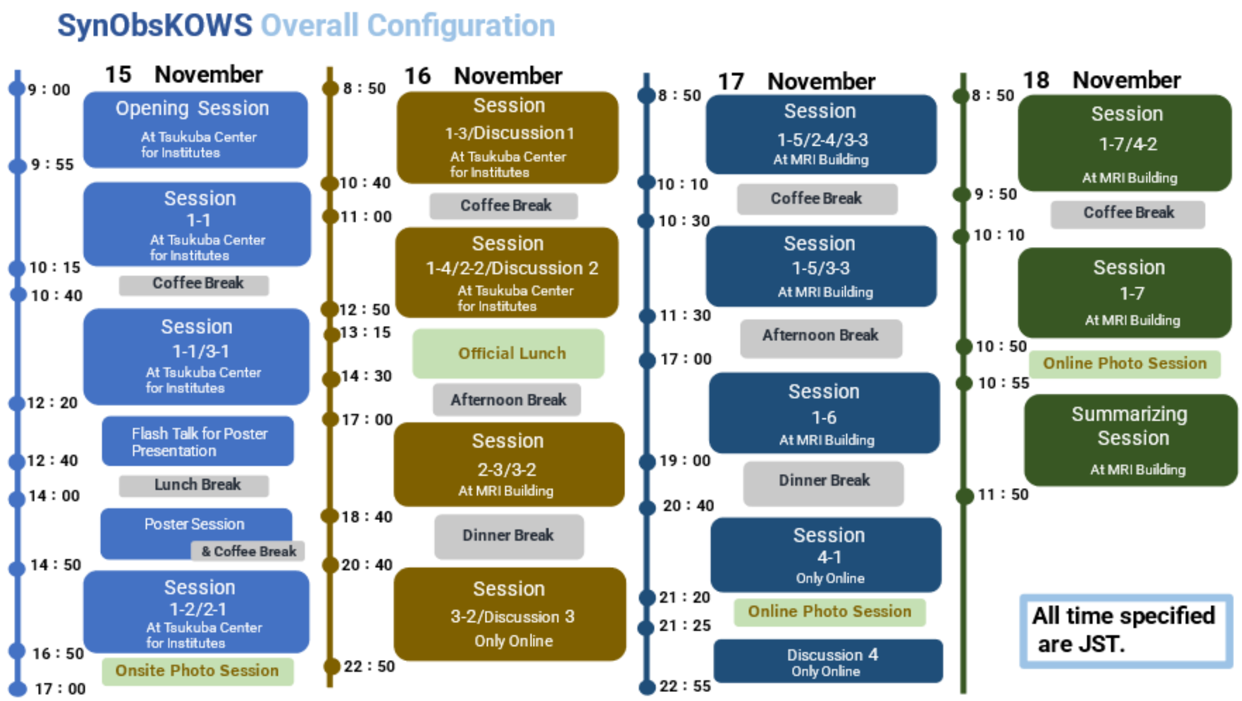
We have also discussed how we can promote developments for increasing oceanic impacts in earth system models. The ocean is a component of the earth system, and accordingly its variations are intrinsically associated with those of other components, such as air-sea interactions. We were impressed by many presentations on cutting-edge research on coupled and earth system predictions during this workshop. We are sure the enhanced linkage between the OS-Eval TT and the CP-TT would be one of the key factors to highlight the importance of ocean observations through the atmosphere-ocean coupling for weather and climate predictions.

Then, we have discussed the future activities of both task teams and SynObs. We have built a consensus that enhancing communication across ocean and coupled predictions as well as observational communities is essential to more effective use of ocean observation data. I am convinced the active collaboration between both task teams and SynObs will certainly contribute to the achievement of the UN Decade of Ocean Science for Sustainable Development. We believe this workshop was a good opportunity to exchange our experiences, and thus an effective kick-off of the SynObs project. We look forward to continuing to work closely with you in order to make this project successful.

We would like to thank all speakers for their excellent talks; the session chairs and moderators for summarizing presentations and facilitating discussions; and all the participants being online or offline for joining fruitful discussions. We also thank the OceanPredict Science Team, the UN Decade programs “ForeSea”, “CoastPredict”, and "Ocean Observing Co-Design” for supporting this workshop. We do appreciate the Meteorological Research Institute and the Japan Meteorological Agency for their comprehensive support.

Finally, thank you to all workshop participants and to everyone involved in planning and holding this event. We are truly grateful for your valuable contributions and attendance.

Appendix 1. Workshop Program



➢ **Day 1 (Nov. 15th)**

09:00-09:08 Takayuki Matsumura (MRI-JMA (Director-General) ,JP)
Greeting on behalf of JMA-MRI

09:08-09:16 Shuhei Masuda (JMASTEC (Director-General of RIGC), JP)
Greeting on behalf of JAMSTEC

09:16-09:24 Yutaka Michida (University of Tokyo, JP)
Greeting on behalf of UN Ocean Decade Japanese domestic committee

09:24-09:35 Yuhei Takaya (MRI-JMA, JP)
Workshop Purpose and Logistic Information

09:35-09:55 Yosuke Fujii (MRI-JMA, JP)
SynObs Introduction

09:55-10:15 Caihong Wen (NOAA/NWS/NCEP/CPC, US) Abst. No.1.26
Invited ： Real-time Ocean Reanalyses Intercomparison Project

10:15-10:40 Coffee Break

10:40-11:00 Iwao Ueki (JAMSTEC, JP) Abst. No.1.24
Tropical Pacific Observing System -synergy with modeling and assimilation activities –

11:00-11:20 Takuma Yoshida (JMA, JP) Abst. No.3.10
Ocean Initialization of the Coupled Prediction System Version 3 (CPS3) for Seasonal Forecasts

11:20-11:40 Danni Du (University of Colorado, Boulder, US) Abst. No.3.3
Assessing the Impact of Ocean In-situ Observations on MJO Propagation across the Maritime Continent in ECMWF Subseasonal Forecasts

11:40-12:00 Yuhei Takaya (MRI-JMA, JP) Abst. No.3.8
Importance of ocean observations for sub-seasonal to seasonal forecast in East Asia

12:00-12:20 Dimitris Menemenlis (NASA JPL, US) Abst. No.1.17
Invited：Potential NASA GEOS Nature Runs for Next Generation Colocated Air-Sea Measurement Satellite

12:20-12:40 Flash Talk for Poster Presentation

12:40-12:50 Onsite Photo Session

12:50-14:00 Lunch Break

14:00-14:50 Poster Session & Coffee Break

14:50-15:10 Mounir Benkiran (Mercator-Ocean International, FR) Abst. No.2.2
Impact of SWOT observations in a global high-resolution analysis and forecasting system

15:10-15:30 Nozomi Sugiura (JAMSTEC, JP) Abst. No. 2.12
Ocean data assimilation based on MMD between sets of profiles

15:30-15:50 Dimitris Menemenlis (NASA JPL, US) Abst. No.2.8
Introduction to the Estimating the Circulation and Climate of the Ocean (ECCO) project

15:50-16:10 Toshio Suga (JAMSTEC and Tohoku University, JP) Abst. No.1.22
Argo "Abrupt Salty Drifters" – the problem, impacts, and lessons learned

16:10-16:30 Miki Hattori (JAMSTEC, JP) Abst. No.1.9
Potential Impact of Aeroclipper Observations on a Tropical Cyclone Analysis in a Global Model

16:30-16:50 Marilaure Gregoire (Liege University, BE) Abst. No.1.8
Invited：The WMO Rolling Review of Requirements process: Ocean perspective

- **Day 2 (Nov. 16th) Morning**

08:50-09:10 Matthieu Le Henaff (University of Miami, NOAA/AOML, US) Abst. No.1.14
Observing System Evaluation showcase: Impact of ocean observations on hurricane forecasts - The cases of Hurricanes Maria (2017) and Michael (2018)

09:10-09:30 Andrew Moore (University of California Santa Cruz, US) Abst. No.1.18
Invited：Forecast Sensitivity-based Observation Impact (FSOI) in an Analysis-Forecast System of the California Current Circulation

09:30-09:50 Lidia Cucurull (NOAA, US) Abst. No.1.2
Invited：Ongoing efforts at NOAA to develop a global ocean Observing System Simulation Experiment (OSSEs) capability

09:50-10:40 Discussion 1 Observing System and OSE/OSSE

10:40-11:00 Coffee Break

11:00-11:20 Julie Jakoboski (MetOcean Solutions, NZ) Abst. No.1.11
Crowdsourcing Ocean Observations in Partnership with the Fishing Sector and Coastal Ocean

11:20-11:40 Joao M. A. C. de Souza (MetOcean Solutions, NZ) Abst. No.2.1
Assimilation of new operational fishing vessel derived observations for New Zealand

11:40-12:50 Naoki Hirose (RIAM, Kyushu University, JP) Abst. No.2.6
Invited : Coastal ocean data assimilation with fishing vessels

12:00-12:50 Discussion 2 Use of Fihsery Data and coastal data

13:15-14:30 Official Lunch (Onsite Speakers and Foreign Guests only)

- **Day 2 (Nov. 16th) Evening**

17:00-17:20 Olivier Goux (CERFACS, FR) Abst. No.2.5
Accounting for correlated observation error in variational ocean data assimilation: application to wide-swath altimeter data

17:20-17:40 Hao Zuo (ECMWF, UK) Abst. No.2.13
Assimilation of SST observations with the new ECMWF Ensemble Ocean DA system

17:40-18:00 Siva Reddy Sanikommu (KAUST, SA) Abst. No.2.11
Insights from Large Ensembles Experiments with the Red Sea Ensemble Data Assimilation System

18:00-18:20 Jennifer Waters (Met Office, UK) Abst. No.3.9
Assessing the impact of proposed satellite observations in a global ocean forecasting system

18:20-18:40 David Ford (Met Office, UK) Abst. No.3.4
Two-way physics-biogeochemistry coupling constrained by ocean colour data assimilation

18:40-20:40 Dinner Break

20:40-21:00 Magdalena Balmaseada (ECMWF, UK) Abst. No.3.1
Impact of Ocean Observations in ECMWF S2S forecasts

21:00-21:20 Ronan McAdam (CMCC, IT) Abst. No.3.6
Seasonal forecasting of subsurface marine heat waves

21:20-22:50 Discussion 3 CP-TT Activity Plan

- **Day 3 (Nov. 17th) Morning**

09:10-09:30 Annie Wong (University of Washington, US) Abst. No.1.27
Argo salinity: bias and uncertainty evaluation

09:30-09:50 Jieshun Zhu (CPC/NCEP/NOAA, US) Abst. No.1.28

Next Generation Global Ocean Data Assimilation System (NG-GODAS): a new reanalysis and OSSE applications

09:50-10:10 Patrick Heimbach (University of Texas at Austin, US) Abst. No.1.10
Ocean Climate Observing Network Design in the Subpolar North Atlantic via Hessian Uncertainty Quanti cation

10:10-10:30 Coffee Break

10:30-10:50 Eric Hackert (NASA/GMAO, US) Abst. No.3.5
Evaluation of TAO Observation System on ENSO Predictions from the GMAO S2S Forecast System

10:50-11:10 Andrew Peterson (Environment and Climate Change Canada, CA) Abst. No.3.7
Towards creating an ensemble of global ocean analysis: Ensemble GIOPS

11:10-11:30 Inseong Chang (Pukyong national university, KR) Abst. No.2.3
Impact of in situ and satellite data assimilation on ocean circulation prediction system in Northwest Pacific

11:30-11:50 Paul Chamberlain (Scripps Institution of Oceanography, US) Abst. No.1.1
Optimizing The Biogeochemical Argo Float Distribution

- **Day 3 (Nov. 17th) Evening**

17:00-17:20 Elisabeth Rémy (Mercator Ocean International, FR) Abst. No.1.7
On the control of spatial and temporal oceanic scales by existing and future observing systems: an OSSE approach

17:20-17:40 David Ford (Met Office, UK) Abst. No.1.5
Towards adaptive monitoring of coastal oceans integrating marine robots and operational forecasts

17:40-18:00 Aurélien Prat (UMR 8105 LACy et Inria, FR) Abst. No.1.20
Pre-processing of sea turtle biologging observations using a clustering algorithm

18:00-18:20 Stefano Ciavatta (Mercator Ocean International, FR) Abst. No.2.4
Monitoring and predicting marine ecosystems by fusing observations and models

18:20-18:40 Hugo Dayan (CMCC, FR) Abst. No.1.3
Marine heat waves in the Mediterranean Sea: an assessment from the surface to the subsurface to meet national needs

18:40-19:00 Victor Turpin (OceanOPS/WMO, FR) Abst. No.1.23
Leveraging the multi-system glider data assimilation experiments within EuroSea to the international level

19:00-20:40 Dinner Break

20:40-21:00 Yosuke Fujii (MRI-JMA, JP) Abst. No.1.6
Evaluation of Argo array impacts in the global and regional ocean data assimilation systems in JMA/MRI and the international collaboration through SynObs

21:00-21:20 Magdalena Balmaseada (ECMWF, UK) Abst. No.4.1

OSES for S2S and evaluation of future TPOS

21:20-21:25 Online Photo Session

21:25-22:55 Discussion 4 SynObs Plan

- **Day 4 (Nov. 18th) Moring**

08:50-09:10 Clemente Tanajura (UFBA/REMO, BR) Abst. No.4.2
Investigating the future impact of SWOT data in the South Atlantic circulation with OSSEs

09:10-09:30 Matthieu Le Henaff (University of Miami, NOAA/AOML, US) Abst. No.1.13
Recipe for rigorous OSSE assessments - Illustration in the Gulf of Mexico

09:30-09:50 David Legler (NOAA, US) Abst. No.1.16
Strengthening ocean observation and modeling integration through co-design of a fit-for-purpose ocean observing system

09:50-10:10 Coffee Break

10:10-10:30 Cheyenne Stienbarger (NOAA/GOMOProgram, US) Abst. No.1.21
Co-Designing an Observing System for Improved Tropical Cyclone Forecasts

10:30-10:50 Tong Lee (JPL, California Institute of Technology, US) Abst. No.1.15
A satellite mission concept to unravel small-scale ocean dynamics and air-sea interactions: Ocean Dynamics and Surface Exchange with the Atmosphere (ODYSEA)

10:50-10:55 Online Photo Session

10:55-11:02 Lidia Cucurull (NOAA, US)
Summary of the Theme 1: Co-design and evaluation of ocean observing systems

11:02-11:09 Dimitris Menemenlis (NASA JPL, US)
Summary of the Theme 2: Data assimilation development for better use of observation data

11:09-11:16 Danni Du (University of Colorado, Boulder, US)
Summary of the Theme 3: Ocean modeling and initialization in earth system predictions

11:16-11:23 Yosuke Fujii (MRI-JMA, JP)
Summary of the Theme 4: Discussion on the future activities

11:23-11:40 General Discussion

11:40-11:50 Goro Yamanaka (MRI-JMA, JP)
Concluding Remarks from the Japan Representative of OceanPredict

Appendix 2. Presentation Abstract

1. Theme 1: Science in support to coastal ocean forecasting

Abstract 1.1: Paul Chamberlain, Scripps Institution of Oceanography – （Oral 11:30-11:50）

Optimizing The Biogeochemical Argo Float Distribution

Paul Chamberlain

Scripps Institution of Oceanography

The core Argo array has operated for over 20 years with the design goal of uniform spatial distribution. Recent studies have acknowledged increased variability in some parts of the ocean and recommend increased core Argo density in the equatorial waters, boundary currents, and marginal seas. Biogeochemical (BGC) floats currently observe the ocean from a collection of pilot arrays, but recently funded proposals will transition these pilot arrays to a global array. The current BGC Argo implementation plan recommends uniform spatial distribution of BGC Argo floats. Using modeled, full depth, BGC fields we estimate, for the first time, the effectiveness of current Argo infrastructure. We also study the effectiveness of uniformly distributed BGC Argo arrays at observing the ocean at various float densities. Then, using previous Argo trajectories, we estimate the future distribution of the Argo array and quantify how well it observes the ocean. Finally, using a novel technique for sequentially identifying the best deployment locations, we suggest the optimal array distribution for BGC Argo floats.

Abstract 1.2: Lidia Cucurull, NOAA – （Invited talk 9:30-9:50)

Ongoing efforts at NOAA to develop a global ocean Observing System Simulation Experiment (OSSEs) capability

Lidia Cucurull

NOAA

As new satellite and in-situ observing systems for ocean applications are proposed, a rigorous evaluation of their potential impact in ocean prediction models is necessary, so that a quantitative cost-benefit assessment can be developed for better planning and decision making. The NOAA Quantitative Observing System Assessment Program (QOSAP) was established in 2014 to address NOAA's capability gap for conducting quantitative assessments for proposed changes to the global observing system. Since then, QOSAP has coordinated NOAA assessments of the impact of current and new observing

technologies for atmospheric applications. A primary quantitative assessment tool is an observing system simulation experiment (OSSE). Results from OSSEs help NOAA management prioritize mission designs and configurations in a cost-effective way by analyzing tradeoffs of proposed designs. The nature run is a critical component of any OSSE experiment. Nature runs are expensive to generate, as they require significant computer resources, as well as scientific and technical support staff. Though nature runs have been generated for global and regional atmospheric applications, a long-term high-resolution well-calibrated global nature for the oceans is needed and has yet to be built. An introduction to QOSAP will be provided, along with plans towards developing an ocean OSSE capability with national and international partnership, including the generation of a global ocean nature run.

Abstract 1.3: Hugo Dayan, LMD, IPSL, PSL – (Oral 18:20-18:40)

Marine heat waves in the Mediterranean Sea: an assessment from the surface to the subsurface to meet national needs

Hugo Dayan[1]*, Ronan McAdam[2], Mélanie Juza[3], Simona Masina[2], Sabrina Speich[1]

[1]LMD, IPSL, PSL - Ecole Normale Supérieure, Paris, France
[2]Ocean Modeling and Data Assimilation Division, Centro Euro-Mediterraneo sui Cambiamenti Climatici, Bologna, Italy
[3]Balearic Islands Coastal Observing and Forecasting System (SOCIB), Palma, Spain

Over the last decades, marine heat waves (MHWs) in the Mediterranean Sea have caused mass-mortality events in various marine species and critical losses for seafood industries. To better understand how much each Mediterranean country's territorial waters may be affected by MHW changes, this study assesses the variability of surface and subsurface MHWs over the 1987-2019 period in the whole Mediterranean Sea with a focus on the Exclusive Economic Zones (EEZs), which are national areas where special rights are held by a sovereign country. Combining high-resolution satellite observations and a regional reanalysis, sea surface temperature and ocean heat content are used to define surface and subsurface MHWs. Both basin-scale and EEZ-scale differences between surface and subsurface MHW event characteristics are highlighted, which motivates the widespread adoption of sub-regional subsurface MHW indicators in addition to surface indicators. The results put the spotlight on the necessity of strengthening surface and subsurface observing systems in most national waters to better establish adaptation strategies to address MHW impacts, as well as the need for more local-scale risk assessments to respond to diverse stakeholder needs.

Abstract 1.4: Toshimasa Doi, JAMSTEC –(Poster 14:00-14:50)

Assessing the Impact of BGC Argo float array deployment region on state estimation by using the Estimated Ocean State for Climate Research (ESTOC)

Toshimasa Doi, Satoshi Osafune, Shinya Kouketsu, Shigeki Hosoda and Shuhei Masuda

Research Institute for Global Change, Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokosuka, Japan. E-mail: doit@jamstec.go.jp

BGC Argo float array is recognized as an important tool for observing the ocean environment, and efforts are underway to deploy, maintain, and manage it to cover the global ocean. In order to monitor global ocean environmental variations, it is effective to use numerical models in conjunction with such observation networks. We try to estimate both physical and biogeochemical ocean states by integrating various observations including the BGC Argo float array through a 4-dimensional variational data synthesis system, which is constructed based on a pelagic lower trophic level ecosystem model and oceanic general circulation model. This data synthesize system can estimate dynamically self-consistent ocean state which integrates available ocean observations. By using the data synthesis system, we focused on the dissolved oxygen observation accumulated by BGC Argo, and examined the effectiveness of BGC Argo observations in ocean state estimation. We conducted the data synthesis by estimate the optimal model parameters for the atmospheric exchange coefficient of oxygen at sea-surface and the rate of oxygen consumption by biogeochemical activity with Green's function approach for five basins (Atlantic, Pacific, Indian, Southern Ocean, and Arctic Ocean) of the global ocean. By comparing the results based on obtained optimized parameters between with and without BGC Argo observations, we evaluate the observation impacts on our ocean state estimation. This result is an assessment of the impact on data synthesis for each ocean region where the BGC Argo is deployed and contributes to clarify the importance of the deployment of BGC Argo to the global ocean.

Abstract 1.5: David Ford, Met Office – (Oral 18:20-18:40)

Towards adaptive monitoring of coastal oceans integrating marine robots and operational forecasts

David Ford[1], Shenan Grossberg[2], Matthew Palmer[3], Gianmario Rinaldi[2], Jozef Skákala[4], Tim Smyth[4], Charlotte Williams[3], Stefano Ciavatta[4]

[1]Met Office, UK
[2]University of Exeter, UK
[3]NOC, UK
[4]PML, UK

As a proof-of-concept, we implemented and tried an automated and adaptive system integrating an ocean glider with operational ocean forecasts. The glider was deployed in the Western English Channel during the spring bloom period of 2021 and (quasi-)autonomously controlled by a stochastic prediction model. This combined the glider observations with forecasts from a (pseudo-)operational numerical model, which in turn assimilated the glider observations and other data, to create high-resolution probabilistic predictions of chlorophyll. From these, sets of waypoints were calculated, to direct the glider to where a chlorophyll bloom was most likely to be found. The glider successfully captured details

of the spring bloom in the region at unprecedented temporal resolution. Furthermore, assimilating these observations had a clear impact on operational forecasts.

Abstract 1.6: Yosuke Fujii, JMA/MRI – (Oral 20:40-21:00)

Evaluation of Argo array impacts in the global and regional ocean data assimilation systems in JMA/MRI and the international collaboration through SynObs

Yosuke Fujii, Norihisa Usui, and Nariaki Hirose

JMA/MRI

JMA/MRI has been implementing evaluation of the Argo array using global and regional ocean data assimilation systems operated in JMA. For example, we showed that the improvement of ENSO forecast skill by the Argo data increased with the lead time in the seasonal forecasting experiments. Argo data also had relatively large impacts in the subarctic North Pacific, in which the salinity fields play a significant role in sea surface variations.

JMA/MRI is currently implementing observing system experiments (OSEs) to evaluate the impact of abrupt salinity drift (ASD) in Argo profiles reported after 2015. In this activity, we evaluate the impacts of applying the latest gray list or using delayed-mode Argo data instead of the real-time ones using different ocean reanalysis systems as well as objective analysis systems. A positive trend in the global ocean salt content is visible since 2015 in the control run, while the trend is reduced in the run with the delayed-mode data in which profiles suffered from ASD are removed.

We are currently planning to evaluate the impacts of Argo data on the ocean reanalysis and subseasonal-to-seasonal forecasts through the international collaboration of SynObs in the next 5 years.

Abstract 1.7: Florent Gasparin, MOI, LEGOS/IRD – (Oral 17:00-17:20)

On the control of spatial and temporal oceanic scales by existing and future observing systems: an OSSE approach

F. Gasparin[1,*], E. Rémya, J.M. Lellouche[1], S. Cravatte[2], G. Ruggiero[1], B. Rohith[1]

[1] *Mercator Ocean International, Toulouse, France*
[2] *Institut de Recherche pour le Développement (IRD), UMR5566-LEGOS, Nouméa, New Caledonia*

* Now at Institut de Recherche pour le Développement (IRD), UMR5566-LEGOS, Toulouse, France.
Ocean monitoring and forecasting systems combine information from ocean observations and numerical models through advanced data assimilation techniques. They are essential to monitor and report on past, present and future oceanic conditions. However, given the continuous development of oceanic models and data assimilation techniques in addition to the increased diversity of assimilated platforms, it becomes more and more difficult to establish how information from observations is used, and to determine the utility and relevance of a change

of the global ocean observing system on ocean analyses. Here, a series of observing system simulation experiments (OSSE), which consist in simulating synthetic observations from a realistic simulation to be subsequently assimilated in an experimental analysis system, was performed. An original multiscale approach is then used to investigate (i) the impact of various observing system components (distinguishing between satellites and in situ), and (ii) the impact of recommended changes in observing systems, in particular the impact of Argo floats doubling and enhancements of tropical moorings, on the fidelity of ocean analyses. This multiscale approach is key to better understand how observing system components, with their distinct sampling characteristics help to constrain physical processes. The study demonstrates the ability of the analysis system to represent 40-80% of the temperature variance at mesoscale (20-30% for salinity), and more than 80% for larger scales. Satellite information, mostly through altimetric data, strongly constrains mesoscale variability, while the impact of in situ temperature and salinity profiles are essential to constrain large scale variability. It is also shown that future enhancements of Argo and tropical mooring arrays observations will likely be beneficial to ocean analyses at both intermediate and large scales. This work provides a better understanding on the respective role of major satellite and in situ observing system components in the integrated ocean observing system.

Abstract 1.8: Marilaure Grégoire, Liege University – (Invited talk 16:30-16:50)

The WMO Rolling Review of Requirements process: Ocean perspective

Marilaure Grégoire, Liège University, Joint Expert Team on Earth Observing System Design and Evolution (JET-EOSDE) member
Erik Andersson and Seiyoung Park (JET-EOSDE Chair and Vice-chair),
Etienne Charpentier and Alexander Scheid (WMO Secretariat),
Rosemary Munro (JET-EOSDE), Jochen Dibbern (consultant for drafting of HLG)

The WMO Rolling Review of Requirements (RRR) is a process to develop a consensus view on the design, evolution and implementation of WMO global integrated observing system (WIGOS) observing components as objectively as possible. The RRR collects, vets and records user requirements for all WMO application areas and matches them against observational capabilities.

More specifically, for each application area, the process consists of four stages:

(i) a review of technology-free1 Members' requirements for observations, within an application area covered by WMO programmes and co sponsored programmes;
(ii) a review of the observing capabilities of existing and planned observing systems, both surface- and space-based;
(iii) a Critical Review of the extent to which the capabilities (ii) meet the requirements (i); and
(iv) a Statement of Guidance (SoG) based on (iii) which identifies the gaps between requirements and existing, planned and proposed observing systems. The SoGs serve as a useful resource for dialogue with observing system agencies on whether existing systems should be continued, modified or discontinued;

whether new systems should be planned and implemented; and whether research and development is needed to meet unfulfilled user requirements.

Currently, among the 14 WMO Application Areas supported by WIGOS and listed in the RRR, one is dedicated to the ocean "Ocean application" and additionally, as part of the forthcoming evolved RRR process taking into account WMO's Earth System approach, the ocean appears as an interface in the Numerical Weather Predictions (NWP) and Climate Monitoring applications. A SoG for Ocean Applications was produced in 2016 by the Inter-Programme Expert Team on Observing System Design and Evolution (IPET-OSDE) based on the former Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM) User Requirement Document. A draft updated version of the SoG has been produced in consultation with the Ocean Predict OS-Eval Task Team and will be part of the High Level Guidance (HLG) document that describes actions to support the implementation of the WIGOS 2040 Vision applied for the period 2023-2028.
There is the need to redesign the WMO RRR to better address WMO's Earth System approach. The evolved RRR process will be submitted to INFCOM-2 (Oct 2022) for approval. The ocean community (e.g. OCG, GOOS, OceanPredict) has to be in the driving seat as concerns the extension of the RRR to marine applications: the definition of marine applications and the evolution of ocean observing systems (e.g. the GBON-Expansion). In particular, the Ocean Predict OS-Eval Task Team has a key role to play in the coordination of observation evaluation activities.

Abstract 1.9: Miki Hattori, JAMSTEC – (Oral 16:10-16:30)

Potential Impact of Aeroclipper Observations on a Tropical Cyclone Analysis in a Global Model

Miki Hattori[1], Hugo Bellenger[2], J.-P. Duvel[2], T. Krzemien[2]

[1]*Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Kanagawa, Japan*
[2]*Laboratoire de Meterologie Dynamique, Paris, France*

The Aeroclipper is a new long flight balloon device to measure air-sea interface [1]. In this study, the impact of the Aeroclipper sea level pressure (SLP) observations on the analysis of Tropical Cyclone (TC) Haima in October 2016 was investigated by virtual Observing System Experiments using AFES-LETKF data assimilation system (ALEDAS2). The virtual aeroclipper trajectories were synthesized based on 10 m wind in ERA Interim and their virtual SLP observations using the theoretical surface pressure profile [2] and JMA best track minimum pressure data. Despite the low horizontal resolution of the model (T119), the assimilation of these virtual surface pressure observations led to a clear decrease in the TC central pressure and to a more realistic representation of the vertical structure of the TC, not only in the analysis but also in the forecast. The forecast of the TC trajectory also tended to improve at a lag larger than 24 hours. Finally, the precipitation forecast around the Philippines also improved, suggesting that surface pressure observations by the Aeroclipper could benefit not only high-resolution models used to forecast TC evolutions but also low-resolution models used to produce global (re)analysis products.

*[1] Duvel J.-P., et al., 2009, Bull. Amer. Meteor. Soc, **90**, 63-71.*
[2] Fujita, T., 1952, Geophys. Mag. 23, 437-451.

Abstract 1.10: **Patrick Heimbach, UTEXAS – (Oral 9:50-10:10)**

Ocean Climate Observing Network Design in the Subpolar North Atlantic via Hessian Uncertainty Quantification

Nora Loose[1], Helen Pillar[2], Patrick Heimbach[2]

[1]*University of Colorado, Boulder*
[2]*University of Texas at Austin*

Designing effective ocean observing networks benefits from quantitative strategies to mitigate heavy cost and logistical challenges of ocean observing. We leverage Hessian uncertainty quantification (UQ) within the ECCO (Estimating the Circulation and Climate of the Ocean) data assimilation framework to explore a quantitative approach for ocean climate observing systems. Here, an observing system is considered optimal if it minimizes uncertainty in a set of investigator-defined design goals or quantities of interest (QoIs), such as oceanic transports or other key ocean indices. Hessian UQ unifies three design concepts: (1) An observing system reduces uncertainty in a target QoI most effectively when it is sensitive to the same dynamical controls as the QoI, as quantified by the dynamic proxy potential. The dynamical controls are exposed by the Hessian eigenvector patterns of the model-data misfit function. (2) Orthogonality of the Hessian eigenvectors rigorously accounts for complementarity versus redundancy between distinct members of the observing system. (3) The Hessian eigenvalues determine the overall effectiveness of the observing system as characterized by the sensitivity-to-noise ratio of the observational assets (effective proxy potential), analogous to the statistical signal-to noise ratio. We illustrate Hessian UQ and its three underlying concepts in a subpolar North Atlantic case study. Sea surface temperature observations inform mainly local air-sea fluxes. In contrast, subsurface temperature observations reduce uncertainty over basin-wide scales and can therefore inform transport QoIs at great distances. This research provides insight into the design of an effective observing system in the subpolar North Atlantic that maximally informs the target QoIs.

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Kostov and Y. and H. Johnson and D. Marshall and P. Heimbach and G. Forget and P. Holliday and S. Lozier and F. Li and H. Pillar and and T.A. Smith. Contrasting sources of variability in subtropical and subpolar Atlantic overturning. Nature Geoscience, 14, 491-495, (2021). doi: 10.1038/s41561-021-00759-4.

Abstract 1.11: **Julie Jakobski, MetOcean – (Oral 11:00-11:20)**

Crowdsourcing Ocean Observations in Partnership with the Fishing Sector and Coastal Ocean Stakeholders

Julie Jakoboski, Cooper Van Vranken, João De Souza, Moninya Roughan, Malene Felsing, John Radford, Naomi Puketapu-Waite

MetOcean Solutions (Meteorological Service of New Zealand)

The coastal and shelf regions of the ocean are critical to stakeholders including fisheries, tourism, recreation, and the blue economy. These regions are changing rapidly, yet spatial and temporal coverage of near real-time, subsurface, in-situ observations are often sparse, particularly in regions shallower than 1000 m. This "coastal gap" in available ocean observations exists globally (Van Vranken et al., 2020) and coincides with regions of relatively high fishing activity, providing an opportunity to work closely with the fishing sector to collect oceanographic measurements by using fishing gear deployments as a platform for sensors to obtain water column profiles. Such observations are key to improve the accuracy of operational forecasts where these are most needed.

A range of successful regional programmes worldwide collaborate with fisheries to "catch" oceanographic measurements that can be used for assimilation into hydrodynamic ocean models, model verification, and enable more efficient fishing practices and management. The pioneering eMOLT (USA) and FOOS (Italy) programmes have been running for over 20 years. In New Zealand, the Moana Project's Mangōpare programme has deployed more than 200 sensors on vessels New Zealand-wide. The data pathway is fully automatic, providing near real-time temperature and depth measurements to the Moana Project modeling suite with no human intervention after sensor installation. Measurements are provided back to the vessel that obtained them, ensuring the vessel owner/crew benefit from their data collection efforts. These programmes provide a robust, cost-effective approach to filling the coastal gap in subsurface observations, allowing us to improve ocean model accuracy in regions that strongly impact the global blue economy.

As these programmes depend on fishing sector participation, co-design is essential. Sensors and data output are developed with input from the fishing sector, ensuring benefit to the fishing sector in a circular data pathway. Collaborative work between sectors benefits the fishing sector, science community, industry, and broader ocean community. Programme decisions are made jointly with the fishing sector, providing a knowledge and innovation pathway connecting the science and fishing communities. We are aiming to democratize ocean observation by enabling participation for key coastal stakeholders and making ocean observations economically accessible for all nations.

Abstract 1.12: Shinya Kouketsu, JAMSTEC – (Poster 14:00-14:50)

Comparison of salinity distributions on isopycnal surfaces between optimal interpolation and machine learning methods for better evaluation of ocean circulations

Shinya Kouketsu, Satoshi Osafune, Toshimasa Doi, and Nozomi Sugiura

Japan Agency for Marine-Earth Science and Technology, Kanagawa, Japan

The recent observation network enables us to monitor the synoptic scale distributions of salinity and temperature monthly. Based on the observation network, the representation of the long-term mean distributions can be improved, and the ocean circulation, including sub-grid-scale diffusion as well as geostrophic velocity fields, can be diagnosed even by simple budget analysis. As such diagnosed ocean circulation structures can strongly depend on the gridded datasets obtained with observation networks, it is basically important to clarify and compare products or interpolation methods to reproduce the products. In this study, we try to make and compare products based on optimal interpolation and machine learning methods. The machine learning methods potentially capture the fine-scale structures efficiently, and the representations are about comparable to the fine-tuned (narrow decorrelation length) optimal interpolation methods. We will show differences in ocean circulation structures diagnosed with the products and try to evaluate impacts on the circulation representation.

Abstract 1.13: Matthieu Le Henaff, University of Miami – (Oral 9:10-9:30)

Recipe for rigorous OSSE assessments – Illustration in the Gulf of Mexico

M. Le Hénaff[1,2], G. R. Halliwell[2], A. Srinivasan[3], V. Kourafalou[4], H. Yang[1,2], D. Willey[1,2], R. Atlas[2]

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Observing System Simulation Experiments (OSSEs) have long been used in atmospheric sciences to quantify the performance of alternative or future observation strategies, and they have been more recently applied to oceanography. However, to credibly quantify the impacts of assimilating different observing systems, an OSSE system must follow specific design criteria and be subjected to rigorous evaluation. These procedures are necessary to avoid overestimating or underestimating observing system impacts. A rigorous ocean OSSE system consists of 1) a Nature Run (NR) that represents the true ocean, 2) a second, different ocean model (the ‘‘forecast model’’) coupled to a data assimilation system, and 3) software to simulate observations from the NR and to add realistic errors. The differences (errors) between the forecast model and the NR need to be comparable to the errors between state-of-the-art ocean models and the true ocean, to ensure that the OSSE system has realistic performance. Rigorous evaluation of the OSSE system requires performing Observing System Experiments (OSEs) that evaluate one or more existing observing systems, and then performing OSSEs that are identical to these OSEs except for the assimilation of synthetic observations from the NR. Similar impact assessments obtained from each OSE-OSSE pair validate the OSSE system impact. All these aspects have been described in the reference Halliwell et al. (2014) article and will be illustrated with applications using a Gulf of Mexico OSSE system.

Abstract 1.14: **Matthieu Le Henaff, University of Miami – (Oral 8:50-9:10)**

Observing System Evaluation showcase: Impact of ocean observations on hurricane forecasts – The cases of Hurricanes Maria (2017) and Michael (2018)

M. Le Hénaff[1,2], R. Domingues[1,2,3], H.-S. Kim[2], H. Kang[1,2], G. R. Halliwell[2], G. Goni[2], A. Mehra[4]

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The 2017 and 2018 hurricane seasons in the Atlantic Ocean showed major storms making landfall in the Caribbean region and continental U.S. Accurately forecasting major hurricanes, in particular their intensity, is a critical societal need to support decision making related to marine safety, and to the protection of lives and property. We used a coupled ocean-hurricane model, based on HYCOM and HWRF, to investigate the impact of the observed ocean conditions on the evolution of Hurricanes Maria in 2017 and Michael in 2018, and to investigate the impact of various ocean observing platforms on their prediction. One key finding is that the ocean conditions played a role in the intensification of both hurricanes. In addition, the assimilation of ocean observations contributed to improved ocean representation, and consequently to improved hurricane forecasts. In the case of Hurricane Maria, gliders deployed in the Caribbean Sea helped improve the wind intensity forecast just before the storm made landfall in Puerto Rico. In the case of Michael, the storm rapidly intensified in the Gulf of Mexico as it traveled over several key ocean features: a warm-core eddy, low-salinity areas due to the Mississippi plume, and unusually warm waters in the northeastern Gulf. In both cases, the correct representation of the ocean leads to reduced error in hurricane intensity forecasts, and it is best achieved by assimilating a combination of observations: satellite altimetry to identify mesoscale features, Sea Surface Temperature measurements to represent the mixed layer temperature, and vertical profilers, such as Argo floats or gliders, to constrain the upper ocean vertical structure and heat content.

Abstract 1.15: **Tong Lee, JPL – (Oral 10:30-10:50)**

A satellite mission concept to unravel small-scale ocean dynamics and air-sea interactions: Ocean Dynamics and Surface Exchange with the Atmosphere (ODYSEA)

Tong Lee[1], Sarah Gille[2], Fabrice Ardhuin[3]
and the broader ODYSEA Team

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[2]*Scripps Institution of Oceanography*
[3]*IFREMER*

Air-sea coupling is critical to Earth system interactions and has important consequences for weather and climate systems, ocean circulation, as well as marine ecosystem, biology, and biogeochemistry. Recent studies, many of which based on high-resolution models, have identified the importance of submesoscale air-sea wind-current interaction in air-sea coupling and upper-ocean dynamics including

vertical fluxes. As model resolution increases, including in coupled models, the need to observe submesoscale air-sea interactions has become ever more important for evaluating models and improving forecasts. Various satellite mission concepts have been proposed to advance the capability for observing submesoscale wind-current coupling. Here we present a mission concept “Ocean Dynamics and Surface Exchange with the Atmosphere” (ODYSEA) to be proposed to NASA’s Earth System Explorers that will provide the first ever, simultaneous measurements of ocean-surface winds and currents with 5-km data postings to unravel physical processes of submesoscale air-sea interactions in addition to supporting operational applications. The effort, with participation by scientists and technologists from the US and France, involves a close collaboration between NASA and CNES. Through this presentation and continued interactions, the ODYSEA team looks forward to broader community collaboration including with OceanPredict in general (including the OSEval Task Team and Coupled Prediction Task Team) and with the UN Decade-endorsed effort “SynObs” in particular.

Abstract 1.16: David Legler, NOAA – (Oral 9:30-9:50)

Strengthening ocean observation and modelling integration through co-design of a fit-for-purpose ocean observing system

Dr. David M Legler[1], Prof. Sabrina Speich[2] and Dr. Emma Heslop[3]

[1]*Global Ocean Monitoring and Observations Program/NOAA, USA & OCG Chair*
[2]*LMD-IPSL, France & OOPC co-chair*
[3]*IOC/UNESCO, Act. Head of Section, Ocean Observations and Services, Act. Office Director GOOS*

The Ocean Observing Co-Design Programme, a contribution to the UN Decade for Ocean Science, aims to transform the ocean observing system assessment and design process, creating a new framework with observing, modeling, operational services (from weather predictions to climate projections) and key user stakeholders. Co-design of the observing system will better enable us to take full advantage of new observing technologies, emerging plans for digital knowledge delivery (e.g. digital oceans), and be more responsive to stakeholder needs (locally and globally). Successful Co-Design will also provide readily available, and actionable, ocean information from a more integrated ocean observing system.

The first phase of this Programme is mobilizing the scientific community, stakeholders and end-users around multiple “Exemplars” that focus on specific societal use areas, to drive the development of requirements, identify gaps, and develop diagnostic tools. A critical part of this is strengthening observing-modeling integration to evaluate observing system efficiency and design and identify improvements, to address the development of data assimilation to deliver products that truly serve end-user needs and to demonstrate value to ocean and observing system investors.

By 2030, this Programme will have led to advances in the maturity, robustness and responsiveness of a global ocean observing system infrastructure and forecasting capability, providing the greatest possible impact for investment.

This presentation will focus on emerging plans for the Observing Co-Design Exemplars, and anticipated interactions with the SynObs community.

Abstract 1.17: Dimitris Menemenlis, JPL/NASA – (Invited oral presentation 12:00-12:20)

Potential NASA GEOS Nature Runs for Next Generation Colocated Air-Sea Measurement Satellite Mission Studies and Beyond

Dimitris Menemenelis[1], Andrea Molod[2], Chris Hill[3]

[1]*NASA/JPL, Caltech*
[2]*NASA/Goddard*
[3]*MIT*

We are proposing to present some preliminary details of a completed 14 month fully coupled open science and open source nature-run with sub 10 kilometer grid spacing (7km atmosphere, 2-4km ocean) in all components and covering the 2020 period. We will also show the current status of an ongoing sub 4 kilometer grid spacing (4km atmosphere, 2km ocean) follow-on experiment. Both sets of numerical experiments are based on coupled configurations of the GEOS modeling system with the ECCO-MITgcm ocean option. The initial states of the system derive from coarser resolution data assimilating model configurations.

The nature-runs, themselves, are free-running. Early analysis shows new perspectives on local air-sea coupling. For example, over western boundary current fronts in the Gulf Stream region we see intermittent latent heat bursts that appear to correspond to a secondary circulation that results from the coupling between ocean sub-mesoscales temperature anomalies and atmospheric dry air descent. Globally, we have computed new estimates of air-sea momentum and kinetic energy exchange at high-frequencies and on scales of a few kilometers. The energy exchange on these scales is not insignificant in comparison to established large-scale estimates.

Our current nature runs already seem to be providing potentially valuable information both for process understanding and for colocated ocean atmosphere observation satellite mission design studies. Model states from the nature run have been saved with at least hourly intervals and we are currently working toward making one hundred percent of the raw fields and diagnosed quantities (potentially 5PiB or more in size) openly available over high-speed links together with online cloud computing based tools for basic data examination and plotting. Our fields are currently publicly available today, but with somewhat limited bandwidth and with a small number of example analysis scripts.

Abstract 1.18: Andrew Moore, UCSC – (Invited oral presentation 9:10-9:30)

Forecast Sensitivity-based Observation Impact (FSOI) in an Analysis-Forecast System of the California Current Circulation

Andrew Moore[1], Christopher Edwards[1], John Wilkin[2], Hernan Arango[2], Brian Powell[3], Julia Levin[3], Patrick Drake[1], and Tayebeh TajalliBakhsh[4]

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[2]Rutgers University, U.S.A.
[3]University of Hawaii, U.S.A.
[4]RPS Group, U.S.A.

The U.S. Integrated Ocean Observing System (IOOS) forms the backbone of real-time ocean analysis-forecast systems of U.S. territorial waters. In addition to satellite remote sensing, the IOOS is augmented with in situ observations from a variety of platforms including Argo floats, buoys and gliders. Remote sensing observations of surface currents are also available from an extensive national network of coastal HF radars. Maintenance of these observing systems is obviously labor-intensive and costly. Routine monitoring of the impact of the data from each element of the observing array on ocean analysis-forecast systems is therefore recognized as an important activity, not only for maintaining the array and demonstrating its value, but also as an aid for planning future expansions of the observing network. This talk will focus on current efforts to quantify forecast sensitivity to observation impacts (FSOI) in an ocean analysis-forecast system of the California Current System (CCS) along the U.S. west coast. The real-time system is based on ROMS-4D-Var, and FSOI has been applied to metrics of forecast skill that target important features of the CCS circulation along the central California coast. On average, ~50-60% of all observations assimilated into the model were found to yield improvements in the forecast skill.

Abstract 1.19: Satoshi Osafune, JAMSTEC – (Poster 14:0-14:50)

An improved long-term ocean state estimation using dynamically based schemes for tidally induced vertical mixing

Satoshi Osafune, Shinya Kouketsu, Toshimasa Doi, Nozomi Sugiura and Shuhei Masuda

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We updated the Estimated STate of the global Ocean for Climate research (ESTOC), a long-term ocean state estimation dataset that is obtained by using a quasi-global four-dimensional variational data assimilation system. The ocean general circulation model (OGCM) in this system originally uses three semi-empirical schemes for interior vertical mixing below the surface mixed layer in the open ocean. We replaced those schemes with two dynamically based schemes for tidally induced vertical mixing that provides more realistic three-dimensional distribution of mixing. We also implemented geothermal heat flux. Using this modified OGCM, we conducted a long-term data synthesis experiment. Using this updated ESTOC, we investigated the decadal warming in the abyssal ocean. The reproduction of the warming is improved in this updated ESTOC in comparison with a previous version. From budget analysis and forward impact experiments, we show that the downward heat flux related to bottom-intensified vertical mixing plays an important role in determining the improved distribution of abyssal-water warming in the Pacific Ocean. These results suggest the importance of using dynamically based mixing schemes in long-term ocean state estimation, and possibly the usefulness of assimilating three-dimensional ocean mixing observations into the system.

Abstract 1.20: Aurélien Prat, UMR 8105 LACy et Inria – (Oral 17:40-18:00)

Pre-processing of sea turtle biologging observations using a clustering algorithm

Aurélien Prat
LACy and Inria, July 2022

The international research program Sea Turtles for Ocean Research and Monitoring (STORM) aims to exploit biologging technology in tropical regions from marine turtles equipped with environmental tags. The goals of this pluridisciplinary program are to improve weather forecasts during periods of cyclonic activity, to better understand the interactions between the ocean and meteorological phenomena, as well as to learn more about the spatial and thermal ecology of various species of sea turtles living in the SW Indian Ocean.

Within the STORM framework, a regional configuration of the ocean general circulation modeling tool NEMO was developed over the SWIO to provide ocean forecasts during the cyclonic season (Nov - Apr). This numerical model translates an idealized behavior of the system, which can be corrected by data assimilation of state variable measurements within a given forecast time window to correct the predictions calculated by the model. STORM observations are collected by sea turtles equipped with ARGOS tags that not only provide animal positions but also surface and in-depth quantitative measurements of temperature, salinity and, to some extent, fluorescence along the track of the animal.

Biologging data is assimilated using a variational approach that consists in minimizing a cost function evaluating the discrepancy between the ocean state predicted by the model and the observations. In order to simplify the evaluation of this cost function, the number of collected observations has to be reduced by creating so-called "super-observations", that consist in averaging groups of data with low variability in space and time to reduce the correlation between observations. The considered approach is to cluster observations using an unsupervised learning method such as the k-means algorithm, based on the following three variables as criteria for clustering observations: time, depth and temperature.

In this presentation we will introduce the STORM framework along with a global overview of data assimilation using a variational approach, then we will describe the clustering method used to reduce the number of observations. We will finally discuss the planned biologging observation monitoring and ocean reanalysis that will be of particular interest when assessing the quality of the observing system.

Abstract 1.21: Cheyenne Stienbarger, NOAA – (Oral 10:10-10:30)

Co-Designing an Observing System for Improved Tropical Cyclone Forecasts

Cheyenne Stienbarger[1], Scott Glenn[2], Gustavo Goni[1], Kosuke Ito[3], Sok Kuh Kang[4], Hyun-Sook Kim[1], Matthieu Le Henaff [5], I-I Lin[6], Travis Miles[2]

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[4]KIOST, Republic of Korea
[5]University of Miami/RSMAS, USA
[6]National Taiwan University, Taiwan

This effort stems from the Tropical Cyclone Ocean Observations and Forecasts Exemplar of the Global Ocean Observation System (GOOS) Ocean Observing Co-Design Programme with the overarching goal of providing recommendations for designing an ocean observing system to improve tropical cyclone (TC) intensity forecasts that is co-developed among the global observing and modeling communities.

TCs are among the most destructive weather events on Earth with severe impacts that occur in almost all ocean basins, are modified by warming oceans, rising sea levels, and growing coastal populations, and have inequitable effects on less developed countries and small island developing states.

An essential layer of protection that will save lives and property, and promote equity and resiliency, is provided by actionable TC forecasts and warnings with increased accuracy and lead time that are enabled by an Earth System Modeling (ESM) approach, together with surface and subsurface ocean observations. While progress has been made across ocean basins, no sustained global ocean observing system yet exists in support of TC intensity research and forecasts.

The Tropical Cyclones Exemplar was the subject of one of six breakout sessions in the Co-Design Programme's Inaugural Workshop. Over 50+ members of the international community gathered to discuss the benefits, stakeholders, requirements, observing status, modeling status, gaps, and potential exemplar pilot studies for collaborative activities in ocean basins impacted by TCs.

We envision a collaborative global network of regionally-distributed ocean observing contributions through the co-design process, to improve our understanding of coupled physical processes under intense wind conditions, and to address the current dearth of ocean data available for TC forecasting applications. We will provide examples of how the co-design efforts have already led to successful collaborations between the observing and modeling communities for improving observations and models. We will also discuss the complex competition and offset between atmosphere and ocean that jointly control TCs. Finally, we will conclude with the lessons learned, needs, and challenges to share across ocean basins and how the co-design process helps to bring advancements in TC forecasting regionally and globally.

We view the Co-Design Programme's Tropical Cyclone Exemplar as a high-impact use case for the Synergistic Observing Network for Ocean Prediction project, and anticipate ample opportunities for collaboration between Ocean Observing System Co-Design and OceanPredict communities in the future.

Abstract 1.22: Toshio Suga, JAMSTEC – (Oral 15:50-16:10)

Argo "Abrupt Salty Drifters" – the problem, impacts, and lessons learned

Toshio Suga[1,2], Susan Wijffels[3], Breck Owens[3], Megan Scanderbeg[4], Birgit Klein[5] and Virginie Thierry[6] on behalf of the International Argo Steering and Data Management Teams

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Beginning in 2015, a sensor manufacturing issue caused a higher than expected percentage of Sea-Bird conductivity cells used in Argo floats to experience premature and high rates of salty drift, eventually becoming uncorrectable. The sensor problem generally takes one to two years of deep ocean operation to develop, and with the built-in 12-month delayed modded quality assessment lag, this problem was not diagnosed as a fleet-wide issue until 2018, after many afflicted floats had already been deployed. The Argo community termed this Abrupt Salty Drift (ASD). The rate of "Salty Drifters'' correlates with specific CTD manufacturing batches. Sea-Bird Scientific implemented a manufacturing change at the end of 2018 and issued a recall in 2021 for one of the recent batches of affected CTDs. Despite the recall, the Argo array still contains many affected Sea-Bird CTDs that were deployed prior to the recall warning. Argo posted warnings on both the Argo Data Management Team and Argo Steering Team websites, and a data FAQ in September 2018, warning that real-time data might be biased by this sensor problem. Wong et. al. also noted the issue in their review of the first 20 years of Argo data system in 2020 publication. The data QC teams actively searched for and flagged out the ASD-afflicted floats and the potential salty drifting floats are now being actively monitored. When sensor drift is detected, salinity data from the float in question is flagged by the Argo QC processes in real time or near-real time and adjusted in delayed mode, when possible. Prior to these actions by the Argo data team, a significant number of ASD-biased data were included in the real-time data stream. As a result, several data products and archives were reported to be significantly biased, whereby the global average ocean salinity is seen to rise unrealistically post 2015. The Argo Steering Team has always recommended that all Argo data users and Argo data product creators frequently synchronize their data holdings with the Argo GDAC to obtain the latest quality controlled data, salinity adjustments, and errors. In particular, it is essential that when Argo data are used for global change studies, only delayed-mode adjusted values, when available, should be used or the real time data be carefully assessed. How networks like Argo can do better to inform their users and product creators about these challenging sensor issues should be explored.

Abstract 1.23: Viktor Turpin, OceanOPS/WMO – (Oral 18:40-19:00)

Leveraging the multi-system glider data assimilation experiments within EuroSea to the international level

Victor Turpin[1], Elisabeth Remy[2], Ali Aydogdu[3], Baptiste Mourre[4], Romain Escudier[2], Pierre Testor[5], Jaime Hernández-Lasheras[4], Nikos Zarokanellos[4], Brad deYoung[6]

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[6]*Memorial University of Newfoundland, Halifax, Canada*

In the framework of the EuroSea project, Europe is running an assessment of its capacity to assimilate gliders data operationally and demonstrate the best practices for the intercomparison of the impact on different operational systems. By bringing under the same umbrella the European communities of the ocean observing value chain, from observation at sea to operational data assimilation, Europe is trying to unlock the silo's of the different disciplines and promote cooperation between ocean scientists.
In this talk, from the EuroSea project and other examples, we will demonstrate why the international context is becoming very favorable for a coordinated approach around gliders data assimilation. We will provide suggestions to leverage such efforts at the international level to better understand how to benefit the best from this great sustained coordinated ocean observing effort made by gliders.

Abstract 1.24: Iwao Ueki, JAMSTEC– (Oral 10:40-11:00)

Tropical Pacific Observing System -synergy with modeling and assimilation activities

Iwao Ueki[1], Billy Kessler[2], Fei Chai[3] and Karen Grissom[4]

[1]*RIGC/JAMSTEC*
[2]*PMEL/NOAA*
[3]*SIO/MNR*
[4]*NDBC/NOAA*

The goals of the Tropical Pacific Observing System (TPOS) 2020 Project were to redesign and enhance the TPOS, to meet today and future needs of both research and operational centers. It aimed at building a more integrated, modern and robust observing system, taking advantage of new science and technology. The TPOS 2020 project identified gaps in the current system, the variables and scales to be sampled, and areas of needed research. It proposed a redesign, taking full advantage of the diverse remote and in situ techniques available today, considering their complementarity, and fitting them together in an integrated system. It also specified the model and assimilation improvements needed to fully utilize the observations. TPOS 2020 accelerated advancements in technology, and motivated sponsors to make significant investments in many observational and modeling initiatives.

The vision of TPOS is to build a robust observing system that will be ready to detect and diagnose changes in the tropical Pacific by observing underlying physical processes and refining models. TPOS will provide enhanced capabilities for observing upper ocean and air-sea interactions across a diversity of climate regimes, based on enhanced moorings configuration, and a proposed doubling of Argo floats. Advantages of TPOS for modeling/assimilation activities are real-time acquisition of detailed time series at fixed positions in the wide area, simultaneous time series for multiple variables in the upper ocean and lower atmosphere, and long-term time series. These characteristics are useful for observing system evaluation and derivation of reanalysis products. Alternatively, results from those activities will be helpful for implementation and strategy development of TPOS. We believe improvement of our observation and modeling/assimilation capabilities will be produced by mutual communication between both communities.

Abstract 1.25: Norihisa Usui, MRI – (Poster 14:00-14:50)

Impact of the assimilation of simulated wide-swath altimeter data in a regional eddy-resolving assimilation system at JMA/MRI

Norihisa Usui, Nariaki Hirose, Yosuke Fujii

JMA/MRI

Observing System Simulation Experiments (OSSEs) were conducted to assess the impact of the assimilation of high-resolution sea surface height (SSH) data based on wide-swath satellite altimetry mission such as SWOT (Surface Water Ocean Topography) and COMPIRA (Coastal and Ocean measurement Mission with Precise and Innovative Radar Altimeter, planned by JAXA). A nature run was obtained from a 1-year free simulation experiment using a 2-km resolution ocean model covering the seas around Japan. Pseudo observations for SWOT and COMPIRA as well as conventional data such as nadir altimeters, sea surface temperature, and in-situ temperature and salinity profiles were generated from the nature run. Such observations were assimilated using a 10-km resolution assimilation model based on a four-dimensional variational (4D-Var) method. Assimilation results indicate that both SWOT and COMPIRA data significantly contribute to reduction of analysis errors. The error reduction is relatively large in the western boundary current regions such as the Kuroshio/Kuroshio Extension and Oyashio regions, where root-mean-square errors for the SSH field are reduced by about 10-30%. It was also found that the high-resolution SSH data derived from SWOT and COMPIRA have larger impacts on smaller scale features with a horizontal scale of around 100km.

Abstract 1.26: Caihong Wen, NOAA – (Oral 9:55-10:15)

Real-time Ocean Reanalyses Intercomparison Project

Caihong Wen

NOAA/NWS/NCEP/Climate Prediction Center

Ocean reanalysis (ORA) data sets play an important role in seasonal predictions and climate studies because ORA provides (1) initial conditions for operational dynamical seasonal prediction models, (2) valuable information for real-time ENSO monitoring, and (3) historical context for climate variability analysis. The Tropical Pacific Observing System (TPOS) is one of the major observation sources which are assimilated in the operation ocean data assimilation systems to produce ORAs. A rapid decline of the Tropical Atmosphere Ocean (TAO) array took place during 2012-2013. This degradation of the TAO moored array raised a serious concern whether the temporal variation in the observing system influences the quality of ORA and ENSO prediction skills. To address the concern, NOAA CPC collaborated with eight operational centers from all over the world to initiate the Real-time Ocean Reanalyses Intercomparison Project (RT-ORA-IP) in 2015. The ensemble approach allows a more reliable estimate of climate signal as well as an estimation of climate noise. The purpose of this talk is to provide an overview of the

achievements and status of RT-ORA-IP. We will highlight how the ensemble approach contributes to the TPOS 2020 project. We will also highlight how the ensemble approach is used to support real-time ENSO monitoring and prediction.

Abstract 1.27: Annie P. Wong, University of Washington – (Oral 9:10-9:30)

Argo salinity: bias and uncertainty evaluation

Annie P. Wong[1], John Gilson[2]

[1]*University of Washington*
[2]*Scripps Institution of Oceanography*

Argo salinity is a key set of in-situ ocean measurements for many scientific applications. However, the raw, uncorrected salinity data can contain bias from various instrument problems, most significant of them comes from sensor calibration drift in the conductivity cells. Inclusion of raw, uncorrected Argo salinity has been shown to lead to spurious results in estimates of the global sea level budget. Argo delayed-mode salinity data are data that have been evaluated and, if needed, adjusted for sensor drift, and are the data that should be used in scientific applications. We present an analysis of the delayed-mode evaluation and adjustments that have been applied to Argo salinity since the beginning of the global program. A validation of the Argo delayed-mode salinity dataset has been carried out to identify inappropriate adjustments, egregious residual errors, and any regional variations in uncertainty. The best ways to use Argo data are also described.

Abstract 1.28: Jieshun Zhu, NOAA – (Oral 9:30-9:50)

Next Generation Global Ocean Data Assimilation System (NG-GODAS): a new reanalysis and OSSE applications

Jieshun Zhu[1], Arun Kumar[1], Shastri Paturi[2], Travis Sluka[3], Guillaume Vernieres[4], and Wanqiu Wang[1]

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At NOAA, the UFS modeling infrastructure is being combined with the Joint Effort for Data Assimilation Integration (JEDI) project to establish NOAA's Next Generation Global Ocean Data Assimilation System (NG-GODAS) system. NG-GODAS is based on MOM6 ocean and CICE6 sea ice models and with the JEDI-SOCA 3DVar scheme. In this presentation, we will first demonstrate a new reanalysis completed with NG-GODAS for 1982-present, which assimilated various types of *in situ* and satellite observations, e.g., *in situ* temperature and salinity profiles, sea surface temperature, satellite absolute

dynamic topography, sea ice concentration. Evaluations indicate that NG-GODAS provides improved temperature and salinity analyses compared to current NOAA operational systems (i.e., GODAS and CFSR).

Based on the assimilation system, a series of ocean observing system simulation experiments (OSSEs) were also conducted in support of the Topical Pacific Observing System 2020 (TPOS 2020) Project. For the OSSEs, the atmospheric forcing and synthetic ocean observations are generated from a nature run, which is based on the modified CFSv2 with ocean vertical resolution of 1-meter near the ocean surface. Experiments were conducted to evaluate (1) the current TPOS *in situ* component with a focus on the Pacific tropical moored buoy array (TMA; i.e., the collective TAO/TRITON moored array) and Argo, and (2) the proposed TMA configuration recommended by the TPOS 2020 project.

In future, the same assimilation capability can also be used for collaborative ocean observing system (OSE) experiments across several operational centers.

2. Theme 2: Data assimilation development for better use of observation data

Abstract 2.1: Joao Azevedo Correia de Souza, MetOcean Solutions – (Oral 11:20-11:40)

Assimilation of fishing vessel derived observations into an operational ocean forecast system

Joao Marcos Azevedo Correia de Souza

MetOcean Solutions, a division of Meteorological Service of New Zealand

New Zealand has the 9th larger oceanic Economic Exclusive Zone and is the 52nd-largest national economy in the world. Therefore, it is key to efficiently use resources to support the development of a blue economy that is sustainable and resilient to climate change. While the seafood sector alone brings $4.18B to NZ annually, oil and gas offshore exploration provides about 30% of the country's consumption. Having a robust representation of the ocean dynamics allied to a reliable forecast system is strategic for the country's economy and the community and environment safety and resilience. The Moana Project objective is to provide state of the art science to revolutionize ocean observing and modeling in New Zealand to support the Blue Economy by providing accurate ocean observations, models and data products. We are building a robust view of the past ocean behavior to improve the understanding of the drivers of variability that impact ocean activities, such as commercial fishing and aquaculture. But to do this in an efficient way we need to partner with the communities that have been exploring these very resources for centuries, and we need to observe the ocean. By deploying a New Zealand developed water temperature and pressure sensor – the Magōpare sensor – in partnership with the fishing industry we are building a new "nationwide ocean observing capability". These observations are integrated into our open-access ocean models to understand the past and provide forecasts for the near future (7 days), increasing our capacity to plan and respond to emergencies and changes in the ocean environment. Here we present the first results from a regional simulation with 4DVar data assimilation of observations from the fully automated Magōpare sensor attached to different fishing gear in New Zealand waters.

Abstract 2.2: Mounir Benkiran, MOI – (Oral 14:50-15:10)

Impact of SWOT observations in a global high-resolution analysis and forecasting system

Mounir Benkiran

Mercator Océan Internationale

A first attempt was made to quantify the impact of the assimilation of Surface Water Ocean Topography (SWOT) swath altimeter data in a global 1/12° high resolution analysis and forecasting system through a series of Observing System Simulation Experiments (OSSEs). The impact of assimilating data from SWOT

and three nadir altimeters was quantified by estimating analysis and forecast error variances for sea surface height (SSH). Wave-number spectra and coherence analyses of SSH errors were also computed. SWOT data will significantly improve the quality of ocean analyses and forecasts. Adding SWOT observations to those of three nadir altimeters globally reduces the variance of SSH and surface velocities in analyses and forecasts by about 30 and 20%, respectively. Improvements are greater in high-latitude regions where space/time coverage of SWOT is much denser. The combination of SWOT data with data from three nadir altimeters provides a better resolution of wavelengths between 50 and 200 km with a more than 40% improvement outside tropical regions with respect to data from three nadir altimeters alone. The study has also highlighted that the impact of using SWOT data is likely to be very different depending on geographical areas. Constraining smaller spatial scales (wavelengths below 100 km) remains challenging as they are also associated with small time scales. Although this is only a first step, the study has demonstrated that SWOT data could be readily assimilated in a global high-resolution analysis and forecasting system with a positive impact at all latitudes and outstanding performances.

Abstract 2.3: Inseong Chang, Pukyong National University – (Oral 11:10-11:30)

Impact of in situ and satellite data assimilation on ocean circulation prediction system in Northwest pacific

Inseong Chang[1], Young Ho Kim[1], Hyunkeun Jin[2], Young-Gyu Park[2], Gyundo Pak[2]

[1]Division of Earth & Environmental System Sciences, Pukyong National University, [2]Ocean Circulation Research Center, Korea Institute of Ocean Science & Technology

In order to evaluate the contribution of in situ and satellite observation data to the high-resolution ocean circulation prediction system, a sensitivity experiment was conducted by applying Ensemble Optimal interpolation(EnOI) to Korea Operational Oceanographic System – Ocean Predictability Experiment for Marine environment(KOOS-OPEM) developed by Korea Institute of Ocean Sciences and Technology(KIOST). In situ temperature/salinity data collected from NOAA's World Ocean Database and the Korea Oceanographic Data Center(KODC), in-situ data around Korea marginal seas, as well as OISST (NOAA's Optimum Interpolation Sea surface Temperature) and along-track altimetry data of ERS-1 and Topex/Poseidon released by AVISO are assimilated in this study. When assimilating satellite altimetry data, an indirect assimilation method proposed by Cooper and Haines (1996) was applied. In this indirect assimilation system, the pseudo profiles created by vertically rearranging the preexisting model profile by assuming the conservation principle are assimilated into the model. When evaluating the performance of each experiment with respect to independent observation data, satellite altimetry data improved the subsurface structure of temperature/salinity compared to the control experiment, and in particular, the correlation of ocean surface currents significantly improved. When KODC's temperature data were assimilated, the subsurface structure of temperature/salinity in Kuroshio Extension and Oyashio Current region as well as in the East/Japan Sea was improved, and the correlation of ocean surface currents with respect to observation data in Kuroshio Extension and Oyashio Current region was also increased by 5.29% and 10.29%, respectively. Conclusively, the contributions of each observation components have been evaluated in this study. In particular, it is interesting that the regional observation around Korea peninsula

has contributed to improve the ocean reanalysis in the northwest Pacific as well as Korea marginal seas. It is worth paying attention to the role of regional ocean observing networks in the ocean prediction systems.

Abstract 2.4: Stefano Ciavatta, MOI – (Oral 18:00-18:20)

Monitoring and predicting marine ecosystems by fusing observations and models

Stefano Ciavatta[1], Marjorie Friedrichs[2], Frank Muller-Karger[3] on the behalf of the MEAP TT

[1] *Mercator Ocean International*
[2] *Virginia Institute of Marine Science, William & Mary*
[3] *Institute for Marine Remote Sensing, University of South Florida*

Marine ecosystems provide us with vital climate and food services. They absorb 30% of anthropogenic carbon emissions and support the livelihoods of over three billion people. However, marine ecosystem services are shifting under pressure from both direct human pressures and climate change. To better understand and to predict how marine life, ecosystems and human livelihoods are impacted by stressors, we require long-term observations and improved modeling forecast systems. Marine operational forecasting centers aim to produce accurate ocean-monitoring products, establish baselines, quantify anomalies, and provide the infrastructure for operational forecasting services by integrating remotely-sensed satellite data, *in situ* ocean observations, and ocean models. Whilst integrating observations and models of ocean physics is a common practice in operational centers worldwide, relatively few centers integrate observations with models of ocean biogeochemistry and higher-trophic-levels. This hampers our ability to monitor and predict vital marine ecosystem services.
The scientific development, implementation, and application of systems that integrate ecosystem observation and models, from biogeochemistry to higher trophic levels, are the main objectives of the Marine Ecosystem Analysis and Prediction (MEAP) Task Team of OceanPredict.
In this presentation, the MEAP Teams' scientific highlights and exemplars are reviewed in the context of ocean health evaluation, optimal monitoring system design, and marine management. This encompasses integration of data from multi-platform observing systems (e.g. satellites, floats, ships and gliders) for physical and biogeochemical data (e.g., SST, ocean color, nutrients) into one-way and two-way coupled model systems (physics/biogeochemistry/higher trophic levels/ecology) in coastal, regional and global domains. The applications showcased include (i) the operational forecast and reanalysis of ecosystem indicators in the Mediterranean Sea, (ii) the evaluation of the global biogeochemical-Argo fleet in Observing System Simulation Experiments (OSSE); (iii) a "smart" glider driven by bloom forecasts in the English Channel that assimilated the glider data themselves, and (iv) novel carbon flux estimates in the global ocean derived by assimilating data from floats, gliders, and satellites. Drawing on these applications, we advocate for integrating biogeochemical, biology and ecology Essential Ocean Variables in models that can be used by operational centers. We discuss the merits and feasibility of expanding integration approaches to higher trophic levels, from microbes to marine mammals, and from habitats to ocean basins. An important goal is to advance monitoring and predicting marine biodiversity as a contribution to the UN

Decade of Ocean Science for Sustainable Development (the Ocean Decade) by linking the communities of various Ocean Decade programs and projects such as SynObs, ForeSea, and Marine Life 2030 to help manage marine ecosystem services sustainably.

Abstract 2.5: Olivier Goux, CERFACS – (Oral 17:00-17:20)

Accounting for correlated observation error in variational ocean data assimilation: application to wide-swath altimeter data

Olivier Goux

CERFACS

In variational data assimilation, the analysis is obtained by iteratively minimizing a cost function measuring the weighted least-square fit of an estimate of the state of the system to the background state and to the observations. The weights are determined by the respective error covariance matrices of the background and observations, B and R. In order to avoid explicitly building these matrices, the cost function is minimized using a B-preconditioned Conjugate Gradient, which only involves matrix-vector products with B and R-1 . While B has been thoroughly studied and is well represented in the current data assimilation system, R is generally assumed to be diagonal to simplify the access to its inverse.

This assumption is not appropriate for all observation types and is especially suspicious for high resolution satellite data. Not accounting for existing correlations in the observation error leads to overfitting of the observations at large spatial scales and underfitting them at small spatial scales. Common mitigation techniques involve thinning, i.e., assimilating only a subset of distant observations, and artificially inflating variances to reduce the overfit at large scales (which amplifies the underfit at small scales). Both methods are detrimental to the extraction of small-scale features from the observations and limit the potential of high resolution observations.

In order to use high resolution observations at their full potential, data assimilation algorithms need to be able to account for observation error correlations. In particular, we take the example of the SWOT mission, due to be launched in November 2022. SWOT will carry a wide swath altimeter which will provide sea level anomaly measurements at an unprecedented resolution. However, the error budget suggests that its observation error will contain substantial long range spatial correlations. Using simulated data from the JPL/CNES SWOT simulator, we characterize these correlations and suggest a method based on diffusion operators to account for them in variational data assimilation. Diffusion operators, originally designed to model correlations in B, have been recently adapted for observation error correlations. They provide easy access to the inverse operator R-1 at a low computational cost even for large datasets and are suitable for unstructured data such as observations.

Abstract 2.6: Naoki Hirose, RIAM, Kyushu University – (Invite Oral talk 11:40-12:00)

Coastal ocean data assimilation with small-scale fishing vessels

Naoki Hirose

RIAM, Kyushu University

Large number of in-situ measurement data have been recently collected from small-scale fishing vessels in the Tsushima Strait and surrounding areas. This study presents the data assimilation efforts of these CTD and ADCP data into coastal ocean models. The detailed comparison validates the viscous land-sea boundary conditions learned from CFD turbulent models. The weaker viscosity at the wall boundary allows realistic intensity of coastal currents and subsurface advections. The coastal motions and TS changes can be improved by unstructured sparse Kalman filters furthermore. Many coastal fishermen enjoy the short-term ocean predictions through Android App and actually save the fuel cost and working hours motivating the in-situ measurements.

Abstract 2.7: Shoichiro Kido, JAMSTEC – (Poster 14:00-14:50)

Development and application of eddy-resolving quasi-global ocean reanalysis product -JCOPE-FGO

Shoichiro Kido[1], Masami Nonaka[1], and Yasumasa Miyazawa[1]

[1] Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Application Lab

Ocean reanalysis and forecasting systems, which combine information derived from observations and numerical ocean models through data assimilation scheme, serve as a powerful tool for nowcasting and forecasting the ocean state. Recent progress in observational and modeling techniques as well as increase in computational power have enabled us to routinely monitor the state of world oceans, and various ocean reanalysis products have been released so far. In this presentation, we will present an overview of our newly-developed eddy-resolving quasi-global ocean reanalysis product, named the Japan Coastal Ocean Predictability Experiments-Forecasting Global Ocean (JCOPE-FGO). The JCOPE-FGO is a global extension of the regional JCOPE system originally configured for the western North Pacific, and it covers the global ocean from 75°S to 75°N with a horizontal resolution of 0.1°x0.1°. In this system, observational information obtained from in situ temperature and salinity profiles (including those from Argo profiles) and satellite observations of SST and SSHA are dynamically incorporated into an eddy-resolving ocean general circulation model with the 3DVAR scheme. The JCOPE-FGO provides estimates of three-dimensional oceanic states from January 1993 to present. Comprehensive validations of analyzed oceanic fields of the JCOPE-FGO against various types of available observations revealed that the product can realistically represent spatial distributions of water mass structures and dynamical fields in most part of the global ocean, although some quantitative discrepancies are also identified over several specific regions. The temporal variations in these fields are also correctly captured both in the tropical and extratropical oceans. This suggests that this product serves as a useful tool for monitoring changes in oceanic state and understanding their physical origins. Preliminary results for forecasting experiments using the JCOPE-FGO will also be briefly introduced during the presentation.

Abstract 2.8: Dimitris Menemenlis, JPL/NASA – (Oral 15:30-15:50)

Introduction to the Estimating the Circulation and Climate of the Ocean (ECCO) project

Dimitris Menemenlis

JPL/NASA

The Estimating the Circulation and Climate of the Ocean (ECCO) consortium aims to make the best possible estimates of ocean circulation and its role in climate. ECCO was initiated in 1999 to synthesize hydrographic data from the World Ocean Circulation Experiment (WOCE) and TOPEX/Poseidon satellite sea surface height measurements into a complete and coherent description of the ocean. ECCO is based on the Massachusetts Institute of Technology general circulation model (MITgcm) and its automatically-generated adjoint model. Solutions are obtained by combining ocean configurations of the MITgcm with satellite and in-situ data sets in a physically and statistically consistent manner. ECCO circulation estimates have been used for studies of ocean variability, sea level, water cycle, ocean-cryosphere interactions, geodesy, and many more. The property-conserving nature of ECCO estimates makes them particularly well-suited for ocean ecology and biogeochemistry studies.

Abstract 2.9: Shun Ohishi, Riken/R-CCS – (Poster 14:00-14:50)

LETKF-based Ocean Research Analysis (LORA): Assimilating high-frequency satellite observations

Shun Ohishi[1], Takemasa Miyoshi[1], and Misako Kachi[2]

1: RIKEN/R-CCS,
2: JAXA/EORC

To provide accurate ensemble ocean analysis products, we have developed an ensemble Kalman filter (EnKF)-based regional ocean data assimilation system assimilating satellite and in-situ observations at a short interval of one day, and performed sensitivity experiments on incremental analysis update (IAU; Bloom et al. 1996), various covariance inflation methods [multiplicative inflation, relaxation to prior perturbation (RTPP; Zhang et al. 2004), and relaxation to prior spread (RTPS; Ying and Zhang 2015)], and adaptive observation error inflation (AOEI; Minamide and Zhang 2017). The results show that the combination of the IAU and RTPP, in which the forecast ensemble perturbations are relaxed toward the analysis ensemble perturbations by 80-90 %, significantly improves both dynamical balance and accuracy (Ohishi et al. in review). Around the Kuroshio Extension regions where the representation errors associated with fronts and eddies are exceedingly large, the AOEI reduces erroneous large temperature and salinity increments through adaptively inflating the observation errors (Ohishi et al. in review). As a result, the AOEI suppresses strong vertical salinity diffusion and improves the low-salinity structure in the intermediate layer.

Currently, no EnKF-based analysis products exist in the Pacific region to the best of our knowledge, although there are two regional EnKF-based datasets known as TOPAZ4 (Sakov et al. 2012) around the Arctic region and BSH (Brüning et al. 2021) in the North and Baltic Sea. Therefore, we aim to create EnKF-based ocean analysis datasets with high horizontal resolution of 0.1° in the western North Pacific (WNP) and Maritime Continent (MC) regions, and to compare the accuracy with the existing analysis and observational datasets. The datasets constructed in this study are referred to as LORA-WNP and LORA-MC, in which LORA stands for the local ensemble transform Kalman filter (LETKF)-based Ocean Research Analysis.

The validation results show that the root mean square differences (RMSDs) of the LORA-WNP relative to surface horizontal velocities from the independent drifter buoys are smaller in the mid-latitude region compared with JCOPE2M (Miyazawa et al. 2017), but larger in the subtropical region. Compared with the AVISO (Ducet et al. 2000), the LORA-MC is more (less) close to the drifter buoys in the coastal (offshore) regions. We have calculated the RMSDs relative to other observations and concluded that the LORA-WNP and LORA-MC have sufficient accuracy for a variety of geoscience research as well as fisheries, marine transports, and marine environment consultants.

Abstract 2.11: Sivareddy Sanikommu, KAUST– (Oral 17:40-18:00)

Insights from Large Ensembles Experiments with the Red Sea Ensemble Data Assimilation System

Sivareddy Sanikommu[1], Naila Raboudi[1], Peng Zhan[2], Bilel Hadri[1], Moha El Gharampti[3], Ibrahim Hoteit[1],*

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Ensemble Kalman Filters (EnKFs), which assimilate observations based on statistics derived from ensembles of ocean states, have become the norm for ocean data assimilation (DA) and forecasting. Using large enough ensembles is important to obtain robust statistics as was confirmed in simplified settings. Only limited ensembles (~10-100 members) could be, however, afforded in real-time applications. With ever increasing computational resources, the use of large ensembles will become possible. Here we assess the performance of a fully realistic high resolution ocean EnKF-DA system with very large ensembles.

A series of 1-year-long Large Ensemble Experiments (LEEs) was conducted with the Red Sea DA system using tens-to-thousands of members. The system uses a 4km MITgcm for forecasting and DART ensemble Adjustment Kalman Filter (EAKF) for assimilation. It accounts for model uncertainties by integrating MITgcm with ECMWF atmospheric ensemble fields and perturbed internal physics, and assimilates satellite and in-situ observations.

The results indicate that accounting for uncertainties in atmosphere and physics enhances the system robustness to localization. While the systematic increase in ensemble size leads to marginal improvements and seems to saturate at about 250 members, localization is still needed even when the system is configured with thousands of members. This is explained by (i) amplified spurious long-range

correlations due to perturbed physics and in particular to the low-rank nature of the ECMWF ensemble, and (ii) non-Gaussianity generated by the nonlinear nature of the forecast model. Large ensemble forcing fields and non-Gaussian DA methods will be needed to maximize the benefits from large ensembles in ocean DA.

Abstract 2.12: Nozomi Sugiura, JAMSTEC – (Oral 15:10-15:30)

Ocean data assimilation based on MMD between sets of profiles

Nozomi Sugiura

Japan Agency for Marine-Earth Science and Technology

Oceanic observation is often obtained as a profile, e.g. Argo profile, which is composed of a sequence of vectors, consisting of pressure, salinity, and temperature. In data assimilation, it is thus natural to compare observation and model profiles. However, conventional data assimilation just tries to bring closer the vectors at the corresponding spatio-temporal points in model and observation. Whereas, our new data assimilation tries to bring closer the functional values assigned to the corresponding profiles in model and observation. To do so, we first transform a profile into the path signature, which is a central notion in rough path theory. Then, we compare the monthly averaged signatures, within each horizontal mesh, of observation and model. This procedure is well justified as an estimation via minimizing the maximum mean discrepancy between two probabilistic laws of generating a set of profiles. We implemented this algorithm as cost function for an ocean general circulation model. The performance is then tested in a data assimilation experiment with green's function method.

Abstract 2.13: Hao Zuo, ECMWF – (Oral 17:20-17:40)

Assimilation of SST observations with the new ECMWF Ensemble Ocean DA system

Hao Zuo, Philip Browne, Marcin Chrust, Patricia de Rosnay, Magdalena A. Balmaseda

ECMWF

An ensemble data assimilation (EDA) system has been developed and tested for the ECMWF ocean and sea-ice reanalysis-analysis system. Compared to the traditional parameterized covariance model used in the current operational OCEAN5 system, this new ensemble-based system is constructed with a hybrid covariance model. Thanks to some novel approaches implemented for ensemble generations and correlation model computation, this EDA system can provide flow-dependent background error variances and correlation scales, both of which are critical for better assimilation of sea surface observations. As an example, we demonstrate benefits of this new ocean EDA system by assimilation of SST observations. One key aspect in SST assimilation is the vertical propagation of information from the surface. This has been found that, compared to SST nudging, direct assimilation of SST data with

parameterized correlation model (OCEAN5-like) improves the SST diurnal cycle but degrades performance of ocean analysis both at surface and below (verified against in-situ observations). Switching to an EDA based vertical diffusion tensor and a hybrid-B formulation has greatly reduced SST biases, especially in the Gulf Stream regions where the ¼ degree NEMO model has a persisted warm water over-shooting issue to the North of Cape Hatteras. These SST biases can be further corrected by applying a-priori bias correction that is estimated with assimilation increments. It has been found that SST performance is also very sensitive to the forward model used in observation operators, as well as observation data quality control and pre-processing strategy. Introducing an EDA system in ocean and sea-ice analysis has paved the way for the development of a coupled sea surface temperature analysis system, as we learned that the parameterized background error covariance formulation is not optimized to deal with very dense surface observations from satellites together with a sparse ocean in-situ observing network.

3. Theme 3: Ocean modeling and initialization in earth system predictions

Abstract 3.1: Magdalena Alonso Balmaseda, ECMWF – (Oral 20:40-21:00)

Impact of Ocean Observations in the ECMWF S2S forecasts

Magdalena A. Balmaseda, Beena Balan Sarojini, Michael Mayer, Frederic Vitart, Chirstopher Roberts, Steffen Tietsche, Hao Zuo

ECMWF

We evaluate the impact of the in-situ ocean observations on subseasonal and seasonal forecasts of both ocean and atmospheric conditions. A series of coupled reforecasts have been conducted for the period 1993-2015, in which different sets of ocean observations were withdrawn in the production of the ocean initial conditions.
Results show that the in-situ observations have a profound and significant impact on the mean state of forecast ocean and atmospheric variables, and can be classified into different categories: i) impact due to local air-sea interaction, a direct consequence of changes in the upper ocean initial conditions, and visible in the early stages of the forecasts; ii) changes due to different ocean dynamical balances, most visible in the Equatorial Pacific at time scales of 3-4 months; iii) changes to the atmospheric circulation resulting from changes in large scale SST gradients; these are non-local, mediated by the atmospheric bridge, and depend on the differential impact of the observing system in different regions.

Abstract 3.2: Takeshi Doi, JAMSTEC – (Poster 14:00-14:50)

Impacts of interannual variations of chlorophyll on seasonal predictions of the tropical Pacific

Takeshi Doi and Swadhin Behera

Application Laboratory (APL)/Research Institute for Value-Added-Information Generation (VAiG)/Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokohama 236-0001, Japan

In this study, we explored impacts of interannual variations of chlorophyll on seasonal predictions of the tropical Pacific by the SINTEX-F2 dynamical climate prediction system, which is highly skillful at predicting El Niño/Southern Oscillation (ENSO) and other tropical climate phenomena. We conducted twin re-forecast experiments; one system used the observed climatology of chlorophyll to compute the shortwave absorption in the upper ocean, while the other used the observed chlorophyll with year-to-year variations. Although the chlorophyll impacts on predictions of the Niño 3.4 index were limited, improvements are noticed in the predictions of sea surface temperature over the eastern edge of the Western Pacific Warm Pool. This region corresponds to the separation between warm, low-salinity waters of the warm Pool and

cold, high-salinity upwelled waters of the Pacific cold tongue in the central-eastern equatorial Pacific. The improvement was very striking in the 2015 case, when a super El Nino occurred.

Keywords: chlorophyll, seasonal prediction, ENSO prediction, tropical Pacific, climate model

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Abstract 3.3: Danni Du, University of Colorado – (Oral 11:20-11:40)

Assessing the Impact of Ocean In-situ Observations on MJO Propagation across the Maritime Continent in ECMWF Subseasonal Forecasts

Danni Du

University of Colorado, Boulder

When the Madden-Julian Oscillation (MJO) propagates eastward from the Indian Ocean into the western Pacific, it tends to decay and sometimes stall over the Maritime Continent (MC). The MJO events passing the MC (MJO_P) and those stalled have significantly different SST patterns. Oceanic processes can contribute to such SST differences. Therefore, ocean subsurface data assimilation (DA) prior to the hindcast initialization can potentially contribute to better MJO prediction over MC. Two sets of ECMWF ensemble subseasonal hindcasts over two decades are analyzed. The all_obs is initialized from the ocean reanalysis with all subsurface observations assimilated, while the no_insitu is initialized without subsurface DA. We will first present the forecast mean state biases in the SST field and their difference between these two experiments. We will then present results from the MJO analyses. The filtered OLR anomaly field is used to identify the MJO tracks. 79 MJO_P events are identified using NOAA interpolated OLR, among which only 35 and 37 events are successfully predicted by all_obs and no_insitu respectively. We see no significant improvement in MJO forecast skill over the MC in all_obs compared to no in situ. To explain why ocean DA doesn't lead to better MJO hindcasts, we will show the Moist Static Energy (MSE) budget analysis results, which reveals that a systematic meridional wind bias in the model dominates the underestimation of the MSE accumulation for MJO convection. We will also show the MLD mean biases for two experiments, which suggests that the forecast model loses information gained from DA. These results will guide future development of models in our forecast systems to improve the impact of observations on subseasonal forecasts. We also plan to evaluate the impact of ocean salinity assimilation on the MJO forecast skill.

Abstract 3.4: David Ford, Met Office – (Oral 18:20-18:40)

Two-way physics-biogeochemistry coupling constrained by ocean color data assimilation

David Ford[1], Susan Kay[1]

[1]Met Office, UK

We implemented two-way physics-biogeochemistry coupling in the global NEMO-MEDUSA model, via the use of model chlorophyll in the light attenuation calculations. This was tested with and without assimilation of chlorophyll observations from ocean color to constrain the model, and the impact on model physics and biogeochemistry assessed. The assimilation was found to enhance the impact on model physics, including ocean heat content. It could also be used to evaluate the relative uncertainty in the coupling introduced by errors in free-running model chlorophyll. Furthermore, the sensitivity of model air-sea CO2 flux to the use of skin SST and significant wave height in the flux parameterisation was explored, with implications for reanalyses and projections of ocean carbon uptake.

Abstract 3.5: Eric Hackert, NASA/GMAO – (Oral 10:30-10:50)

Evaluation of TAO Observation System on ENSO Predictions from the GMAO S2S Forecast System

E. Hackert, S. Akella, H. Rahaman, J. Carton, and P. Heimbach

NASA/GMAO

The Tropical Atmosphere Ocean (TAO) mooring array measures in situ temperature (and fewer salinity) observations at depth within the Pacific equatorial waveguide. Since the early 1990's this pervasive source for equatorial information has been useful for observing Kelvin and Rossby wave propagation which is key for El Nino/Southern Oscillation (ENSO) prediction. However, recent funding issues and the availability of other sources of in situ data (e.g., Argo) have highlighted the need to rigorously assess the impact of the TAO observing system on ENSO predictions. Therefore, we evaluate the TAO observing system using data assimilation observation denial experiments, commonly called Observing System Evaluation (OSE) experiments, to assess the impact on coupled atmosphere/ocean predictions. This presentation will evaluate the tropical Pacific Ocean TAO observing system relative to its impact on ENSO prediction for 2015, a big El Nino year.

From the best available NASA GEOS-S2S V3 seasonal prediction initialization system that assimilates all available observations, we have completed spin-up (July 2014-Dec 2014) and experiment periods (Jan 2015 – Dec 2015) for both the CONTROL experiment (that assimilates all available data except withholds 20% of Argo for validation) and the NOTAO experiment that is the same as the CONTROL but excludes all TAO observations. We have analyzed observation minus analysis (OMA) statistics from the ocean data assimilation system and shown that noise from regions of strong eddy activity contaminate TAO region NOTAO minus CONTROL statistics over time. However, early analysis indicates improved OMA statistics for all assimilation variables (SSH, SSS, Tz and Sz) for the CONTROL versus NOTAO. In addition, validation of these reanalyses shows that TAO assimilation generally improves comparisons of temperature, salinity, and sea level versus EN4 gridded in situ observations. A surprising result is that assimilating TAO sometimes degrades temperature as compared to gridded observations, especially along the thermocline, but the observed east-west slope of the thermocline depth is remarkably well reproduced in both experiments. Even with relatively few observations, salinity is improved almost universally except near 120^{o}W near the surface.

ENSO forecasts were performed that were initialized from these NOTAO and CONTROL experiments. For the 9-month forecasts which were initialized in January and April, there was no difference in the NINO3.4 SST forecasts with or without TAO assimilation. This is contrary to our original hypothesis that assumed that TAO would have a big impact on downwelling Kelvin waves which propagate along the equator during the initiation phase of El Nino. However, during the late buildup and peak of the 2015 El Nino, initialization with TAO observations in July and October improves the ENSO forecasts.

Abstract 3.6: Ronan McAdam, CMCC – (Oral 21:00-21:20)

Seasonal forecasting of subsurface marine heat waves

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Marine heat waves (MHWs) cause devastating damage to ecosystems and ocean services, with effects being identified mostly below the ocean surface. Current forecasting efforts, however, focus only on the ocean surface. To create a user-relevant detection system, it will be necessary to provide forecasts of subsurface events. Here, we demonstrate the feasibility of seasonal forecasting of subsurface MHWs by using ocean heat content, a more relevant indicator than surface temperature for marine stakeholders. Subsurface MHWs are validated against the multi-decadal GREP (Global ocean Reanalysis Ensemble Product) 4D physical ocean reanalysis. The principal finding is that subsurface summer MHWs are predicted with high skill across much of the global ocean, and with greater skill than surface MHWs. However, we highlight some regions which have experienced infamous MHWs (e.g. the Western Mediterranean) that were not reliably predicted. This work highlights the need for a widespread availability of subsurface ocean observations to increase quality of forecasting initial conditions, and to provide regional-scale means of forecast validation.

Abstract 3.7: K Andrew Peterson, ECCC – (Oral 10:50-11:10)

Towards Create an ensemble of global ocean analysis: Ensemble GIOPS

Andrew Peterson

Environment and Climate Change Canada

Environment and Climate Change Canada's (ECCC's) Global Ensemble Prediction System (GEPS) generates an ensemble of atmospheric initial conditions using a sophisticated local ensemble transform Kalman filter (LETKF) approach. Conversely, the ocean and sea ice in this coupled system are initiated with a single analysis, the global ocean and ice prediction system (GIOPS) that also supplies initial conditions for

ECCC's Global Deterministic Prediction System (GDPS). Compared to the atmosphere, therefore, the ocean and sea ice are quite underdispersive, especially at short lead times, and thus fail to accurately represent the large uncertainties in unobserved regions, or the uncertainties in the observations ingested into the assimilation system.

As a first step towards rectifying this asymmetry, we have developed a simple ensemble analysis system using the spread in atmospheric forcing available from the ensemble atmospheric initialization system, along with a set of stochastic parameterization approaches available for the NEMO ocean model through the STOPACK stochastic physics package (Storto 2021): stochastic parameter perturbations (SPP), stochastically perturbed parameterization tendencies (SPPT), and stochastic kinetic energy backscatter (SKEB). In this presentation we will detail this ensemble ocean analysis system and investigate, using comparisons with assimilated and non-assimilated observations, how the resulting ensemble of analysis better estimates uncertainties in the best estimate of the ocean state compared to a single ocean analysis. Prospects for future use, particularly in the coupled medium range forecast, will then be explored.

Abstract 3.8: Yuhei Takaya, MRI-JMA – (Oral 11:40-12:00)

Importance of ocean observations for sub-seasonal to seasonal forecast in East Asia

Yuhei Takaya, Yosuke Fujii

Meteorological Research Institute, Japan Meteorological Agency

The sub-seasonal to seasonal (S2S) prediction largely depends on the initial states of the ocean, which are estimated based on various ocean observations. Recent studies have revealed the pivotal roles of the tropical Indian Ocean (IO) and Pacific in inducing extreme climate events in East Asia. For instance, the record high temperature in East Asia in 2019/2020 was associated with a strong positive phase of the Indian Ocean Dipole (IOD). In addition, the subsequent IO warmth after the 2019 IOD enhanced Meiyu-Baiu rainfall in early summer 2020, causing devastating floods in China and Japan. Model simulations revealed that these anomalous events did not realize if there had not been anomalous IO conditions. Both the tropical IO and Pacific have significant variability of the atmosphere-ocean dynamics, thus ocean assimilation can benefit from ocean observations. This talk also discusses the importance of ocean observations for assessing the IO states and providing operational S2S forecasts in East Asia.

Abstract 3.9: Jennifer Waters, Met Office– (Oral 18:00-18:20)

Assessing the impact of proposed satellite observations in a global ocean forecasting system

Jennifer Waters[1], Robert King[1], Matthew Martin[1], Elisabeth Remy[2], Isabelle Mirouze[3], Lucile Gaultier[4], Clement Ubelmann[5]

[1] *Met Office, UK*

[2] *Mercator Ocean International, France*
[3] *Cap Gemini, France*
[4] *OceanDataLab, France*
[5] *OceanNext, France*

The impact of assimilating simulated observations from proposed altimeter and total surface current velocity (TSCV) satellite missions in the Met Office global ocean forecasting system (called FOAM) have been assessed using observing system simulation experiments (OSSEs). The experiments allow us to test assimilation methodology for these proposed observation types/constellations and determine requirements from the operational ocean forecasting community for future satellite missions.

The altimetry OSSEs assess the potential impacts of two likely future altimeter constellations on the next-generation Sentinel-3 satellites: scenario 1 includes 12 nadir SAR altimeters, while scenario 2 includes 2 Wide-Swath Altimeters (WiSAs). Both these constellations provide significant benefit in terms of forecast accuracy compared with the existing observing network, with the largest impacts in the western boundary currents. In the FOAM system the 12-nadir constellation is shown to give larger improvements than the 2-WiSA constellation.

The TSCV OSSEs investigate the impact of assimilating simulated observations from a Sea surface KInematics Multiscale monitoring (SKIM) like satellite. The results from the OSSE suggest that assimilation of TSCV observations could produce a major improvement to the forecast accuracy of surface and subsurface currents, particularly in the western boundary currents, the Antarctic Circumpolar Current and near the equator. Assimilating the TSCV data also gives significant improvements to the accuracy of SSH and sub-surface temperature and salinity. There is scope to optimise the performance of the assimilation further by improving retention of the assimilated ageostrophic component of the observations in the ocean model.

Abstract 3.10: Takuma Yoshida, JMA – (Oral 11:00-11:20)

Ocean Initialization of the Coupled Prediction System Version 3 (CPS3) for Seasonal Forecasts

Takuma Yoshida, Hiroyuki Sugimoto, Yutaro Kubo, Shoji Hirahara, Toshinari Takakura, Takuya Komori, Jotaro Chiba, Takafumi Kanehama, Ryohei Sekiguchi, Kenta Ochi, Yosuke Fujii, Yukimasa Adachi, and Ichiro Ishikawa

Numerical Prediction Development Center, Japan Meteorological Agency / MRI-JMA

The Japan Meteorological Agency (JMA) has updated its Coupled Prediction System to the third version (CPS3), which is used for our seasonal prediction and El Niño outlook. The CPS3 became operational in February 2022 and features a quarter-degree ocean model, oceanic four-dimensional variational (4D-Var) initialization, and sea ice concentration assimilation. The upgrade also includes a higher-resolution atmospheric model, updated atmospheric physics tuned for seasonal prediction, and initialization of the land surface model. The coupled model is initialized every day with a five-member ensemble.

The ocean and sea ice parts of CPS3 are initialized by Multivariate Ocean Variational Estimate Global version 3 (MOVE-G3), an essential component of CPS3. The MOVE-G3 also provides ocean initial perturbations approximating its analysis errors and dynamically downscales the lower-resolution 4D-Var

analysis to the quarter-degree ocean component of the forecast model. In order to provide ocean initial conditions every day with a 6-hour delay, the real-time MOVE-G3 analysis uses our operational atmospheric Global Analysis (GA) while the behind-real-time cycle analysis uses the Japanese Reanalysis for Three-Quarters of a Century (JRA-3Q) as surface forcings.

We evaluate the skill of CPS3 with a re-forecast experiment spanning 1991 to 2020, which contains more than 3000 instances of 240-day integrations. The re-forecasts are initialized with JRA-3Q-provisional and MOVE-G3 reanalyses. Our verification shows overall improvements from the previous version, apparent in predictions of El Niño, anomalous surface temperature, and ocean variability.

4. Theme 4: Discussion on the future activities of OS-Eval TT, CP-TT, and SynObs

Abstract 4.1: Magdalena Alonso Balmaseda, ECMWF – (Oral 21:00-21:20)

OSES for S2S and evaluation of future TPOS

Magdalena A. Balmaseda, Yosuke Fujii, William Kessler, Arun Kumar, Annesh Subramanian, Yuhei Takaya, Frederic Vitart, Jieshun Zhu, Hao Zuo

ECMWF

Here we propose a coordinated OSE experiment for S2S in order to identify robust characteristics of the impact of the insitu ocean observations on forecasts of ocean and atmospheric variables at subseasonal and seasonal time scale. The initiative is motivated by recent results with the ECMWF system, which show that the in-situ observations have a profound and significant impact on the mean state of forecast ocean and atmospheric variables at these time scales. These experiments will prepare the ground for the evaluation of the upcoming implementation of TPOS.

Abstract 4.2: Clemente A. S. Tanajura, REMO – (Oral 8:50-9:10)

Investigating the impact of SWOT data in the South Atlantic circulation with OSSEs

Clemente A. S. Tanajura, Filipe B. Costa, Leonardo P. Brito, Janini Pereira, Vitor F. R. S. Vidal

Physics Institute, Federal University of Bahia (UFBA)
Oceanographic Modeling and Observation Network (REMO)

A preliminary observing system simulation experiment (OSSE) was performed over the South Atlantic region (34o S-11o S, west of 34o W) to evaluate the assimilation impact of the Surface Water and Ocean Topography (SWOT) altimetry data into the Hybrid Coordinate Ocean Model (HYCOM) and the REMO Ocean Data Assimilation System (RODAS). RODAS is based on the ensemble optimal interpolation method and in this experiment 126 ensemble members were chosen according to the assimilation day. The OSSE was performed from January 1 to December 31, 2011. HYCOM was configured with 1/24o of horizontal resolution and 21 vertical hybrid layers, nested in a free run of HYCOM with 1/12o and 21 layers. Assimilation in HYCOM 1/24o was performed each 3 days. Sea surface temperature (SST) and sea surface height (SSH) from a free run of the Regional Ocean Modeling System (ROMS) over the same region with 1/24o of horizontal resolution and 32 vertical levels were used to offer synthetic data the HYCOM+RODAS. However, SSH data was first offered to the Gaultier et al. (J. Atmos. and Oceanic Tech, 32, 2016) synthetic data generator to obtain the data and errors along the SWOT tracks. Due to the limitation of the HYCOM resolution, the SSH data from the synthetic data generator was produced with 8 km resolution. Three runs were performed in addition to the free run: (i) one with assimilation of only SST; (ii) one with assimilation of SST and along-track nadir data; and (iii) one with SST and SWOT data.

The results showed a strong influence of SST into SSH, since it could increase the SSH correlation with respect to the "truth" from 0,31 to 0,47. Adding the nadir data and the SWOT data, the correlation was improved to 0,52 and 0,56, respectively. Impacts in the circulation were also obtained (Fig. 1). For instance, assimilation of only SST produced an improvement of root mean squared error of the meridional velocity of only 4,3% with respect to the control run, while the assimilation of SST and along-track nadir data improved 3% and assimilation of SST and SWOT data improved 10%. However, the impact of SWOT data was not as big as expected. This could be explained by the use of all six main errors that are expected to be associated with SWOT data. Probably if these errors are reduced, the assimilation would be much more effective.
New experiments are underway. In these, only the Karin data will be employed to assimilate the synthetic data. Also, a 2-yr run is being performed for 2011 and 2012, so that it will be possible to focus on the results over the second-year run, when the mean sea surface height will be more influenced by the data. In these new experiments, vertical temperature and salinity profilers will be also assimilated to perform a more accurate evaluation of the impact of the SWOT data

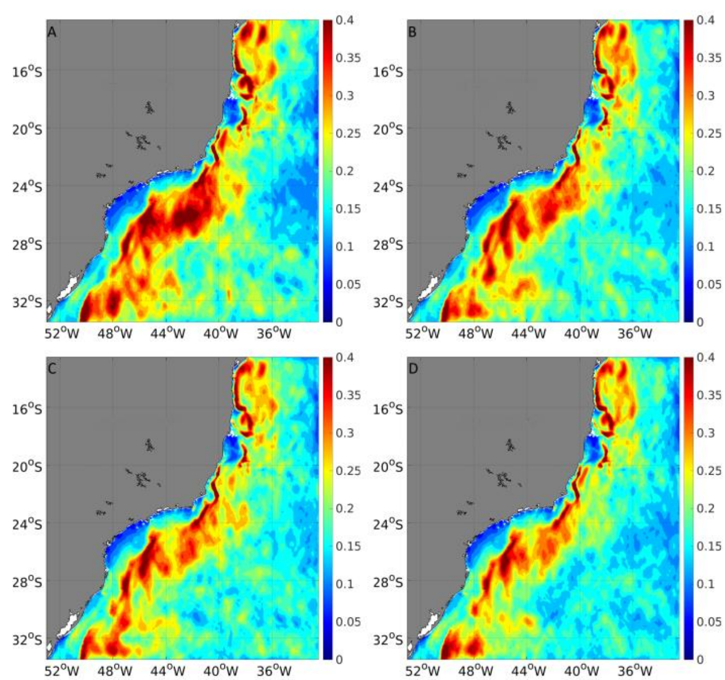

Fig.1 Root mean squared error of meridional velocity (m/s) produced by HYCOM free run (top left); HYCOM+RODAS with assimilation of only SST (top right); HYCOM+RODAS with assimilation of SST and along-track nadir SSH (bottom left); and HYCOM+RODAS with assimilation of SST and SWOT SSH (bottom right).

Appendix 3: Statistics and list of participants

➢ Statistics

- In-person 38 persons
  - Japan 34 persons
  - USA 4 persons
- Online 108 persons
  - Japan 28 persons
  - USA 22 persons
  - France 12 persons
  - UK 10 persons
  - Italy 5 persons
  - Australia 4 persons
  - Brazil 4 persons
  - Canada 4 persons
  - South Korea 4 persons
  - Belgium 3 persons
  - China 2 persons
  - India 2 persons
  - New Zealand 2 persons
  - Ireland 1 person
  - Norway 1 person
  - Portugal 1 person
  - Saudi Arabia 1 person
  - South Africa 1 person
  - Spain 1 person

➢ list of participants（In-person）

First Name	Family Name	Affiliation	Country	Abst. No.
Toshio	Suga	JAMSTEC and Tohoku University	JP	1.22
Toshimasa	Doi	JAMSTEC	JP	
Takeshi	Doi	JAMSTEC	JP	
Miki	Hattori	JAMSTEC	JP	1.9
Yoshimi	Kawai	JAMSTEC	JP	
Shoichiro	Kido	JAMSTEC	JP	
Shinya	Kouketsu	JAMSTEC	JP	
Shuhei	Masuda	JAMSTEC	JP	

Yasumasa	Miyazawa	JAMSTEC	JP	
Akira	Nagano	JAMSTEC	JP	
Satoshi	Osafune	JAMSTEC	JP	
Nozomi	Sugiura	JAMSTEC	JP	2.12
Iwao	Ueki	JAMSTEC	JP	1.24
Akira	Toda	FURUNO ELECTRIC CO., LTD.	JP	
Yuichi	Ura	FURUNO ELECTRIC CO., LTD.	JP	
Shinya	Nakano	ISM	JP	
Hiroshi	Murakami	JAXA	JP	
Takuya	Hasegawa	JMA	JP	
Takuya	Komori	JMA	JP	
Yutaro	Kubo	JMA	JP	
Takanori	Mizuno	JMA	JP	
Takashi	Yamada	JMA	JP	
Takuma	Yoshida	JMA	JP	3.10
Yosuke	Fujii	JMA/MRI	JP	1.6
Nariaki	Hirose	JMA/MRI	JP	
Ichiro	Ishikawa	JMA/MRI	JP	
Takayuki	Matsumura	JMA/MRI	JP	
Izumi	Okabe	JMA/MRI	JP	
Yuhei	Takaya	JMA/MRI	JP	3.8
Norihisa	Usui	JMA/MRI	JP	
Goro	Yamanaka	JMA/MRI	JP	
Naoki	Hirose	RIAM, Kyushu University	JP	2.6
Shun	Ohishi	RIKEN/R-CCS	JP	
Yutaka	Michida	AORI, The University of Tokyo	JP	
Dimitris	Menemenlis	NASA JPL, California Institute of Technology	USA	1.17/2.8
Lidia	Cucurull	NOAA	USA	1.2
Danni	Du	University of Colorado, Boulder	USA	3.3
Kate	Zhang	JIFRESSI, UCLA	USA	

➢ List of participants（Online）

First Name	Family Name	Affiliation	Country	Abst. No.
Sayaka	Yasunaka	Tohoku University	JP	
Behera	Swadhin	JAMSTEC	JP	
Derot	Jonathan	JAMSTEC	JP	
Ryou	Furue	JAMSTEC	JP	
Shigeki	Hosoda	JAMSTEC	JP	
Toru	Miyama	JAMSTEC	JP	
Haruka	Nishikawa	JAMSTEC	JP	
Masami	Nonaka	JAMSTEC	JP	
Hideharu	Sasaki	JAMSTEC	JP	
Kanako	Sato	JAMSTEC	JP	
Akira	Yamazaki	JAMSTEC	JP	
Hemmi	Tadashi	JAMSTEC	JP	
Kai	Matsui	JAXA	JP	
Sho	Hibino	JMA	JP	
Chihiro	Kawamura	JMA	JP	
Shinya	Kobayashi	JMA	JP	
Atsushi	Kojima	JMA	JP	
Masatoshi	Miyamoto	JMA	JP	

Masashi	Sumitomo	JMA	JP	
Hiroshi	Takahashi	JMA	JP	
Masao	Ishii	MRI	JP	
Chiaki	Kobayashi	MRI	JP	
Nobumasa	Komori	Keio University	JP	
Norihiko	Sugimoto	Keio University	JP	
Osamu	Isoguchi	Remote Sensing Technology Center of Japan	JP	
Eitaro	Oka	Tokyo University	JP	
Kosuke	Ito	University of the Ryukyus	JP	
Hiroshi	Ichikawa	JpGU	JP	
Mikhail	Entel	Bureau of Meteorology	Australia	
Yonghong	Kim	Bureau of Meteorology	Australia	
Colette	Kerry	UNSW-Sydney	Australia	
Fernando	Sobral	UNSW-Sydney	Australia	
Marilaure	Gregoire	Liege University	Belgium	1.8
Inga	Lips	EuroGOOS AISBL	Belgium	
Pauline	Simpson	IOC-UNESCO	Belgium	
Filipe Bitencourt	Costa	REMO/UFBA	Brazil	
Clemente	Tanajura	Federal University of Bahia (UFBA) and REMO	Brazil	4.2
Janini	Pereira	Federal University of Bahia	Brazil	

Leonardo	Pires	Universidade federal da bahia	Brazil	
K Andrew	Peterson	Environment and Climate Change Canada	Canada	3.7
Hal	Ritchie	Environment and Climate Change Canada	Canada	
Greg	Smith	Environment and Climate Change Canada	Canada	
Dorina	Surcel-Colan	CCMEP/ECCC	Canada	
Shizhu	Wang	First Institute of Oceanography, MNR	China	
Qian	Zhao	First Institute of Oceanography, MNR	China	
Mounir	Benkiran	Mercator-Ocean International	France	2.2
Stefano	Ciavatta	Mercator Ocean International	France	2.4
Pierre-Yves	Le Traon	Mercator Ocean International	France	
Elisabeth	Remy	Mercator Ocean	France	1.7
Florent	Gasparin	Mercator Ocean International, LEGOS/IRD	France	
Olivier	Goux	CERFACS	France	2.5
Anthony	Weaver	CERFACS	France	
Hugo	Dayan	LMD, IPSL, PSL - Ecole Normale SupÃ©rieure, Paris, France	France	1.3
Claire	GOURCUFF	Euro-Argo ERIC	France	
Emma	Heslop	UNESCO-IOC	France	
Aurélien	Prat	UMR 8105 LACy et Inria	France	1.20
Victor	Turpin	OceanOPS/WMO	France	1.23
PUNYA	P	Kerala Agricultural University	India	
Hasibur	Rahaman	INCOIS	India	

Mairead	O'Donovan	GOOS, IOC-UNESCO	Ireland	
Emanuela	Clementi	CMCC	Italy	
Ronan	McAdam	CMCC	Italy	3.6
Leonardo	Nascimento Lima	CMCC	Italy	
Simona	Masina	Euro-Mediterranean Center on Climate Change	Italy	
Andrea	Storto	CNR – ISMAR	Italy	
Joao Marcos	Azevedo Correia de Souza	MetOcean Solutions (Meteorological Service of New Zealand)	New Zealand	2.1
Julie	Jakoboski	MetOcean Solutions (Meteorological Service of New Zealand)	New Zealand	1.11
Yiguo	Wang	Nansen Environmental and Remote Sensing Center (NERSC)	Norway	
Armin	Halicki	University of Porto	Portugal	
Siva Reddy	Sanikommu	King Abdullah University of Science and Technology (KAUST)	Saudi Arabia	2.11
Tamaryn	Morris	South African Weather Service	South Africa	
Inseong	Chang	Pukyong national university	South Korea	2.3
Sang-Hun	Jeong	KIOST	South Korea	
Deoksu	Kim	KIOST	South Korea	
Yeong-Yeon	Kim	KIOST	South Korea	

Begoña Pérez	Gómez	Ports of Spain	Spain	
David	Ford	Met Office	UK	1.5/3.4
Chris	Harris	Met Office	UK	
Robert	King	Met Office	UK	
Daniel	Lea	Met Office	UK	
Matthew	Martin	Met Office	UK	
James	While	Met Office	UK	
Jennifer	Waters	Met Office	UK	3.9
Kristian	Mogensen	ECMWF	UK	
Magdalena	Alonso Balmaseda	ECMWF	UK	3.1/4.1
Hao	Zuo	ECMWF	UK	2.13
Santha	Akella	NASA	USA	
Eric	Hackert	NASA/GMAO	USA	3.5
David	Legler	NOAA	USA	1.16
Ann-Christine	Zinkann	NOAA	USA	
Cheyenne	Stienbarger	NOAA Global Ocean Monitoring and Observing Program	USA	1.21
Caihong	Wen	NOAA/NWS/NCEP/Climate Prediction Center	USA	1.26
Jieshun	Zhu	CPC/NCEP/NOAA	USA	1.28
Matthieu	Le Henaff	University of Miami/CIMAS - NOAA/AOML	USA	1.13/ 1.14

Shastri	Paturi	IMSG @ NOAA/NWS/NCEP/EMC	USA	
Ho-Hsuan	Wei	CU Boulder/CIRES/NOAA PSL	USA	
Aneesh	Subramanian	University of Colorado Boulder	USA	
Villy	Kourafalou	Univ. of Miami	USA	
Paul	Chamberlain	Scripps Institution of Oceanography	USA	1.1
Ruoying	He	North Carolina State University	USA	
Patrick	Heimbach	University of Texas at Austin	USA	1.10
Chris	Hill	MIT	USA	
Tong	Lee	JPL, California Institute of Technology	USA	1.15
Andrew	Moore	University of California Santa Cruz	USA	1.18
Hans	Ngodock	Naval Research Lab	USA	
Jay	Pearlman	FourBridges	USA	
Cooper	Van Vranken	Ocean Data Network	USA	
Annie	Wong	University of Washington	USA	1.27

Appendix 4: Atmosphere of the workshop and Japan

The workshop was held shortly after the COVID-19 pandemic had subsided and the visa waiver program for entry into Japan had resumed. Therefore, there are very few airport buses from the Narita airport to Tsukuba, and one needs to take three trains from Narita to Tsukuba. In addition, one needs to purchase a different ticket for each train because they are owned by different companies. This seems a lot but was actually an easy trip. None of the connections were longer than 10 minutes and tickets could be purchased from ticket machines. It seems that most international people feel it is very safe to explore new places and that Japanese people are very kind and helpful. But it should be noted that the ticket machines often do not accept credit cards in Japan. Having cash in hand is a must when traveling in Japan. If you don't have cash and need to withdraw it from ATMs, then a major post office would be the best option. As they are government-owned, their ATMs have a higher level of clearance and accept international credit cards and cash cards. Convenience stores also have ATMs as well as regular banks.

Three of four international participants stayed in the Daiwa Roynet Hotel Tsukuba. The guests praised that the hotel breakfast was extraordinarily delicious! The hotel crew put in lots of effort preparing it and the breakfast included traditional soups, cooked vegetables, little fish, seaweed, and a variety of pickles. One could get to use many little dishes and taste different flavors to fill your hungry stomach. Eating breakfast was truly a sensory experience for them. Western style food was also provided but they tended to be bland and less authentic. So, it is generally recommended to eat Japanese breakfast in Japan.

Since the work was organized before Japan eliminated the COVID-19 restrictions, only four international guests from the US managed to attend. Although it was a small in-person workshop, participants got to interact and to know one another really well during the four days. They were privileged to go to the MRI and see where the Japanese colleagues worked. Thus, a small workshop can actually be very efficient.

An official lunch was organized at the Nikko Hotel and participation was by invitation only, in order to prevent rapid COVID-19 infection. There were four tables and four guests at each table. The guest praised that the presentation of the food was so beautiful that they hesitated to touch it. It consisted of many delicate and beautiful small dishes and bowls, similar to the hotel breakfast. International guests were overwhelmed and one of them asked about the correct order for eating all the dishes. Dr. Masuda (a member of the local organizing committee) confirmed that one can eat the dishes in any order they like. At the official lunch, guests had the chance to introduce themselves and have a chat.

Drs. Fujii and Takaya (members of the local organizing committee) took the international guests to a sushi restaurant for lunch after the workshop was closed on Friday. They ate many delicious pieces of sashimi and drank tea. When the bill came, the price was so good that it would barely cover a simple lunch in the US. The low Japanese Yen was hurting its economy and they sincerely hoped that things would change soon.

Some international participants have an opportunity to take the Shinkansen, the Japanese bullet train. They were amazed by how well the Shinkansen was operated and its accessibility from a network of trains. Since they took Kodama (the slow train) which stops at all stations, they had to wait for it to pass. It took only a few seconds for it to go by and the whole station shook. They were able to work on Kodama and the ride was very pleasant. They wondered how Japan managed to build and operate such an excellent train system.