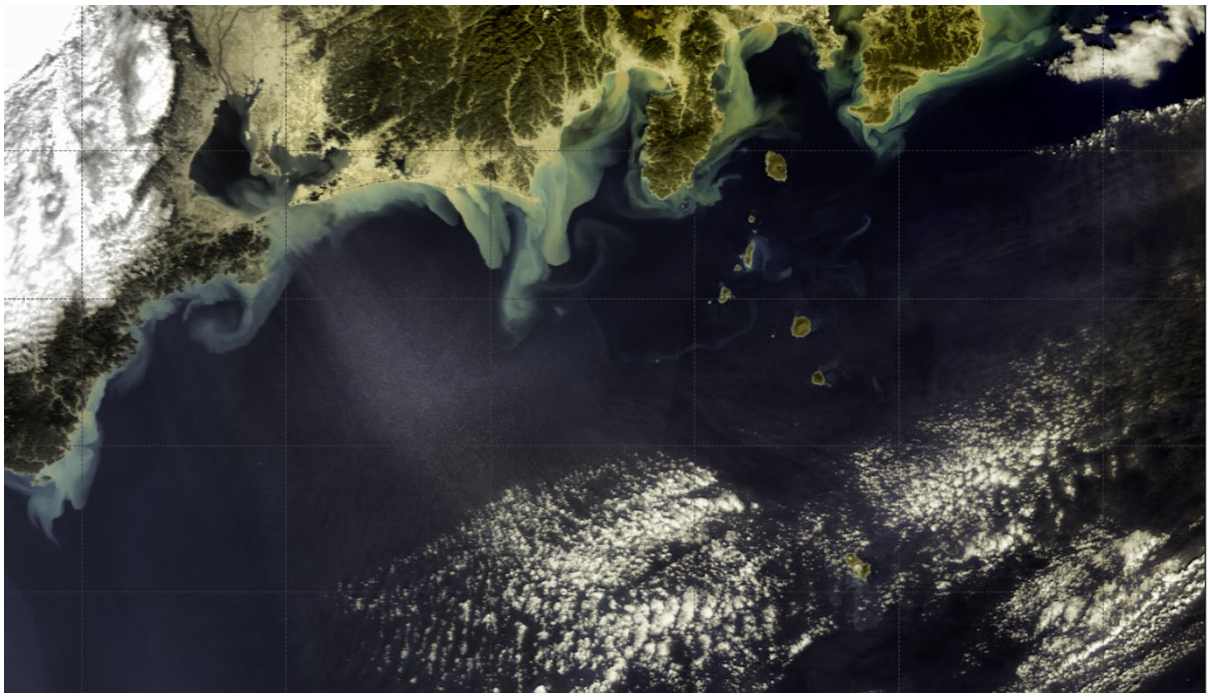

Report of the

Second International Operational Satellite Oceanography Symposium

25-27 May 2021

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This document is the symposium report summarising the symposium contents, the identified challenges and suggested recommendations. Additional information about the Second International Operational Satellite Oceanography Symposium can be found at: https://www.eventsforce.net/osos2021.

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Acknowledgements

The OSOS-2 Executive Steering Committee and the Programme Committee Chairs acknowledge and greatly appreciate contributions from Sylwia Miechurska and Joana Betencourt for their support in planning, executing and follow up actions which provided the logistical foundation for a successful second symposium.

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1 EXECUTIVE SUMMARY

The Operational Satellite Oceanography Symposia biennial series was conceived by the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) and the National Oceanic and Atmospheric Administration (NOAA) in 2017 for the purpose of bringing together the international community of providers and users of operational satellite oceanographic data and products and was envisioned to span ~10 years. These symposia are co-organised and co-sponsored by NOAA and EUMETSAT and the role of primary host has alternated between the two agencies. The aim of these symposia is to increase the benefits of satellite data throughout the value chain by strengthening the links from data to knowledge, that is, between the "upstream" satellite data providers and the "downstream" users by helping users to identify fit-for-purpose data, by connecting stakeholders, including the private sector, and reinforcing international collaboration. Ultimately, this series of symposia is intended to facilitate the efficient exploitation of satellite observations to substantially improve ocean and coastal environmental applications and decision-making.

The Second International Operational Satellite Oceanography Symposium (OSOS-2) was primarily hosted by EUMETSAT, 25 to 27 May 2021. Originally intended to take place in Darmstadt, the meeting was moved to a virtual format in the face of restricted global travel due to the COVID-19 Pandemic. The inaugural First International Operational Satellite Oceanography Symposium (OSOS-1) was primarily hosted by NOAA and held in the Washington DC area 18 to 20 June 2019.

Approximately 500 people from 57 countries registered for OSOS-2. About 300 people joined the meeting each day and around 2000 views of the recordings on YouTube were noted. Fifty-seven people participated in an optional training day on the processing and use of oceanographic satellite data on Friday, 28 May 2021. A combination of oral presentations, panels, and poster sessions informed attendees about the latest in Operational Satellite Oceanography science and issues. Over 70 poster presentations and over 30 talks were made available during nine interactive sessions. The recordings and presentation slides remain available for viewing on the meeting website.

The compelling agenda for the OSOS-2 programme grew directly out of recommendations for future actions collected during OSOS-1 and with guidance and input from the distinguished OSOS-2 Programme Committee. Satellite remote sensing of ocean properties is a technology of continuously increasing maturity and scope. Sea surface temperature, sea surface height, ocean colour, sea ice, ocean winds, roughness-derived parameters (e.g., oil spills) and other measurements are now available on a routine and sustainable basis. Some of these products are integral to operational applications for routine and event-driven environmental assessments, predictions, forecasts, and management. Yet ocean satellite data are still underutilised and have a huge potential for contributing further to societal needs and the "blue, green and white" economy. The foundational OSOS-1 focused on the "upstream" data provider components of the value chain with strong participation of satellite operators and high-level operational "power users". OSOS-2 was intended to extend farther along the value chain to a more diverse array of users. The focus of OSOS-2 included satellite data assimilation methods; the use of satellite data in coupled numerical models for ocean, weather, climate and environment analysis and prediction; and coastal operational applications.

The meeting was organised into an introduction followed by several plenary thematic sessions addressing:

- data assimilation;
- ocean data services;
- coupled models;
- large range of applications, with a focus on coastal applications.

The final session was specifically dedicated to an operational agency outlook during which the agencies presented the future programmes and missions that will support operational oceanography in the twenty coming years. The symposium adjourned after key recommendations and closing remarks.

Key Recommendations from OSOS-2

While many recommendations listed are ongoing and "perpetual" those in bold represent some areas that received enough attention to warrant specific attention going forward in justification for and anticipation of OSOS-3 targeted to be held in 2023:

- Regarding Data and products
  - Address product uncertainties
  - **Reduce latency for NRT but maintain non-time critical higher quality products**
  - Improve spatial and temporal resolution (a forever challenge)
  - Increase operational *in situ* data collection systems for calibration & validation
  - **Fill gaps in observations: currents, waves, salinity, bathymetry**
  - Fill gaps in coastal products
  - Create sensor agnostic products
  - **Generate consistently processed, accurate, state-of-the-art, operational multi-mission long-term time-series, especially needed for analysing climate trends**
  - Simplify complex satellite data into straightforward information that is fit-for-purpose
  - Keep working on harmonising data policies (standards, format….)
  - Keep Agency data open and free
- Regarding Data usage
  - **Expand use of satellite observations for initialization or data assimilation in models**
  - Develop Level 1 data assimilation for better and faster forecast
  - Further develop AI all along the value chain
  - Investigate and reinforce connections between ocean and its multi-directional interfaces (atmosphere, land, sea ice, waves, lake).
  - Always improve access to data (visualisation, extraction)
  - Prioritise hosting processing to avoid moving ever larger data.
  - Adapt our infrastructure
- Regarding Data 'democratisation'
  - **Improve outreach, training and communication**
  - Compile, establish and socialise best practises for engaging users
  - Educate users on what data and products can/will be provided
  - Identify different categories of users and adapt our support offer
  - Solicit user feedback on product/services/applications on a routine and sustained basis
  - **Adopt methodologies to assess the value of satellite observations and apply them consistently and systematically**
  - Establish a framework and mechanism to better coordinate and integrate among and across data providers, information providers, and end users

OSOS-2 was a success with an extended participation compared with OSOS-1 in the number of participants and international participation, likely due in part to the virtual platform. However, the timing of the sessions generally deterred live participation by Asian and Australian colleagues. The next symposium, OSOS-3 will be primarily hosted by NOAA during Spring 2023 and organized to facilitate global inclusivity, including Asia and Australia. In addition to the proactive inclusion of Asian and Australian colleagues, OSOS-3 will flow from the key results of OSOS-2.

Marching orders for justification of and planning for OSOS-3 targeted for Spring 2023 include:

1) Geographical focus on Asia, Australia and the Pacific, including blue water oceanography and climate (how satellite data can be applied to understanding trends and addressing impacts).
2) Community progress in producing consistently processed, accurate, state-of-the-art, operational multi-mission long-term time-series.
3) Continue to highlight methods and applications for use of satellite data in ocean/atmosphere/earth coupled models

4) Bring attention to methods and studies that quantify the socio-economic benefits leveraged from global, agency investments in earth-observing satellite missions and coordination of virtual constellations.
5) Continue the practice of offering user training in association with the OSO symposium.

2 PROGRAM OVERVIEW

Detailed program available at https://www.eventsforce.net/osos2021

(UTC)	25 May 2021	26 May 2021	27 May 2021	28 May 2021
12.00-13.00	Introduction Welcome, Purpose, Introduction	Coupled Models	Coastal Applications - I	TRAINING
BREAK				
13.30-14.30	Data Assimilation - I	Applications - I	Coastal Applications- II	
BREAK				
15.00-16.00	Data Assimilation - II	Applications - II	Operational Agency Outlook	
BREAK				
16.30-17:30	Ocean Data Services	Applications - III	Closing wrap up	

3 BRIEF SESSION SUMMARIES

3.1 Welcome, purpose, introduction

Chairs: A. O' Carroll and J. Gault – Rapporteur: Gareth Davies

EUMETSAT and NOAA convened the 2nd OSOS meeting virtually. The meeting welcome address was given by the newly appointed EUMETSAT Director General, Phil Evans, to over 450 global scientists attending. The meeting took place at a time when operational oceanography is high on European and global agenda, especially for the United Nations (UN) Decade of Ocean Science for Sustainable Development, which offers an opportunity to reverse the decline in ocean health.

A status update on the UN Decade of Ocean Science for Sustainable Development was presented by the IOC's Vladimir Ryabinin. Science has been focused and successful on problem diagnosis to date, but should move to providing solutions and motivation to action. The funding base has been focused on research, with not much supporting sustainability so far and therefore change is needed. It is also very important that all nations are represented which is not the case today (e.g. from Africa).

Operational Satellite Oceanography is defined as the use of mature, fit-for-purpose, both near real time and delayed mode, satellite observations for research and/or applications that support assessments, predictions, forecasts and resource management, etc., in ocean, coastal, and aquatic environments. NOAA CoastWatch "links" from data to knowledge in the "value chain" to proactively get satellite data into useful, impactful applications. NOAA CoastWatch services, ranging from data access to training to research and development collaborations, help users to leverage ocean, coastal and inland water satellite data for effective and impactful applications.

The Copernicus Marine Service (CMEMS), uses satellite data to provide Global and Regional Ocean Monitoring and Forecasting, covering essential variables for blue, white and green ocean. It provides free and open access to data and supporting information (Ocean Products, Ocean State Report, Ocean Monitoring Indicators and Ocean Visualisation). It is a user and policy driven service, whose core activity is to provide ocean information, as well as supporting users via helpdesk and training workshops, and engaging with them through other outreach activities. User feedback and engagement provides inputs to service evolutions.

3.2 Data Assimilation Part I

Chairs: S. Abdalla, E. Bayler - Rapporteurs: C. Brown, H. Roman-Stork

This session provided an overview of present data assimilation activity, future developments, and explored further integration of knowledge and the value of data assimilation to benefit all components of the operational oceanographic value chain. Data assimilation provides the primary avenue for exploiting satellite ocean observations for enhanced operational ocean and sea ice predictions. An overview of the operational oceanographic value chain highlighted the need for all elements, explicitly including data assimilation, to work together, noting that data assimilation, traditionally a part of the prediction component, also has impact over the other components of the value chain. The international collaboration OceanPredict provides a platform for knowledge exchange, communication, and coordination for operational oceanography, focusing on the ocean observations value chain and explicitly addressing various aspects of data assimilation. Data assimilation, which adds value to ocean observations, targets improved predictions for informed decision-making, thereby broadly enabling the Blue Economy, sustainability, and resilience sectors and government, academic, and private sector services. Regional and finer-scale models increasingly employ data assimilation. Additionally, data assimilation provides a tool for evaluating observing systems and testing observation methodologies for impact and effectiveness.

With the vastly increasing quantities and types of satellite ocean observations, along with associated differences in phenomenologies and measurement errors, exploring, developing, and extending data assimilation methodologies helps address the challenges of exploiting the bounty of data. Creating a coherent and representative picture of the marine environment requires optimally combining the observation data with the ocean modelling, employing complex mathematics for represented model physics and assimilation algorithms. Shared modular assimilation components and methodologies provide greater leveraging of expertise and technologies, as well as a common framework for evaluation. The advent of machine-learning techniques introduces new potential data assimilation approaches, particularly for high-resolution data, where data volume becomes an issue for operational production timelines. Machine learning also can contribute to 1) assessing and addressing quality control, bias correction, model error estimation, parameter estimation, error covariance, etc.; 2) estimating parameters of forecast models, especially where parameters are difficult to empirically describe; and 3) product generation, especially for large-scale forecasts. Machine learning requires high-quality observations with high-spatiotemporal coverage and can be similar to and complement data assimilation.

Common factors for data assimilation across disciplines include the need for accessibility, interpretability, and explainability, the importance of common infrastructure elements to share and use data, along with experiment results, and the need for entraining young experts. Fundamentally, operational oceanography requires a better structural framework to enable a more coherent value chain. In this regard, as a part of the UN Decade of Ocean Science for Sustainable Development, OceanPredict sponsors the approved ForeSea and CoastPredict Decade Programs. Data assimilation enables greater extraction of knowledge for satellite ocean observation, creating better information for decision-making and, consequently, greater societal benefit.

3.3 Data Assimilation Part II

Chair: A. Pascual - Rapporteurs: C. Donlon, J. Ceniceros

Discussion continued on the topic of Data Assimilation and this session included three presentations and six posters. NOAA recently expanded its operational assimilation of satellite ocean observations, specifically adding sea-surface salinity and absolute dynamic topography, with assimilation of sea ice parameters and ocean colour on the near horizon - the former to support NOAA's operational coupled ocean-atmosphere-ice model, and the latter in development for biophysical feedback and ecological modelling. HF radar has proven to add value on the high-resolution model results, especially in coastal areas.

The development of an ensemble Kalman filter-based regional data assimilation system by RIKEN (Japan) was described. Results show some inflation methods when using incremental analysis update (IAU) do better for sensitivity, balance, and accuracy, but relaxation to prior perturbations (RTPP) + IAU was the most suitable for high frequency data assimilation. Ensemble data assimilation in regional coupled ice-ocean and biogeochemical models of the Arctic was also summarised.

The Ensemble Kalman (EnKF) filter and Ensemble Kalman Smoother (EnKS) have proven useful for the assimilation of new observation types to an existing system, as in the case of sea surface salinity. EnKF is also integrated into Arctic forecasts and reanalysis systems for CMEMS. Problems using these techniques include adjustable parameters, and of location errors like using multi-scale alignments and developing the capacity to assimilate sea ice deformation from Sentinel-1 Synthetic Aperture Radar observations. Overall, EnKF is now being used in near real time forecasting and physical reanalysis.

Discussion ensued about unresolved problems in Data Assimilation. Data gaps remain problematic in coastal areas for the use of many applications and such high-resolution processes require more localised observations. Several solutions are worth exploring, such as including observations from coastal services like the navigation and fishing industries, drones and automated sampling systems, or end-user contractors supplying crucial data in exchange for a discounted price on the predictive forecast products. Sufficient wave data is currently available, but more is better. Data assimilation goals include moving everything into a virtual cloud environment, but with that transition, data security and ownership become increasingly important, especially if the data is feeding into a satellite product. Data certification that is secure enough for the model and computational system will be a challenge. Satellite data works well in the cloud but *in situ* measurements do not as there are no standards, so a lot of *in situ* data is lost. Publishing data with standards and quality control remains a challenge. Public data sharing may not be the issue, a change of perspective into worrying more about analysis investigations and what you do with the data, instead of dataset ownership, can work best in a virtual environment. In addition to standards and a place to put your data, there is a need for education and training where satellite and *in situ* people come together to share data.

Modellers are trying to improve models: what parameters do they need to increase modelling capacity? To improve models, special attention should be made to increasing the modelling capacity of ocean-atmosphere surface interface. Currently, the ocean is under sampled so the need for any additional ocean data is great. High frequency data is crucial, so investment in automated sampling systems to make such observations over time is necessary. Collaboration between satellite and *in situ* communities to increase sea ice observations is needed, especially incorporating data from indigenous communities. By providing locals with spatial products and maps, they will also help the research community obtain measurements from those areas if they ever find themselves there. For *in situ* data to be considered real-time it must be made available to researchers in less than three hours.

3.4 Ocean Data Services

Chairs: E. Smail, A. Mangin - Rapporteurs: S. Groom, R. Wegener

This session provided a synopsis of data services, applications and trainings. An overview was provided of WEkEO, a portal for Copernicus data and information that provides free an open access to data. WEkEO includes a commercial environment to support industry. The service also has a webportal and user support services including user training services. An overview of Committee on Earth Observation Satellites' (CEOS) analysis ready data (ARD) applications for ocean research and applications was made, which admitted ARD was historically used for the land surface imaging community and ocean products are lagging behind. The definition of ARD is not constant and depends on the community of interest but includes access to data and interoperability with other datasets. The MLOps architecture for estuarine water quality monitoring and modelling was described. This architecture brings algorithms together to build a predictive model. They are using the Chesapeake Bay as a case study and have put together a "hack the bay" fest for this. One thing they have found is that their models tend to drop in performance over time and that higher frequency reparameterization might help maintain model performance. Finally, an overview of the Copernicus and NOAA CoastWatch training to be provided at the meeting to encourage participation. Overall recommendations from the session were that the community pursue the effort of working together to advance cloud computing, analysis ready data, modelling and other efforts to improve data integration and open access to data and data processing. The land observing community is ahead of the ocean observing community in this arena.

3.5 Coupled Models

Chairs: H. Roman-Stork, T. McNally - Rapporteurs: T. McNally, Gareth Davies

Recent advances in coupled modelling were discussed with a focus on the assimilation of satellite observations and parameterization of air-sea fluxes at European Centre for Medium-Range Weather Forecasts (ECMWF). Coupled models are utilized for ensemble forecasting in order to better characterize uncertainty and the coupling of the models is dependent on the required outputs of the system. Different configurations of coupled models require different coupling strategies and differing methodologies also exist based on whether the models are strongly or weakly coupled together. Recent developments in coupled ocean-atmosphere data assimilation focus on the coupling system itself, such as introducing coupled observation operators, introducing a model with 4DVar (a four-dimensional variational method) to replace an atmosphere only model, and passing information from the atmosphere to the ocean for skin temperature analysis.

At present, satellite observations from altimetry (Sea Level Anomaly, Significant Wave Height), Sea Surface Temperature (SST), Sea Ice Concentration, and atmospheric corrections are assimilated, whereas other parameters (Sea Surface Salinity, Sea Ice Thickness) are used primarily for verification. In the future, new methodologies (radiance, altimetry, scatterometer surface stress, etc.) are being investigated and initial results suggest that the assimilation of these parameters (such as radiance) can reduce model error. Additional variables, such as ocean currents, would be valuable if added, but calculated products with incorrect values would impact model results. ECMWF is not presently looking to introduce additional satellite observations into coupled models, at least until it is clear that as much data as possible is being extracted from extant sources, but the possibility of high wind estimates from Synthetic Aperture Radar (SAR) presents an intriguing possibility for the future. The latency of satellite observations also has impacts, and the faster the data is provided, the more impactful it can be. Due in part to this, ECMWF has moved to Level 1 radiances which are then converted to Level 2 or Level 3 for SST. As this assimilation moves to lower levels, data providers will need to provide better calibrations and an improved inter-calibration would have major impacts. Significant steps are being taken to better parameterize heat and moisture fluxes and drag coefficients. A new approach to modelling 10m wind and wave model parameterization that depends on the sea state is being tested, and whether or not this new approach improves overall forecasts is being assessed. By introducing these new parameterizations and the new sea state heat and moisture fluxes, instances where models previously struggled, such as within tropical cyclones, were improved.

Overall, ECMWF's fully coupled atmosphere-wave-ocean circulation operational forecasting system was described along with recent improvements and developments within the coupling system, parameterizations, and data assimilation. Coupling these different models provides a clear benefit but creates new challenges for which new parameterizations will need to be created or revised, such as in the case of the sea state heat and moisture fluxes. Future plans include an upgrade for the ocean and sea ice model, improvements in the radiative transfer and emissivity models, and further exploitation of satellite missions and observations, especially regarding SST.

3.6 Applications Part I

Chairs: B. Foli, D. Byrne - Rapporteurs: G. Davies, M. Abecassis

While much of the emphasis in Application Session I was on fisheries and marine habitats, there is no doubt that the physical environment remains important, with operational products providing information such as high resolution coastal winds, and estuarine and coastal sea levels also sharing the limelight. Session attendees agreed that application end users such as resource managers, fisheries scientists, and regional or local governments want a single product, easy to use, generated and vetted by experts. They don't want to mess with quantities such as radar returns or spectral bands, but would prefer something in familiar units, such as chlorophyll-a (mg/L), temperature (°C), or centimeters of sea level. End users don't care about sensor specifics; they need reliable products that fill their regional and temporal needs on a regular basis, and documentation. Some end users want long time series, going back as far as possible in order to conduct change or anomaly detection. This precludes the use of platform-dependent algorithms. Other users have a need to extend algorithm applications geographically, going from a few training sites to an algorithm that can be applied on a regional, national, or even global domain. Expert support is needed to reach these goals, and the end user is not the one equipped to provide it.

A further challenge is that not all satellite sensors operate on the same frequencies or spectral bands, or with the same viewing geometry or resolution; this increases the difficulty in providing unbiased, gap-free time series. Sometimes users need to accept a lower resolution in order to obtain a consistent time series over a long period. These challenges underscored the need for deep expertise to be brought to bear in order to provide platform/sensor-independent products to support operational uses. Gridded, harmonized and gap-free long time-series products are a way to satisfy these needs.

A number of innovative expert-developed products were introduced during the session. Examples included the utilization of cloud-based processing workflows such as Google Earth Engine with high resolution image data (thus solving the problem of storage and processing requirements for very large image datasets) and the application of neural networking to map successfully from one set of spectral bands to another. Other presentations underscored the painstaking *in situ* verification, with dozens of verification sites to hundreds of training data sets required to produce a truly useable operational product from raw satellite data, whether it be estuarine sea levels, harmful algal blooms, or mapping of a specific type of habitat. Innovative applications were also profiled, including information products for fishers to help them reduce bycatch, and long-term projections of coastal fish distributions to help managers plan for fisheries management in a changed climate. Remote sensing scientists repeatedly mentioned the need for decade-spanning products in order for their end user communities to be able to maximize the impact of satellite-derived operational products.

3.7 Applications Part II

Chairs: F. Davidson - Rapporteurs: A. Mangin, L. Gibson

Overall the session highlighted clear benefits of remote sending for various applications, and if future coverage gaps in a particular satellite observation sensor type occurred, related applications would be impacted. This session's talks covered aquaculture, ocean energy, ice thickness in the Arctic for

seasonal weather forecasting, and applications over shallow tropical banks for characterizing and quantifying carbonate exchange with deep waters. Talks and posters covered examples of synergistic use and benefit of using remote sensing, *in situ* observations, and prediction systems.

From an industry perspective, whether aquaculture or energy, common needs and goals included 1) increasing industry awareness, literacy and access to remote sensing and derived prediction products; 2) developing mutual benefiting two way relationships and feeds between industry and information providers (remote sensing and prediction); and 3) finding a value proposition for industries as a whole and individual operators in sharing their environmental observations.

Benefits of remote sensing were well highlighted in various applications including dramatic increase in seasonal predictability of arctic sea ice concentration when assimilating remotely sensed sea ice thickness; more accurate positioning of energy and aquaculture sites; more efficient industry operations; and improvements in sea level trend prediction in areas with only a short time span of *in situ* tide gauge coverage. A common element in posters and talks was the value in combining or assembling information together including remote sensing as one of the ingredients. One interesting remark was made that for Arctic ice measurements, the quantity of present ice collection capacity was not an issue. However, making better use of all observations, *in situ* and remotely sensed, would clearly improve predictions

A blue economic perspective covered most of the talks. For instance, for both renewable energy and aquaculture, precision operations with added value real time and historical environmental information were key for economic success, adapting to climate change, insuring/preparations against risk and protecting animal welfare. Additionally, forecasting ability, such as forecasting fish yields in aquaculture using remote sensing, or forecasting power production from tidal currents, sea water thermal stratification, winds and waves, is vital. Precision forecasting for various industry applications is vital for protecting industry operations against harmful algal blooms, oil spills, and infrastructure wear and tear. A particular example of remote sensing and prediction importance was during installations of heavy infrastructure for renewable energies, such as putting a large tide turbine in place. In those cases, good forecasting of all relevant environmental parameters were key.

Some overall challenges were presented and discussed:

- Increasing ocean prediction and satellite observation literacy to enable informed product end users.
- Improvements in efficiency and use of existing satellite and *in situ* observation resources, ensuring sustainability.
- Exploiting opportunities for synergistic approaches on observation investments between remote sensing, prediction and observation people when designing observation systems and deployments.
- Need for continuous, gap-free remote sensing data streams. A 36-month gap in remote sensed sea ice thickness measurements is a concern, as current ice thickness measuring satellites are expected to cease by 2024, with new satellites expected in 2027.

3.8 Applications Part III

Chairs: Z. Jelenak, C. Donlon - Rapporteurs: J. Gault, E. Obligis, V. Lance

This final applications session presented several successful remote sensing applications covering coral diseases, and several winds projects. Disease outbreaks represent a major threat to coral reefs, primarily driven by temperature with additional impacts due to biology, physical forcing and human activities. Utilizing a Bayesian modelling framework disease prediction model for coral disease outbreaks risk has been developed for the Pacific Ocean and implemented with 5 km resolution, which provides a weekly updated disease forecast. Through this web tool, users can gauge the risk and look up the timeseries of prediction and the interactive map feature allows users to zoom in their area of interest, use the predictions model and view historical data used to develop the prediction model. One of the major findings of the study is that larger corals have higher disease risk.

It was apparent that availability and latency factors with Cyclone Global Navigation Satellite System (CYGNSS) prevented its inclusion in a recent trade study and there are probably better data sets available for the wind community to use. Storm size and wind direction were not factors for the sensors in this study. Recalibrated wind data is useful to researchers and discussion ensued around calibration and measured vs real data and which is most important for the product users. Altimetry was not useful for windspeed studies because sampling is very poor and sensitivity goes down as windspeed increases. Within MAXSS (Return Maximum Scalar Single-Precision Floating-Point Value), there is a plan to recalibrate all active and passive systems at each sensor resolution with dropsondes. The wind product research community should come up with a set of consistent high and extreme winds for all systems at "dropsonde scale", but it is not clear if this is what the windspeed data users want. For nearshore windspeed application examples, would the algorithm remain valid for other locations given the need for significant *in situ* calibration? There is a need for global agreement and access to data across regions on *in situ* calibration and that this may be facilitated by organisations such as Group on Earth Observation's Blue Planet and Aquawatch initiatives, but funders to support such endeavours were difficult to find. Marine Geo (Smithsonian) –MarineGEO | What we do (si.edu) is a good resource and mirroring the efforts by other international sectors and linking between applications and national, regional and international policies are all beneficial.

3.9 Coastal Applications Part I

Chairs: E. Armstrong, M.B. Neely - Rapporteurs: E. Obligis, Gareth Davies

Remote sensing of the coastal zone presents unique challenges yet also opportunities where satellite observations can advance scientific understanding, improve resource management and impact decision support. The presentations in this session addressed these points and demonstrated advances in the applications of coastal remote sensing on both international and regional scales, together with the roles played in various initiatives (UN's Sustainable Development Goals and the UN Decade of Ocean Science for Sustainable Development) and participating organisations (GEO, CEOS, Intergovernmental Oceanographic Commission/Global Ocean Observing System, UN Environment, World Meteorological Organisation, Coordination Group for Meteorological Satellites, Global Climate Observing System, OceanPredict, Coastal Information Systems (Netherlands), ESRI and CMEMS).

A consistent theme which emerged was the challenges at the land/ocean boundary and the need to bridge the land-sea-atmospheric domains requiring high resolution, multi-sensor, long term time series, and interdisciplinary Earth Observations. There are also operational challenges with regard to the quality, timeliness, spatial/temporal coverage and length of satellite observations (and their *in situ* and modelling cohorts) necessary to detect and assess important marine features such coastal eutrophication, eddy dynamics, marine heat waves, coral bleaching, water quality, sea level rise and erosion. Human economic and population pressures place additional needs for improving coastal monitoring and assessment. The appeal to downstream users of curated, on demand information products and ecosystem forecasting which utilise Geographic Information Systems and offer early warning or alert systems were of interest to many. On an international scale, programs such as the CEOS Coastal Observations, Applications, Services, and Tools effort is generating the data requirements and information systems necessary for coastal management that can be deployed on a user need and fit-for-purpose basis.

Partnerships and coordination across data providers together with users to design and implement these systems are important success criteria with a key requirement being that common data formats, services and capabilities are necessary for user uptake and application sustaining. Similarly, on regional levels, space agencies in the US, Europe, and South Africa are leveraging existing space assets in conjunction with information systems to address specific regional or national needs. Often these needs require specialised high resolution, blended, and value-added products (e.g., gap-filled) critical for addressing coast management. As part of these information systems it is recognized that in addition to satellite observations, the importance of *in situ* observations and modelling data, and their integration in the value chain cannot be understated. Furthermore, advanced and emerging computation capabilities such

as on demand cloud computing, machine learning and the role of ARD and data services are part of the evolving landscape of coastal applications.

Being open source, ensuring data democracy/transparency, establishing a 'partnership' with users and ensuring continued stakeholder engagement were considered hallmarks of successfully co-designed/co-developed projects by the entire panel. Finally, the role of the commercial sector in these applications is acknowledged where they can fill precise focused roles for coastal management and stewardship, as exemplified by the CoastObs project that enabled low-cost production, created user familiarity and acceptance, and expanded the user base.

3.10 Coastal Applications Part II

Chair: L. Krug, S. Groom - Rapporteurs: V. Lance, J. James

For this second part of the session, three presentations were followed by a question/answer session and a panel discussion, all focusing on operational applications in coastal waters. The oral presentations showed results from combining operational data and artificial intelligence to determine composition of systems dedicated to beach safety and disaster risk assessment and early warning, ultimately offering quantitative information for decision makers.

During the question/answer session, the audience directed questions and suggestions related to methods, operability and accuracy of systems. Based on live polls during the session, the audience participants were mainly data providers who collaborate transnationally on development of regional coastal applications, using mainly remote sensing products for operational monitoring. In the closing panel, discussion ensued about open access protocols, standardisation of data and metadata formats, and user-specific tools to support decision-making.

3.11 Operational Agency Outlook

Chairs: C. Wilson, P. Y. Le Traon - Rapporteurs: M.B. Neely, B. Brown

This concluding topical session provided an overview of operational agency outlook from the European Commission, EUMETSAT and NOAA. The European Commission presentation outlined how Copernicus, with its space component (Sentinels) and its marine service (CMEMS), has organised an operational user and policy driven European Union service for over 20 years. The EUMETSAT presentation summarised the operational oceanography activities of EUMETSAT for the Copernicus programme, the MeteoSat 2nd and 3rd Generation (MSG/MTG) and polar programmes, the Ocean and Sea Ice Satellite Application Facility and the WEkEO Data and Information Access Services (DIAS) platform. The NOAA presentations explained how NOAA has developed its service areas for weather, resilient coasts, climate and healthy oceans, and reviewed OSOS-1 recommendations for agencies and discussed future perspectives. The summary below reflects these operational agency views and provides a series of recommendations for future activities.

Satellite Sea surface temperature, sea surface height, ocean colour, sea ice, sea surface salinity, waves, ocean winds, roughness-derived parameters (e.g., oil spills) and other measurements are now available on a routine and sustainable basis. Some of these products are integral to operational applications for routine and event-driven environmental assessments, predictions, forecasts, and management. Yet ocean satellite data are still underutilised and have a huge potential for contributing further to societal needs and the “blue, green and white” economy. There are still observing needs and gaps that need to be filled. We have decades of data from different satellites but these data need to be made available to users as long-term, consistent, high-quality, multi-mission time series, with anomaly products and uncertainties information provided as well. Ecological forecasting still lags relative to ocean and weather forecasting. Ecological forecasts are needed for marine, estuarine and inland waters. The data distribution network between satellite producers and end-users needs to be strengthened. We need to ensure that satellite data is used to support national strategic agendas such as monitoring extreme events and hazards, coastal resilience, water availability and quality and to ensure the development of a

sustainable blue economy. We need to improve connections between the ocean, atmosphere & terrestrial domains, and establish connections to socio-economic drivers with global to local anthropogenic influences. The increasing volume of data available can create its own problems. How do we effectively distil and deliver petabytes (and more) of data ? What role does the cloud have in data dissemination? There needs to be more coordination and collaboration between the different operational satellite agencies. International collaboration is especially needed in regions of socioeconomic importance such as coastal zones, polar regions, small island states and the tropics. The UN Decade of Ocean Science for Sustainable Development is an excellent opportunity to better work together on all these issues.

4 OSOS-2 TRAINING DAY

On 28 May 2021, a training day was organised about Operational access and use of Ocean and Coastal Data from the Copernicus Marine Data Stream and from NOAA CoastWatch. Held over one afternoon with three 1hr blocks separated by short breaks, the agenda covered CMEMS assimilation of multiple products into a Level 4 data product, NOAA/CoastWatch demonstration of ERDDAP data service system and the CoastWatch data portal visualisation platform, and EUMETSAT's options to access the Copernicus Marine Data Stream (CMDS) - both interactive and Application Programming Interface based - and how to utilise Snap or Python for operational data download and processing using Graphic Processing Toolkit (GPT). The broad agenda was very well received with content relevant to attendees in each section. The content aligned with the presentation of ERDDAP allowing the introduction of EUMETSATs upcoming data services.

Initially ~200 people registered for the event. Ultimately, around 60 people attended (peak was 72 for a few minutes). This ~30% rate of attendees to registrations was likely due to the class being free and not compulsory. The attendees comprised an engaged audience who were interested in the topic, with a good gender (about 35% percent women) and geographical representation (participants from many countries and the 5 continents). EUMETSAT's online training infrastructure was used for the course. The 3 training blocks split around coffee breaks worked well, helping to keep attendees engaged. Based on the few, high quality questions, it was apparent that the attendees were able to link concepts together, e.g., working with CMEMS data in Python, linking presentations. This second successful training session underscores the expressed desire by attendees for the continuation of these free training opportunities during future OSOS meetings.

5 CONCLUSIONS AND NEXT STEPS

In response to OSOS-1 recommendations, several steps forward have occurred over the intervening 2 years:

The Committee on Earth Observation Satellites (CEOS) and the Coordination Group for Meteorological Satellites (CGMS) have been engaged regarding satellite observations and requirements. NOAA and EUMETSAT have identified common intermediate providers and are leveraging the existing NOAA-EUMETSAT partnership to jointly assess and advance agency knowledge of user requirements.

Ocean Predict members were engaged in the OSOS-2 programme planning and participated in OSOS-2 sessions vis-à-vis satellite observations to facilitate their greater assimilation and support for improved ocean forecasting.

GEO Blue Planet and other international organizations serve as frameworks and mechanisms to better coordinate and integrate among data providers, information providers, and end users.

Tangible needs are now being fulfilled: Long term merged time series for all parameters, as well as compile training resources and best practices. However, gaps and limitations still exist. For example, linking surface ocean observations with the deep ocean models for a comprehensive understanding of the 4-dimensional ocean still needs work.

Connections have been improved between the ocean, atmosphere & terrestrial domains, and to socio-economic drivers with global to local anthropogenic influences through activities such as the GEO COAST project.

In response to OSOS-1, OSOS-2 focused on topics for extracting information from products toward development of improved indicators and indices; synergistic ocean forecasting, including linking ocean to weather prediction, in cooperation with large weather organizations; and application support, especially for the coastal zone and its diverse users which have significant socio-economic ramifications.

The key recommendations arising from OSOS-2 are:

Regarding Data and Products

- Reduce latency for NRT but maintain non-time critical higher quality products;
- Fill gaps in observations: currents, waves, salinity, bathymetry;
- Generate consistently processed, accurate, state-of-the-art, operational multi-mission long-term time-series, especially needed for analysing climate trends.

Regarding Data usage

- Expand use of satellite observations for initialisation or data assimilation in models.

Regarding Data 'democratisation'

- Improve outreach, training and communication;
- Adopt methodologies to assess the value of satellite observations and apply them consistently and systematically.

Next Steps: Justification of and Planning for OSOS-3

Marching orders for justification of and planning for OSOS-3 targeted for Spring 2023 include:

1) Geographical focus on Asia, Australia and the Pacific, including blue water oceanography and climate (how satellite data can be applied to understanding trends and addressing impacts).
2) Continue to engage users for better definition of priorities and needs, production of consistent, accurate, state-of-the-art, operational multi-mission long-term time-series.
3) Continue to highlight methods and applications for use of satellite data in ocean/atmosphere/climate coupled models, reinforce communication and coordination on science and expertise between the coupled model producers, and the producers of the satellite observations.
4) Bring attention to methods and studies that quantify the socio-economic benefits leveraged from global agency investments in earth-observing satellite missions and coordination of virtual constellations.
5) Continue capacity building by providing user training in association with the OSO symposium and in coordination with CEOS Capacity Building team (WGCapD).