International Ocean Colour Science Meeting 2025

Advancing Global Ocean Colour Observations

Darmstadt, Germany
1-4 December 2025

IOCCG International Ocean Colour Coordinating Group | HOSTED BY EUMETSAT esa | WITH SUPPORT OF PROGRAMME OF THE EUROPEAN UNION Copernicus

Proceedings of the

2025 International Ocean Colour Science Meeting (IOCS-2025)

Darmstadtium Science & Congress Centre, Darmstadt, Germany
1 - 4 December 2025

Convened by the International Ocean Colour Coordinating Group (IOCCG)
Sponsored by EUMETSAT, ESA, and the European Union Copernicus Programme

IOCCG International Ocean Colour Coordinating Group | HOSTED BY EUMETSAT esa | WITH SUPPORT OF PROGRAMME OF THE EUROPEAN UNION Copernicus Europe's eyes on Earth

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1. Introduction

1.1. Background

International Ocean Colour Science (IOCS) meetings began in 2013, and are working meetings with the goal of fostering communication among the research community, international space agencies, and organizations with an interest in ocean colour remote sensing of the aquatic environment and its societal applications. This communication manifests in the form of concrete recommendations made about specific topics that are discussed in detail in dedicated breakout sessions, and which form the basis for future scientific direction and satellite missions. IOCS meetings are convened biennially by the International Ocean Colour Coordinating Group (IOCCG) who form the IOCS Scientific Committee, and are hosted and sponsored by an IOCCG sponsoring agency or team of agencies (who form the IOCS Organizing Committee) with a rotating location through the Americas, Europe, and Asia/Oceania. As all of Earth's water is connected to the ocean, the meeting and the associated science community involve researchers working in the aquatic continuum, from in-land freshwater to the coastal and open ocean.

The sixth International Ocean Colour Science (IOCS) meeting was hosted by the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), the European Space Agency (ESA), and the European Union Copernicus Programme. It was held on 1 - 4 December 2025, at the Darmstadtium Science & Congress Center in Darmstadt, Germany, which was the venue of the inaugural meeting in 2013 that was hosted by EUMETSAT. Online streaming of the plenary sessions was provided by EUMETSAT, a first for the IOCS. The theme for IOCS-2025 was *Ocean Colour: serving Earth system science & our society,* with a focus on key applications to determining water quality and aquatic biodiversity, as well as quantifying aquatic carbon from space.

Travel support for participants to the meeting was provided by IOCCG, EUMETSAT, and the European Commission Joint Research Centre (EC-JRC). The logistical organization of the meeting was handled by EUMETSAT, led by Ewa Kwiatkowska and Sylwia Miechurska.
IOCS-2025 was followed by a GEO AquaWatch & GEO Blue Planet Data Service Provider Panel, a WATERHYPERNETS Data Users Meeting, an IOCCG Capacity Building Townhall, and three training events, including the first multi-day EUMETSAT-IOCCG training course on *Multi-Sensor Satellite Ocean Colour*. Many side meetings of various IOCCG working groups and task forces were also held in association with IOCS-2025.

1.2. Participants

A total of 300 researchers from 6 continents and 39 countries attended the four-day meeting in-person (90% of the 334 in-person registered attendees), with an additional 49 streaming online (33% of the 148 online registrations). Participants hailed from Argentina, Aruba, Australia, Belgium, Brazil, Bulgaria, Canada, Chile, China, Croatia, Denmark, Estonia, Finland, France, Germany, Greece, India, Indonesia, Ireland, Italy, Japan, Kenya, Mexico, Morocco, The Netherlands, Norway, Philippines, Poland, Portugal, Puerto Rico, Romania, Singapore, South Africa, South Korea, Spain, Sweden, Switzerland, Uganda, UK, and the USA, with distributions displayed in Fig. 1. While researchers for universities were the largest contingent of the meeting (48%), representatives from major government space and research agencies and non-government organizations comprised 37%, and representatives from industry and the commercial sector comprised 15% of meeting participants (Fig. 1). All in-person attendees, regardless of affiliation, had equal access to participate in all sessions, including to share research in poster sessions and lightning talks, and participate in breakout workshops.

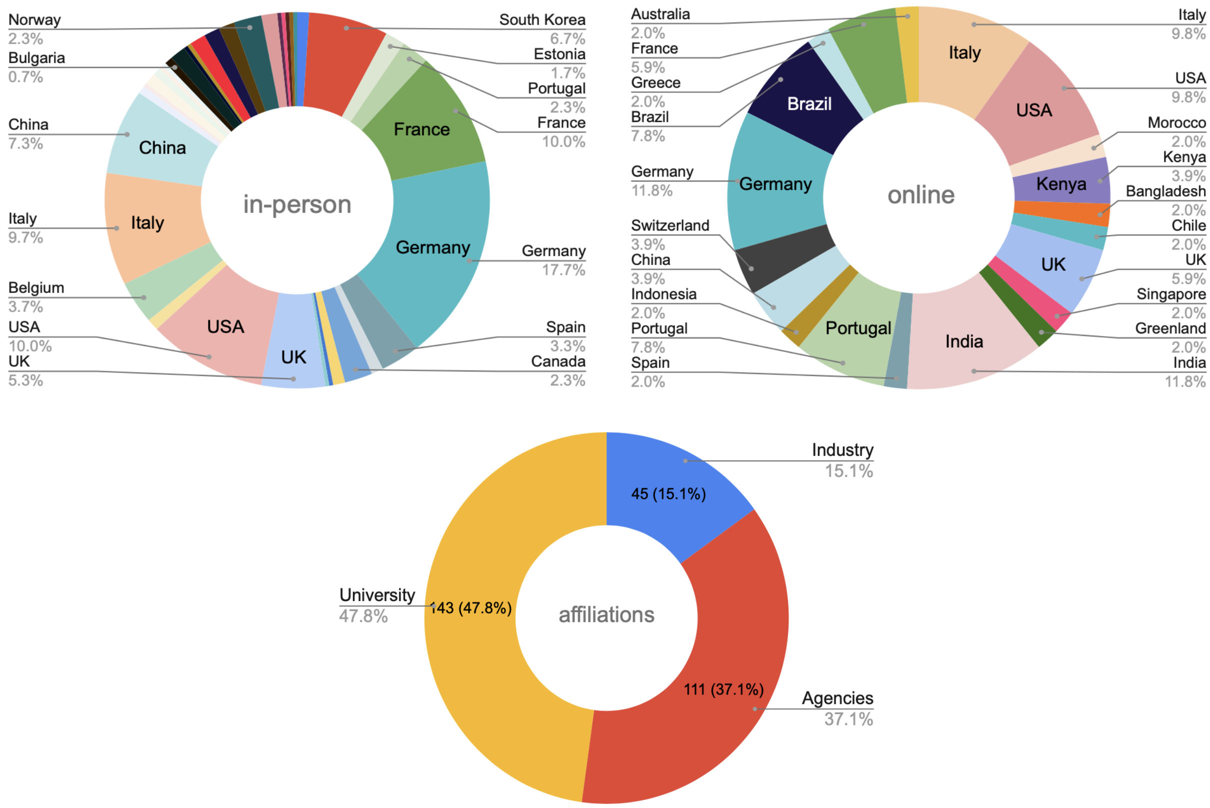


Figure 1: Distribution of IOCS-2025 meeting participants by country of residency (left) and affiliation (right).

1.3. Programme

The IOCS-2025 programme was chaired by Shubha Sathyendranath (IOCCG Chair), with the help of volunteer session chairs and panel moderators, who are all gratefully acknowledged and listed in Appendix I. Plenary sessions included four invited keynote talks, one per day, that covered the meeting's themes of aquatic carbon, delivered by Bob Brewin (day 2), water quality, by Tiit Kutser (day 3), and biodiversity, byRoy El Hourany (day 4), and began with an inspirational opening talk by Paula Bontempi (day 1) on future possibilities in the field. There was one panel discussion per day, that covered measurements and uncertainties for in situ data for satellite validation (day 1), and applications of Earth observation to quantifying aquatic carbon (day 2) and water quality (day 3), with the final panel (day 4) being an open question-and-answer (Q&A) session between the audience and a panel of the IOCCG agency representatives. All IOCCG agencies that had an update on their missions and activities to share gave an individual presentation during the week.

As for all previous meetings, several poster sessions were scheduled throughout the meeting and it allowed 224 scientists to discuss various aspects of their work, with 55% (123) opting to advertise their poster with a 35-second lightning talk.

Daily breakout sessions enabled in-depth discussion in smaller groups on major topics of interest that were proposed by the community during an open call for proposals more than six months prior to the meeting. These topics were: the current status & future directions in the correction of adjacency effects in inland & coastal waters; in-water radiometry on autonomous profiling floats in support of satellite ocean colour validation activities; synthesis and planning for next steps for a priority list of marine biodiversity metrics to observe from space; ocean colour satellite sensor calibration; a blueprint for large-scale, operational, EO-based systems for harmful algal bloom monitoring; bridging the gap between different measurement methods for in situ aquatic radiometry SI-traceability; challenges in optical remote sensing for marine litter and floating matter; quantifying ocean carbon from space; demonstration of Earth observation's applicability to water quality; and pathways to the development of merged, long-term ocean-colour data products. Included in these discussions were reviews of the status of any previous recommendations made on the topic, and the formulation of new recommendations to shape the direction of future science and missions, or aid in stronger societal applications.

The full meeting agenda is available as well as presentation slides from all plenary sessions, and the IOCS-2025 Book of Poster Abstracts, which contains all accepted abstracts for the meeting.

2. Opening Session

2.1. Welcome

Shubha Sathyendranath (IOCCG Chair) welcomed all participants to the IOCS meeting in Darmstadt and online, and introduced the theme of the meeting (*Ocean Colour: serving Earth system science & our society*) and what we hoped to achieve in the four days. She gave a brief overview of the structure of the IOCCG and thanked all of the many people who contributed to the planning and staging of the event, with special thanks to the hosts EUMETSAT and ESA, and the audience.

The hosts, represented by Director General Phil Evans and Bojan Bojkov, Head of the Remote Sensing and Products Division for EUMETSAT, and Inge Jonckheere, Head of the Green Solutions Division at ESA each gave a special welcome and echoed much of the thanks to the organizers and the participants. Bojan Bojkov's welcome included an introduction to EUMETSAT and a highlight of the agency's activities and their operations of the fleet of 13 satellites, including the Sentinel satellites within the Copernicus Earth Observation Programme, with special mention of the status of Sentinel-3 OLCI ocean colour (OC) products. He highlighted future work on geostationary and a global system for OC System Vicarious Calibration (SVC; recommendations from IOCS meetings in 2013, 2017, 2019 and the OC-SVC white paper), and past work on developing and implementing Fiducial Reference Measurements (FRM) activities for OC validation, and emphasized the importance of the discussions that emerge from the IOCS meetings in shaping the operational activities of

EUMETSAT on a decadal timescale. Inge Jonckheere, in her welcome, shared the tangible support that ESA has planned for science and applications related to Earth observation, including of the oceans and the aquatic environment, as reflected in their newest budget. They all expressed sincere interest in the discussions slated to occur at the meeting, and wished the participants a wonderful and successful meeting.

2.2. Keynote 1: The Art of the Possible, Paula Bontempi (U. Rhode Island).

Following the welcome, Paula Bontempi presented the first keynote talk, *The Art of the Possible*, which took the audience through opportunities in Earth observation, in three main parts: 1) reasons for investing in science and technology; 2) the value of science to the public; and 3) setting a scientific vision for the way forward. She went through the launch of the earliest technologies in satellites, and the decision to make data available and accessible for all, which changed the way we navigate, do science, and understand the context of our place in the galaxy. The internet also led to new ways of communication. She highlighted that we should invest in science because, while Earth observation can be costly in time and money, the advances in technology have significantly improved our lives. While data showed that public trust in science is quite high in some regions, there is still uncertainty around scientists and their data, and we should work to improve this. She showed the value of science to the public by highlighting the revenue that companies make from new devices, and the cost of the science and underlying technology behind those devices, which typically come from government scientific investments and global supply chains. Paula argued that Earth observations, and the opportunities they bring, can lead to economic prosperity, but we need an intersection of science and business to operate sustainably.

She highlighted a sample of the strategies that governments have outlined for their way forward (NASA OBB Program, ESA EO Science Strategy, Japan's Basic Plan for Space Policy, EC Ocean Pact, UN Sustainable Development Goals, etc.) as a view into the public needs and challenges. We know the future will include hyperspectral remote sensing, and Paula showed some existing applications already of hyperspectral data from the PACE mission (e.g. to inform beach closures in Australia, mapping global primary production, mapping global identification of phytoplankton). She also showed application of active remote sensing using airborne and space-based LiDAR (using High Spectral Resolution LiDAR, HSRL-2; IceSAT-2; CALIPSO, although not optimized for the ocean) to map vertical profiles of the water column and determine predator-prey interactions, offering promise for ocean applications especially if there were ocean-focused missions. Airborne and drone LiDAR and Multispectral imaging Detection and Active Reflectance (MiDAR) also show promise, and other topics not able to be covered: geostationary (more use of GOCI data), big data and machine learning, commercial smallsats and cubesats. She implored us to continue to bring together the entire talent pool, and accept that the value of our science is irreplaceable and tied to the future of the planet. The slides from her presentation are available on the IOCS-2025 archive website at iocs.ioccg.org/iocs-2025-meeting.

Q&A: Hubert Loisel (U. Littoral) asked about public trust and science - he thought it was decreasing, but as a scientific community should we be less shy in communicating certainties? Paula encouraged us to actively listen to public sentiment so that we can engage sufficiently. But she also mentioned that a recent poll in the US indicated that 85% of the public trust science. Shubha asked if maybe engaging the public in the journey of discovery might be helpful in building that trust? Paula agreed and indicated that she herself tries to engage people, starting with topics of most interest to the listener.

2.3. Panel Discussion: Supporting Earth observation (EO) with high-quality in situ measurements, Moderator: Giuseppe Zibordi

Panelists:
Agnieszka (Aga) Bialek (National Physical Laboratory, UK), Andrew Barnard (Oregon State U., USA), Stefan Simis (Plymouth Marine Lab, PML, UK), Sindy Sterckx (VITO, Belgium).

An opening panel discussion on supporting EO with high-quality in situ measurements was moderated by Giuseppe Zibordi. The objectives of the panel discussion were to explore innovative approaches to in situ data acquisition, processing, analysis and integration; focus on the high quality of in situ measurements for validation (e.g., Fiducial Reference Measurements - FRM); and incorporate industry partners and community science cost-effective measurement solutions. Giuseppe gave a two minute introduction to FRM, which was established in order to highlight the need of high quality in situ measurements to support post-launch satellite activities (calibration and validation, or cal/val). In situ FRM ideally should be performed following published and verified, community-shared measurement protocols and have detailed quality assurance (QA) criteria, and should be executed with instruments that have documented radiometric performance, among other things.

Giuseppe opened the discussion with a focus on uncertainties, stating that the quantification of uncertainty is perceived to be a major task that might inhibit scientists from attempting. He asked Aga for her recommendation to such scientists on approachable ways to quantify uncertainties. Aga indicated that the first focus should be on understanding the measurement and the biggest contributors to uncertainty, and then on trying to quantify them. She said that although the entire task might seem overwhelming or difficult, if you do rough estimates of your largest uncertainty contributors from the beginning (no details, just rough numbers to start with), then you can spend time afterwards validating and refining your initial rough estimate, which is much more approachable than trying to quantify everything at the end.

Giuseppe indicated that Sindy managed workshops recently on investigating the state of the art on the use of drones for aquatic measurements, and asked her to outline the advantages and disadvantages of using drones for supporting satellite ocean colour application. Sindy indicated that advantages included speed, flexibility, and spatial coverage. Drones can be more precise, move quickly, and reach places that are difficult to access. Measurements do not disturb the water surface (no boat plumes). Drones can complement HYPERNET stations and do assessments of the spatial heterogeneity around the station. Transects that go towards the land can be done in order to validate adjacency correction algorithms in rivers, lakes, and coastal areas for higher spatial resolution instruments. Disadvantages include the need for authorization to fly drones (including spatial permissions), with the process being lengthy in some places. Logistics for flying offshore can also be a bit complicated, especially the further out you go. If the data collected by drones are for cal/val of satellite data, then currently there are missing protocols for how to take measurements, do the processing, and include uncertainty propagation. Moving towards FRM has many aspects still to tackle. Stefan added that another advantage is that economies of scale are already achieved because drones are so widely used for inspection and monitoring across industries, so we only need to do the final step of bolting our sensors onto the drones. Sindy agreed.

Giuseppe asked Stefan, who is involved in community science and the use of high-tech, low-cost sensors, which could be conflicting elements, how to put these instruments to use for ocean colour applications to get high quality data. Stefan indicated that we first needed to understand what a *high quality* observation means. He argued that high quality observations are simply a lot of information on a phenomenon, and that the most capable optical instrument in the room is the human eye coupled to impressive data processing capabilities (the brain) based on neural networking. As humans are good at seeing and observing, if a measurement can be incorporated into a model or a data assimilation strategy, and we know the uncertainty associated with that observation (or we can make a good guess), then that is information we would not otherwise have had. The quality then lies in the number of observations, and in reaching environments for which we don't normally get data. Thus, objectifying that strategy of humans taking environmental observations still has enormous potential. He further argued that if we combine the observation with the motivation to take it, many of our prime customers will gather far more information. Since people often have a reason for recording their observation in the first place, this motivation is a data layer that is missing from only interpreting optical signals.

Giuseppe indicated that data must satisfy application needs, so depending on the application, uncertainties will help to determine data quality and often collecting large quantities of data, regardless of the accuracy, can still not satisfy requirements. He asked Andrew, who bridges industry and academia and works on the other end of the spectrum with high-cost instruments, his thoughts on whether autonomous profiling floats can support system vicarious calibration (SVC), and any drawbacks behind these systems. Andrew indicated that for SVC (which is one of the most complex applications) HyperNAV is doing a fairly good job. There are frequent calibration and uncertainty checks, but one of the major limitations is battery power. They are working on extending to ~120-day deployments with partnerships with other companies. There are still challenges, as getting <4% uncertainty across most of the spectral region across all areas of uncertainty for SVC application is a high bar.

Bror Jönsson (U. of New Hampshire) asked, regarding interpreting uncertainties in connection to products, how natural variability should be included and addressed when we compare a 4x4 km grid cell from satellite data with 1 liter of water for in situ measurements. Aga acknowledged that it is a difficult problem, and indicated that there are metrics to account for spatial variability (for example) but they will be estimations. Additional data to determine the spatial variability of a pixel (e.g. via drones) can be useful and incorporated. Giuseppe added that the issue is increased in coastal regions, and can be addressed with the number of data points used for validation. You can then assume that the variation on the ground (spatially, or temporally, depending on the region, application, etc) is accounted for in the match-up figure, and use this to better address the uncertainties in your final data.

Bengt Karlson (Swedish Meteorological & Hydrological Institute) indicated that with new hyperspectral sensors there is the potential to get information on high biomass harmful algal blooms (HABs) in the coastal ocean. For reference data, automated techniques (like the Imaging Flow Cytobot) have been around for 20 years and while used to be fixed in location, are also now operated on ferries, etc. He asked how we could incorporate these measurements as reference data for ocean colour applications. Stefan indicated that it is really difficult for even hyperspectral data to recreate cell concentrations of specific species. He indicated that satellites and the in situ instruments measure two different things and so the two are operating on different principles. As pigments are expressed based on environmental drivers, he suggested that we can model the likelihood of the environment under which these pigments were expressed, and then use satellite data synoptically to confirm or adjust the models in a useful way. He indicated, however, that we would need to have this conversation with ecological modelers.

An audience member asked about refrigeration of low-cost sensors. He indicated that, while it's easy to get the cameras on drones, hyperspectral sensors in the SWIR region require refrigeration, and these sensors weigh a lot, so what are the prospects for low-cost SWIR sensors. Sindy indicated that they do not yet use drone-based sensors in the SWIR region because indeed cooling can be an issue. Aga said that it depended on how far into the SWIR region you wish to go, but there are some sensors that go up to 1600 nm, and they can operate in 0-10 °C, mostly so far for land application. They are not heavy and could possibly be used for aquatic applications.

Rosa Roman (Technical U. of Munich) asked about benthic monitoring by drones for ocean colour, especially as the first mass coral bleaching event has been reported as a global tipping point. Sindy indicated that corals can indeed be mapped by airborne and satellite sensors and especially using hyperspectral data to get more than just a bleaching indicator. Drones have the added value of much higher spatial resolution for this purpose. Heidi Dierssen (U. Connecticut) added that she is the chair of the IOCCG Report on benthic reflectance for aquatic applications, which was recently drafted, and the report has much more detail on these types of measurements (including for corals), which she admitted are not easy to make. She requested for the community to ensure they comment on the document when it is released for community review.

Heidi asked about the use of percentages in quantifying uncertainties as a % of a small value can be a large value. Community members struggle with this and would love better guidance. Giuseppe agreed and indicated that a solution was recommended in a publication—that both relative (%) and also absolute values should be indicated. He said that the reason for % is that it is immediate and everyone understands what it means, but we need to be sure we are comparing the same qualities (amplitude of the signal, etc.). When the uncertainty budget is done, the % is important, e.g. for absolute calibration. But if uncertainty is related to the validation of data products, it is also important to define the range of values of the products that you are assessing. Thus, the recommendation is to report relative (%), absolute values, and the range of values for which uncertainties have been quantified.

Heidi also asked about how downwelling light from drones are measured. Sindy indicated that, within FRM4DRONES, there were 3 different ways emerging: 1) irradiance sensors on drones, but then it is important to remain horizontal; 2) reference panels that are placed on land, but then there is a risk that the irradiance has changed once the drone has left, and 3) irradiance sensors from other equipment, e.g. From HYPERNET stations. There is not yet an agreement on which is the best approach. Aga indicated that some also model the downwelling irradiance. Stefan indicated that, as some measurements are approximations and some are direct measurements, it would be hard to say how close these measurements get to FRM standards. Sindy agreed that uncertainty and SI traceability is very challenging. Stefan asked Sindy if there was a plan to develop minimum requirements for the sensor market. Sindy indicated that they are not yet there, and that the first step will be an intercomparison within the community as there is large variation in the sensors being used.

Ewa Kwiatkowska (EUMETSAT) asked if, hypothetically, we are achieving the uncertainty standard and have the full uncertainty budget, how do we relate these in situ measurements to the satellite data and assign uncertainties to the satellite data based on these measurements. Aga indicated that we first need to compare the satellite measurements to the in situ measurements, but in metrological terms each of these measurements have their own uncertainties. You would not use one measurement to derive uncertainty in the other. Giuseppe said the difference is to be explained by the uncertainties. Andrew said that for SVC there is an uncertainty in the atmospheric correction itself that is not included in the in situ budget. Ewa explained that the context is validation of the products with FRM certified procedures. Stefan said the best way to prove statistically that your satellite product is better today than yesterday is to introduce the uncertainty on the in situ reference measurement. Aga reiterated that the purpose of in situ validation is not to determine the uncertainty in the satellite measurement but to ensure the satellite product is matching and that there is agreement.

3. Aquatic Carbon from Space

3.1. Keynote 2: Aquatic Carbon from Space, Bob Brewin (University of Exeter)

Bob Brewin opened day 2 of the IOCS with a keynote talk on aquatic carbon from space. He gave an overview of carbon in the ocean, walking through the various partitions of carbon and the latest data on their fluxes as outlined in the global carbon budget, published by the Global Carbon Project in 2025. He highlighted that the ocean and the atmosphere are the two main observational constraints on the budget calculations of global carbon, and so monitoring of aquatic carbon is essential for understanding the global carbon budget. Satellites are a key component of how we model aquatic carbon, but there are key limitations: satellites only see the surface layer, and only those fluxes of carbon that have an optical signature that is detectable from space. Thus, observations need to be linked to in situ data in order to observe carbon pools and fluxes within the water column and those invisible to satellite sensors. Even so, some carbon pools and fluxes are difficult to measure from either satellite or in situ data, and those gaps are filled using carbon models. He highlighted the last 5 years of satellite applications to measuring ocean carbon, and indicated other carbon initiatives that are underway, including the aquatic carbon roadmap, being led by the CEOS Ocean Colour Radiometry Virtual Constellation (OCR-VC) with community input, including during breakout sessions at this IOCS.

In terms of where the field is going, climate data records are required and many groups are working on this aspect, including a new IOCCG Task Force dedicated to climate data records for ocean colour. We need to harness recent and emerging satellite platforms to improve understanding of the carbon cycle. Hyperspectral remote sensing increase the resolution of surface ocean data, geostationary platforms allow for daily fluctuations in the carbon pools and fluxes and the dynamic land-sea interface, lidar can shed new light on carbon cycles in the ocean, other missions and platforms that focus on understudied regions. Commercial satellites are also now available that have higher spatial and temporal resolution, including ocean colour cubesats that have potential use in monitoring ocean carbon, but challenges exist in calibration. For in situ data, -omics data can help to further our understanding and improve numerical ecosystem models. Citizen science and open hardware, as well as ocean robotic platforms also allow us to get additional data. A fully coupled multi-platform carbon observing system is what we should be considering for the future of the field. He emphasized the importance of open science (having data and hardware be findable, accessible, and interoperable to more people) and international collaboration to assist the field in moving in this direction. The slides from his presentation are available on the IOCS-2025 archive website at iocs.ioccg.org/iocs-2025-meeting.

Q&A: Astrid Bracher asked about the huge uncertainty in observations. Bob indicated that we could take the approach of the fiducial reference measurements (FRM) and ask biologists and modellers in the field whether they would consider using this FRM approach to measure and therefore quantify uncertainties.

Wonkook Kim asked if we need to use a deterministic or mechanistic approach rather than depending on empirical or statistical algorithms, given that there is so much change by region and time? Bob indicated that he tends to always want to move towards a mechanistic understanding of fluxes but that doesn't mean that they will produce the most accurate results. And if we think about the application of the products, then it might help to answer the question.

3.2. Panel Discussion: Ocean Carbon: policy, adaptation and mitigation, Moderator: Marie-Hélène Rio

Panelists:
Gemma Kulk (PML, UK), Rosa Roman (Technical U. of Munich, Germany), Hubert Loisel (U. Littoral, France), Luke Gregor (Swiss Data Science Centre, Zürich, Switzerland)

As a follow-on to the virtual *Ocean Carbon from Space workshop*, a panel discussion on *Ocean Carbon: policy, adaptation and mitigation* was held in the plenary right after the IOCS keynote talk on aquatic carbon. The goals of the panel were to identify major gaps in scientific understanding and observing capabilities of the ocean carbon cycle as a key component of the global carbon budget; to discuss how satellite data can support emerging mitigation and adaptation policies around ocean carbon (e.g. global carbon stocktake), and to set priorities and direction for future research that will feed into the CEOS Aquatic Carbon Roadmap.

Marie-Hélène started the discussion by asking each panelist what they thought was the main priority for inclusion in the aquatic carbon roadmap.

- Gemma focussed on the biological carbon cycle, and the inclusion of biodiversity with clear links to the ecosystems. For example, phytoplankton biodiversity is important for some of the components of the ocean carbon cycle. We are improving our estimates of biodiversity as well as of carbon from OC satellite data, so we could start to combine these in order to improve our understanding.

- Rosa works on supporting member states to track progress on their commitments within the global stocktake of the Paris Agreement, so she indicated for inclusion a higher participation of Member States in reporting their blue carbon targets and highlights of some of the challenges that need to be overcome before we can use satellite data to estimate blue carbon in the global stocktake, both for mitigation and adaptation.
- Luke indicated that his work is focused on the inorganic component of the marine carbon cycle and he would like to see the inclusion of pH. This can be inferred from satellite data (not directly observed), but over time it is becoming a larger issue and should be a key component.
- Hubert indicated that phytoplankton carbon (C_{phyto}) needs greater assessment effort, because its derivation currently depends on biovolume and a conversion factor to get carbon, which varies a lot. He referenced papers showing how it could be measured (e.g. a 2012 paper coupling cytometry measurements with elemental analyses) and encouraged the community to make more measurements of C_{phyto} to develop and validate algorithms. He also added that there has been major progress on the export of carbon in open ocean waters, but not as much progress on lateral or vertical fluxes in coastal waters, which are the transition zones between the open ocean and land.

Marie-Hélène indicated that society takes for granted that the ocean will continue to provide key services, but asked whether this is actually the case, and how confident are we that the ocean will continue to act as a carbon sink under climate change. She asked what needed to be the focus in research and observations to better understand the uncertainty around the ocean's role as a carbon sink. Luke indicated that as long as we keep increasing atmospheric CO_2 at a faster rate than the ocean can uptake, the ocean will continue to uptake. However there are certain processes that operate on different temporal scales (annual, decadal, etc.) and affect the efficiency of this uptake. During El Niño events there is a reduction in CO2 outgassing, for example. He gave additional examples of how decadal cycles affect CO2, as well as mentioned general ocean carbonate chemistry—as we increase DIC in the ocean, the efficiency of the carbon pump is reduced. Gemma indicated that uncertainties are an important question and great progress has been made in the last few years on estimating per pixel uncertainties for most of the ocean carbon products, but that we don't yet fully understand where uncertainties come from. The biological components need our focus—most biological components show a positive trend, but the trend is small and within the uncertainties. We don't typically produce uncertainties for primary production estimates. Ocean carbon is changing and we see this clearly in the ocean carbon sink, but it is difficult to know the direction of change of some of the biological components from an EO perspective. Marie-Hélène summed that for primary production there is a need to reconcile the different products and better understand the uncertainty. Gemma added that this becomes very important regionally, especially in coastal regions. Hubert added that, for coastal regions, parameters and processes can be estimated with their own uncertainties, but in coastal waters it is not only about the concentration of carbon parameters, but also the origin of the carbon (land-based, refractory, etc). A framework needs to be established based on water residence time, which can vary from 15 days to 5 months. Rosa indicated that the oceans involve major Earth system tipping points, including ocean circulation such as AMOC (Atlantic meridional overturning circulation) for which remote sensing has a role in understanding salinity and temperature changes, for example, in the Labrador region. Taking for granted that ocean circulation is going to be stable under the increased weight of higher CO2 is a major assumption. Another important provision of oceans is coral reefs, and fisheries, and the 2025 tipping point report showed that a warm water tipping point for corals passed a limit of no return. We are losing functionality and provision of services from corals, with many regions reducing live coral cover, and these all add to uncertainties when we talk about ocean provision services. Marie-Hélène indicated that there is an importance of the physical component of ocean circulation, and the impact of the change in ocean physics on the marine ecosystem.

Marie-Hélène asked Rosa about policy adaptation and mitigation. She sees that ocean carbon management is increasingly discussed in climate policy, but asked for some realistic pathways to incorporate ocean carbon observation into policy frameworks to support effective mitigation and adaptation strategies. Rosa focussed on the policy framework of the UNFCCC, which relates to the provision of greenhouse gas (GHG) inventories, and then the Paris Agreement, which relates to national contribution and mitigation. She recommended enhancing the dialogue on understanding the specifics of nations reporting GHG inventories under the UNFCCC guidelines. The Global Carbon Budget provides benchmarks to be compared with national datasets, but these datasets do not always match. In the case of blue carbon, open ocean or off-shore cycling information will not be used for national reporting because these are not linked to human activities. But alkalization, and carbon dioxide removal (CDR) for blue carbon and macroalgae fields are more relevant. Most stocks of blue carbon are within the sediment, but UNFCCC focuses only on fluxes (stock changes and losses) and not standing stocks. Reporting of temporal trends also needs to start from 1990, so any data needs to be normalized using the best available satellite data, with focus on aerial **changes**. She recommended that agencies and the scientific community support with methods that countries can use in a standardized manner and have easy access to raw satellite data. She indicated, for example, that there is currently data on seagrass and mangrove extent that are not being used because the global dataset uses generic algorithms that are not specific to nations, and nations want control over reporting of their final emissions. Expert reviewers who examine the validity of country GHG reports and inventories need to verify country reports using global datasets of aerial trends, so this is one very useful application.

An audience member asked, regarding understanding the mismatch in the sink estimate of dissolved inorganic carbon (DIC) in the ocean, on which one of the following the panelists might choose to focus: observation, data assimilation with modeling, or satellites. Luke indicated that this area is data-limited because they cannot observe DIC from space and so they need to use pCO2 with remote sensing observable parameters. Although it is good to see autonomous platforms contributing, if we want to improve things we need fusion approaches (biogeochemical (BGC) ocean models + machine learning, ML). BGC models can solve all equations accurately and ML offers a cheaper computational method to derive solutions. Ultimately, in the weather prediction domain, ML is used more and is likely to see more application in the ocean domain in the future. Hubert said that for DIC, pCO2 is one of the unique parameters for which many different methods can be applied to derive it from space, especially due to the SOCAT (Surface Ocean CO2 Atlantis) dataset, with 500K match-ups. Algorithms can be developed based on the dataset, and uncertainties linked to atmospheric correction included. If we had the same opportunities with other parameters, this would be wonderful. He gave an example of CDOM and salinity, which are linked in coastal waters, and could be derived from satellite measurements.

Shubha Sathyendranath (PML) said that uncertainties have to be traced back to a global primary reference standard. If we are dealing with physical properties we know the standard. However, for biological properties, where are the standards? For remote sensing, we need to know whether radiance from SeaWIFS is the same as radiance from MODIS etc., and so intercalibration of measurements becomes very important. If we still don't know what exactly is changing, then underpinning this uncertainty is our uncertainty on standards. Gemma agreed, and gave the example of phytoplankton carbon intercomparison of algorithms, for which results were not great. The results raised a question of whether the in situ data was correct, as it is difficult to measure with no standard procedure for measurement, and introduced many potential sources of user uncertainty that were not addressed in the in situ data. Hubert said that the most important thing is to speak the same language while running international intercomparisons to assess uncertainties on carbon products. He gave the example of a problem with language while comparing POC products, as the definitions of POC among the scientists and modelers were widely different. He stressed that we first need to agree on what we are talking about, and it is time to have a unified language for all the standards.

Marie-Hélène asked, on top of unifying our community's language, for any last thoughts on how to best communicate to external stakeholders. Hubert indicated using people who are trained communicators, perhaps inviting them to these kinds of meetings. Gemma indicated that scientists still have to first communicate their science to these communicators so they understand, so really scientists need to learn how to do this better and have more clear messaging. She emphasized that communications around uncertainties need to be improved to ensure the general message does not sound unsure. Rosa indicated that part of the complexity is that different stakeholders have different needs, and tailoring the data for each would be impossible. For the community on blue carbon, a better understanding on what is available (what we can or cannot report) is needed. Their needs are also much more basic.

Uncertainty levels go from tier 1 to tier 3 and these are communicated well within that group and easy to follow. So having training exercises to share what data is available would be good, but also for the OC community to understand what are the needs of the community they wish to serve, as some of these are very simple.

Marie-Hélène summarized that more communication between scientists and stakeholders is needed, and scientists attending conferences where national needs relating to carbon reporting are discussed might be worthwhile. She thanked the panelists for their contributions, and the audience for their engagement.

4. Remote Sensing application to Water Quality

4.1. Keynote 3: Remote Sensing application to Water Quality, Tiit Kutser (University of Tartu)

Tiit Kutser started day 3 of the IOCS with a keynote talk on the demonstration of remote sensing to water quality applications. There are multiple climate change initiatives and products that allow for the study of how the changing climate is impacting water bodies, and in that vein, Tiit argued we are doing very well with EO serving Earth system science. He added that what is more challenging is EO serving the society, and providing different services like monitoring, reporting, helping with water management, and providing business to business services. He gave some history and context on the topic. Discussions on the application of ocean colour data to water quality have occurred at past IOCS meeting breakout sessions in 2017, 2019, and 2023, and recapped satellite ocean colour applications to water quality over the past 10 years. He indicated a regime shift, as before 2015 there were only demonstration missions, but since then long-term services and the continuous and uninterrupted flow of satellite data through the Sentinel missions have occurred, which allowed for everyday monitoring and support of water management and legislation development. Commercial companies also now provide satellite data.

A lot of development has taken place with hyperspectral data provisions, with the launch of PRISMA, ENMAP, that provide hyperspectral imagery, but at relatively low spatial and temporal coverage, for science rather than routine monitoring. Commercial satellites provide high resolution images on a daily basis, which is a great advancement. PACE, also a science instrument, provides daily data with hyperspectral resolution for many ocean applications, and has a slew of products in development that allows the study of processes in the open ocean. There are also planned improvements to Copernicus satellites for higher spatial and/or spectral resolution for water quality applications. However, as of today, there are still no dedicated satellites for inland and coastal waters. The spatial resolution is the biggest problem. There are about 5000 lakes large enough to be studied with OLCI resolution, but there are 117 million lakes to be studied in all. He showed how spatial resolution complicates spectral responses, as mixed or sub-surface blooms are not able to be detected at larger spatial resolutions. There are operational products within the Copernicus Marine Service as well as the Copernicus Land Service that are available for everyday monitoring of coastal areas and lakes, and the implementation of directives.

Regarding water quality management, for Europe this is managed under different directives: Water Framework Directive (WFD), Marine Strategy Framework Directive, Bathing Water Directive, and the Urban Wastewater Directive. All of these directives have indicators that have to be monitored. Decisions are based on how these indicators change. Tiit indicated that the WFD has more than 80 different indicators, only a few of which can be monitored from ocean colour satellite data (Chl-a, secchi depth, various measurement units of turbidity, suspended matter). The Copernicus program was launched to support this monitoring and management. A Water-ForCE project analyzed what Copernicus services were dedicated towards water quality and quantity, and the results showed >800 products for water quantity, and <10 for water quality. He indicated that the number of thematic hubs (28) and portals that deliver the products are a challenge, leading water managers to be confused about which portals to use, and to be skeptical when so few products are delivered differently in each thematic hub.

There are many operational monitoring examples as well. Some examples include the US EPA which runs a lake cyanobacterial bloom monitoring program for presence/absence of blooms, and now incorporates modeling with verification using satellite data. Australian monitoring network (CSIRO) provides a Chl index, turbidity and other water quality parameters, as well as measuring water volume in lakes and rivers. Fish kills have also been monitored. Different water bodies behave differently, and these can be studied using satellite monitoring. The TARKKA portal, delivered by the Finnish Environmental Institute, provides products for lakes and coastal waters and monitors >300 lakes and ~3000 coastal water bodies for the WFD using remote sensing. Estonia also has monitoring programs for 60 water bodies, and there is a lot of in situ data sites and ferries that collect data, but this is not sufficient and so S3-OLCI data is also used to monitor sites.

He indicated the legal framework in Europe. While some European water bodies receive one or no measurement for an entire year, the WFD only requires reporting one number per water body from April to September. Tiit suggests perhaps making recommendations to increase the reporting requirement or the indicators so that better monitoring can occur (e.g. timeseries), and that even a presence/absence of blooms (change detection), such as is done for the US EPA, could be helpful in many cases. The WFD also dictates how measurements must be taken and analyzed, and current legal guidelines do not include EO data as a method. He suggested that we would need to get remote sensing products to a state where they are accepted as a routine measurement. Tiit indicated that the creation of space-related programs was one of the aims of the Copernicus program, to provide free delivery of satellite products that could be utilized by companies. He indicated, however, that most EO companies in Europe get funding from EU projects rather than from customers and wondered if there was a market for business to business services. He summarized the Water-ForCE Roadmap findings about Copernicus.

Tiit summarized by mentioning the perpetual call for in situ data, adjacency effect removal and glint removal, and data for cal/val from the full range of optical water types, including high pigment concentrations in lakes, and floating matter and macroalgae. Standard procedures for sampling as well as uncertainty estimation are also needed. He suggested additional potential issues that could be further discussed in the panel and water quality breakout session. These included dedicated satellites for inland and coastal waters, higher spatial and spectral resolution with higher signal-to-noise ratios, developing EO-based indicators for water quality monitoring programs, and enabling business-to-business services. The slides from his presentation are available on the IOCS-2025 archive website at iocs.ioccg.org/iocs-2025-meeting.

Q&A: Zhongping Lee (Xiamen University) indicated that the big issue in China is the difference between what the satellites can measure and what the managers want (e.g. dissolved oxygen, or heavy metals). In Europe how do you get around this issue and fill these gaps? Tiit indicated that they have the same problems in the EU, where the directive requires something different from what EO can deliver as the monitoring programs were developed before EO data was available. He suggested doing more convincing, on a political level, to get the products that can be measured into the monitoring program. For DO, there are proxies that can be used to estimate, even if not accurate, to do trend analysis, or can give a general picture, and maybe monitoring programs are happy to accept these. There is great value in time series of in situ measurements and we should not push to stop taking these, but we should find the intersection for where EO can provide crucial information to managers on top of what is already provided.

An audience member indicated that there is not enough in situ data for validation of satellites but in situ data is being collected for policy, but not really suited for our application. If we could use that one sample collected every year it would be orders of magnitude more data for validation. How can we get the water sampling activities to be dual-purpose, both for reporting and for remote sensing validation? Tiit gave the example of joining monitoring cruises to try to get data collected under applicable conditions (clear skies, satellite overpass, etc) but that it can be difficult when schedules are already set, or for large monitoring programs to adapt to new protocols. For small countries, like Estonia, he is able to try to change some protocols, or delay a measurement until clear skies and better conditions, etc., but this is not always possible. Discussion needs to be on-going so that the value is understood on both sides. Milton Kampel (INPE), who was moderating the session, added that there are different regulations and infrastructure in the different countries, and there is no one solution for all. Tiit agreed.

Carsten Brockmann (Brockmann Consult) indicated that he had a different experience regarding the revenues from customers in the water quality sector. The global market is $US 1.24 billion for water quality from space, so where is your statement backed up that most commercial companies in Europe get their revenue from EU project funding? Tiit indicated that he had conversations with small businesses who were involved in EU projects that indicated their intent to get continued funding from future EU projects. He acknowledged that, yes, there are companies like Brockmann Consult and EOMAP who are doing quite well, and if there is money within the commercial sector, this is good.

Juan Gossn (EUMETSAT) asked about the legal requirement for satellite data and whether there were any thoughts on how to go about implementing the use of EO data for monitoring. Tiit indicated that, for example in the EU, that the new WFD is being prepared and suggested trying to get involved in these developments in order to get remote sensing accepted as a reliable method. If there is no other data, then EO can be used, this is done for some EU countries already, but would be good to standardize. Regarding FRM for in situ data, this might be good, especially for Chl. However, OCR might be too complicated for managers. Juan asked if managers might be interested in long-term data. Tiit indicated that it is needed but we would need to demonstrate the many advantages compared to the few in situ samples.

Other questions were held for the panel discussion that followed.

4.2. Panel Discussion: Water Quality, Moderator: Milton Kampel

Panelists:
Jenni Attila (Finnish Environment Institute, Finland), Alessandro de Carli (Bocconi U., Italy), Thomas Heege (EOMAP, Germany), Marie Smith (Council for Scientific & Industrial Research, CSIR, South Africa)

A panel discussion on application of EO to water quality followed the keynote talk on the topic. The goals of the panel were to demonstrate real-life policies and implementations that are operational for water quality applications; to understand roadblocks for using EO data by the reporting agencies, especially with regards to national regulations, legal issues, and guidelines or lack thereof; to understand the water quality commercial sector; and to discuss potential solutions, priorities, actions, and what space agencies could do to help to the community meet the regulatory and water monitoring requirements.

Milton Kampel opened the floor to panelists for comments on the preceding keynote talk.

- Thomas indicated that there are many successful companies in EO, and the question should be why there are not more in the aquatic sector. He indicated that there is a decoupling between what is happening in the private sector and what is happening in science. He gave the example of adjacency effects and the fact that there are some problems that have already been solved in commercial companies but are still being discussed as unsolved in academia. Services like CHL-a for rivers exist, are running, and are used by the commercial sector. So the role of the science community and agencies is to create more trust, and he worries that a focus on the limitations does not create trust. He sees the role of academia for investigating relevant gaps in science, and, especially the space agencies, for driving direction, harmonization, standardization, and best practices, including for industry. Susanne Kratzer (Stockholm University) added, in the context of working in Sweden with monitoring programs, that scientists should reach out more to those working in monitoring programs as a way to integrate the science. She indicated that an investigation of uncertainties in in situ data from monitoring programs showed that satellite data was quite reliable. She suggested that scientists should teach about how to measure optical properties and how to include these measurements in monitoring programs.
- Jenni indicated that Tiit raised many relevant points. He was right that we need to integrate EO data and in situ data as common indicators, and this has been done at the Regional Seas Convention where these complement each other. She agreed with Susanne that we should combine EO data with what comes from the monitoring programs. Regarding the front-end user portals of many of the websites that surface EO data, she agreed that there are many portals, but they are all suitable for certain purposes. She gave the example of huge development in the Copernicus Marine Service portal to provide suitable information for indicators and trend analyses that are all very valuable. These portals provide information to target groups, need to be fit for the user's purpose, and cannot be too general.
- Marie indicated that she has an optimistic view based on her experience. In situ monitoring in estuarine environments in South Africa is very poor, and so having satellite data (S2 and S3) to produce some information and fill in the gaps in measurements is a large step forward. Sensors with even higher spatial resolution would be amazing, but even as it is now, the data is very helpful for monitoring in this region. She indicated that operational services in South Africa have been made possible because of the existence of operational satellites with a planned continuation in the missions. Early investments in understanding the satellite data were able to be harnessed and built-upon when follow-on satellites were available. Knowing that we have processing chains for satellite data that will reliably be available in the future was key. She indicated that while hyperspectral data is now available, she understands and appreciates that it takes time to develop the methods for operational use which maintains the trust of the downstream users. She indicated that her agency feels more confident in being able to produce products for the long-term, and have them be available operationally going forward.

- Regarding the point in the presentation that remote sensing techniques could offer some information about indicators within the Water Framework Directive, Alessandro suggested that, while he agreed, we need to standardize the procedure for using this data to increase accuracy and uptake, since it is not nearly as costly to use or implement as traditional sampling. In order to provide information to decision makers we have to be at a certain readiness level to give standardized information.

Milton asked Jenni to share her thoughts on the requirements that agencies have for water quality products. Jenni indicated that for the WFD, there is nothing against satellite observation for the moment, but the directive does not mention that EO can be part of the monitoring methods. However, there is a proposal for amendments to include that EU Member States are encouraged to use automated methods, including satellite observations, and these should be received by March 2026. She said that in 2024 a survey was launched, together with JRC, to ask EO experts about the largest obstacles for EU Member States in using satellite observations, and the results indicated that there were no simple guidelines around how this data should be used, or how it should be combined with monitoring for the WFD reporting. A follow-up to this survey was done with the WFD working group representatives, launched Nov 2025, to collect input on how they wish the guidelines to look. These guidelines will next be drafted and finalized in 2027.

Maycira Costa (U. Victoria) agreed, and echoed Thomas's comments that there are many cases where EO data are used for monitoring aquatic systems. She gave examples of two North American cases for aquatic management where scientists (e.g. Caren Binding in Canada, and Blake Shaeffer in the US) were part of the agencies doing the monitoring, which she indicated made a major difference for the integration of EO data into the monitoring programs, as the expertise existed in-house. She indicated that each country/region/nation is a different story and some are already using satellite data operationally for water quality monitoring.

Milton asked Alessandro, as a water quality economist, to talk about how EO data adds real value to the economy in a way that can be understood by policy experts to advance higher implementation. Alessandro stated that economists use a cost-benefit analysis to compare different projects, usually comparing the status-quo (business as usual) with a new project. In evaluating the quality of the environment (in-land waters, oceans, etc), EO data could give important spatial and temporal information to support the evaluation of the economic value of these ecosystem services within a cost-benefit analysis. The analysis also evaluates social aspects. He gave an example of a relevant cost-benefit analysis, to try to determine the value of satellite observation compared with in situ observations (the comparison is important). Another example could be the impact of CO_2 emissions on lakes - for this cost-benefit analysis we would have to analyze the full life cycle of CO_2 in order to evaluate the social impact, but it needs to be assessed against another, different situation - again, the comparison is important.

David Antoine (U. Curtin) commented about the disconnect between science, applications and the economic benefit. He indicated that we have many discussions and forums but we don't work together across these sectors often, and among the reasons is that we don’t have the funding mechanisms to bring in non-academic partners. He made the recommendation (in the context of the EU and Copernicus) to try to put together funding mechanisms where small and medium enterprises and scientists can work together. He suggested that this is a good way to build trust, and fully understand each-other’s constraints. Otherwise scientists might think that what they are doing is useful for applications, but others don’t find it very useful for various reasons. There was audible agreement for this.

Masuma Chawdury (U. of Cadiz) indicated that she just completed an industrial PhD in which she had to work closely with end-users to create water quality products for monitoring purposes for bathing beaches in Spain. She indicated that regional institutions measured a lot of in situ data, but that they were not synched to satellite data, which created a hindrance for developing or validating algorithms for application to the water quality guidelines. They merged the scientific effort with the regional governmental efforts by indicating when there would be concurrent satellite overpasses to increase the chance of in situ data match-ups and build trust. While that part was successful, challenges/limitations still exist regarding spatial resolution (small beaches) and the presence of clouds during in situ measurements.

Milton followed up with Marie and asked if she could elaborate on examples of practical implementations of EO for water quality applications that are already operational in South Africa. Marie indicated that one of the most successful policy implementations of coastal remote sensing has been for west coast rock lobsters, whose juveniles are negatively affected after a HAB event due to low oxygen conditions. They get stuck on-shore during low tide when they exit the water to breathe. EO data is used to determine the timing of a HAB bloom and how long it has been within the area, which facilitates response alerting to protect the resource. This effectively occurs every summer. Marie indicated that having different stakeholders involved (researchers, policy-makers) has been another success. Since the beginning of the use of operational EO, they have had technical advisory groups that included municipalities, researchers, and industry, and this has been very successful in making services that are useful, and enabling policy based on the data.

Milton asked Thomas to explain how companies might profit from EO from a market-driven perspective in terms of requirements, and services from the space agencies. Thomas indicated that he believes the role of space agencies is to create synergies between research and topics that are not yet fully developed (e.g. blue economy markets, and nature services), which can help to lead to better climate change analysis in these areas. This type of focus can lead to better use of funding and strengthen the field for all involved, academia as well as industry. He has seen, for e.g., that ESA is moving in the direction of providing services, but he believes this is the role that industry plays, and that governments should not hamper industry but instead build on the science that can allow industry to thrive. When there are no existing industry services, then it makes sense for governments to provide these services (e.g. global ocean services, where you cannot contract an industry partner). He indicated that the question about why there might not be more successful industry players is tied to whether governments are creating a hampering effect for such services in the commercial space. There are many ways for collaboration to strengthen science and develop the economy in a direction that is really needed regarding environmental processes to address climate change. This is definitely an area in which we can work stronger together.

Milton asked Jenni to comment on the roadblocks and opportunities for using EO data. Jenni indicated that one of the largest roadblocks is a lack of knowledge about how to access EO data by those who really need it for status assessments. The guidelines that are being prepared are to address this challenge. Also, funding has been mentioned many times and easy funding for collaborations would be useful. Sometimes the mechanisms for funding can be quite laborious, and those who need the funds are not aware of the funding mechanisms currently in place, which is one of the roadblocks.

Alessandro indicated that, in the European context, many years ago he was involved in a project that was specifically about the interface between science and policy, and it was funded by the European Commission. He suggested that all funded projects now need to have a partner from research, industry, policy/administration, etc, because we have to create the tools to support these fields, and this can facilitate working together more easily.

Ewa Kwiatkowska (EUMETSAT) indicated that it seems clear that all of us (commercial, academia, agencies, organizations) need to press towards collaboration in order to increase trust, especially in the data that space agencies provide for these applications. She's still not clear how these collaborations can happen and what IOCCG could do to better help implement such collaboration, and requested any specific recommendations from the panelists.

Ewa also asked for clarification from Thomas about what agencies could do to better help industry, as they are using satellite data from the agencies. Thomas indicated that a discussion on the product level is too wide as there are so many market sectors. He suggested that if agencies provided globally harmonized, independent algorithms, these would add value. He asked that space agencies provide data that would otherwise not be available from the commercial sector. He gave the example of 2m spatial resolution, which is available commercially and already running. Industry buys this data to provide services to clients. He suggests that space agencies do not therefore need to make satellites that cover this same spatial resolution as it only hampers the companies that already provide this service. He gave another example of LiDAR being offered commercially, and again indicated that space agencies do not need to therefore try and provide this for areas where it already exists. There is instead a need for space agencies to sustain long-term missions, which the agencies have been doing. He made the point that users don't care which satellites the data emerged, just that it is available. So working together to cover the full swath of resolution and needs is better. He would love for agencies and industry to work together and pilot more cases together to understand the environments, which is extremely complex and requires everyone.

Milton thanked all the panelists and the audience for their engagement, and invited further discussion in the water quality breakout session.

4.3. Remote Sensing applications to Biodiversity

4.4. Keynote 4: Remote Sensing applications to Biodiversity, Roy El Hourany (ULCO-LOG)

Roy El Hourany started day 4 of the IOCS with a keynote talk entitled From Genes to Pixels: Towards Biodiversity from Space. He showed the large scale of the biodiversity problem, going from genes that determine the unique signature of life, to the Earth itself. Between these two are many intermediate scales: cells, organisms, communities, ecosystems, and the global ocean. He defined biodiversity, and spoke about the framework of biodiversity and ecosystem functioning across three axes: space, time and organization. He introduced the community framework (the Essential Biodiversity Variables, EBVs) as a way to standardize measurements of biodiversity, and showed the first global biodiversity assessment of the oceans, which showed high species diversity and richness (number of species per area) in tropical areas compared to the poles.

Oceanic planktonic contribute greatly to global ocean species richness. Roy showed example studies that used genetic datasets, such as TARA Oceans, to show the link between plankton groups and environmental gradients, especially temperature. Thus, anthropogenic changes in temperature and stratification are likely to reshape plankton communities across the global ocean. He also showed the relationship between biodiversity and productivity, indicating that biodiversity is highest in intermediate productivity zones, rather than at the extremes of high and low productivity regions.

He covered observation of biodiversity in the oceans, first starting with our eyes, the power of which he indicates that we should not underestimate, and then other tools spanning various spatial resolutions: omics data (genomics, metabolomics, etc); in situ measurements (microscopy, cytometry, etc) including autonomous platforms; and satellites for continuous coverage of surface properties. Satellites measure proxies of biodiversity from spectral reflectance, and phytoplankton properties (concentration, composition, size and physiology) can change the optical properties observable from space. Since biodiversity detection goes beyond Chl-a and relies more heavily on other accessory pigments and optical properties, he explored whether we can observe biodiversity from space. The first map of biodiversity from space for phytoplankton was published in 2013 showing an index that accounted for species richness and evenness. Today, stronger computational methods have been applied to the problem, and machine learning has been used to detect the signatures of primary groups from satellite pixels. A review of the field in 2004 showed wide variability of approaches to target biodiversity from space, and more than 70% relied on diagnostic pigments measured by HPLC due to the wide HPLC dataset of phytoplankton pigments in the ocean. Since pigment composition is related to physiology, the relationship between pigments and the community can be altered from local to global scales, and omics data can help us observe this shift. Many projects (PAN Oceanic Expedition, TARA Oceans, TARA Pacific, etc.) have standardized protocols at the global scale to generate omics datasets to unlock the diversity in a liter of water. This leads to hundreds of thousands of genomes and billions of metabolites—a bit too much data. This volume of data feeds into the fields of metabarcoding, metagenomics, and metatranscriptomics, with the aim to distill the data into EBV metrics, and link those metrics to satellite observables. He showed example studies that have done these kind of links, first using 18S rRNA, then eDNA proteins, that built community structure and co-located these with satellite optical variables (Rrs, Chl-a SST, PAR, fluorescence, bbp, attenuation coefficients, etc.) to construct new maps of community structure from space. These methods have a 65% overall accuracy, but some uncertainties in the prediction of cell abundance can be as high as 100%. Roy explained that he was happy to see this, because the hypothesis of one satellite measurement to detect the wide variability of plankton in a pixel is problematic, and so this is where uncertainty quantification is needed to understand whether a relationship between reflectance and community structure is good or not. He showed other work that focused on using DNA to infer global maps of cell abundance, with the aim of determining the abundance of phytoplankton carbon. Phytoplankton is the only entry point of new carbon into the marine food web and sustains even higher predators. Roy explored whether phytoplankton structure mapped from satellites could tell us something about the trophic state of the system. He shared studies that looked at higher trophic groups in the Southern Ocean, relating their movement to phytoplankton community composition to understand foraging behaviour.

Higher resolution taxonomic data requires more complex data to develop the proper algorithms to match PACE hyperspectral data and other upcoming hyperspectral missions. He discussed a few projects that could help to meet this need (e.g. NASA+ESA-funded PlanktoSpace, PhytoScope) that go from hyperspectral to genomic signatures, try to co-locate omics and optics, and evaluate measurements for algorithm development for future operational biodiversity from space products using the JEDI marker (a tree-of-life scale single PCR). Protocols have been created in the frame of PlanktoSpace to get match-ups with PACE from 1200 sites, done with Seatizens so that sailors can apply and work with the project. Roy summarized that we know that biodiversity is multidimensional and multiscale, and no single observing system is sufficient to address the question of biodiversity from space. It is thus important to have an open, cross-disciplinary consortium to merge the variable fields required to address marine biodiversity from space (biology, ecology, physics, optics and modeling). He indicated that there are still open questions within the field, namely: which marine EBVs can we robustly and routinely infer from EO data, and how do we turn these advances into actionable services for conservation and management. The slides from his presentation are available on the IOCS-2025 archive website at iocs.ioccg.org/iocs-2025-meeting.

Q&A: Carsten Brockmann (Brockmann Consult) asked whether geostationary ocean colour might help with mapping biodiversity from space. Roy indicated that it would help immensely, because every time we change the scale we need a new biodiversity metric. So if we integrate time into the metric and include daily processes, it will give us important answers on how phytoplankton change within the day. Diel migration could also be captured, and it would be a great asset to understand the community fluctuations.

An audience member asked about metatranscriptomics, and whether Roy saw this method playing any role in observing biodiversity using remote sensing. Roy indicated yes. He pointed to a poster within the IOCS meeting that showed, for example, phytoplankton reacting to environmental stress (e.g. iron stress), and these stresses able to be observed via metatranscriptomics as well as fluorescence in the red. So phytoplankton nutrient stress is one potential application, and we can use this and other parameters to quantify relationships between biological communities and the environment.

Stefan Simis (PML) indicated that much of the work showed in the presentation was built on decades of analysing bottle samples, and asked where was the best potential in observing change in biodiversity at a global scale—are we back to observing time series at single stations, or something beyond this? Roy acknowledged that much of the change assessed with in situ sampling will be local, and alluded to the development of algorithms that we hope will be able to be applied globally, though there will be limitations, especially for those organisms that change rapidly on a local scale.

5. IOCCG Agency Updates & Townhall

5.1. EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites)

Ewa Kwiatkowska gave the update for EUMETSAT, and started by thanking everyone for their participation, reiterating the importance of the recommendations from these meetings. In her presentation, she highlighted the specific recommendations that led to some of the current activities at EUMETSAT. Regarding the status of the Sentinel-3 mission, which is a constellation of 2 satellites from the European Commission Copernicus Programme, S3-OLCI is now operating L1 collection 4 algorithms, which were updated in their processing in mid 2024. The update included a new TSIS-1 solar irradiance reference spectrum, and per pixel radiance uncertainties, and introduced a spectral temporal model in order to account for slow drift in OLCI spectral responses. For L2 OC products, EUMETSAT has been operating Collection 3 algorithms for some time, which show good consistency between OLCI A and B products. In addition, new IOP products were introduced at the beginning of 2024, with independent validation that showed good performance. All data is available at the EUMETSAT Data Store at data.eumetsat.int. Ewa highlighted two algorithm developments: 1) new IOP product algorithms developed with independent validation showing good performance; and 2) validation and intercomparison of different BRDF corrections was done for clear water, but since users are Interested in complex coastal and in-land waters, there was additional modeling of BRDF for more diverse optical water classes and a new BRDF model (O25) was developed. New OC processing for Sentinel-3 will be implemented next year (Collection 4), to include updates of the standard atmospheric correction, switching to Rrs products with O25 BRDF correction applied, updates to CHL products with new algorithms based on optical water classes, etc.

Regarding future satellite missions, S3C will launch in 2026 and, after successful commission, will replace S3A optical payload. After S3C only S3D will be left to complete the 1st generation Sentinel-3 missions. For the longer time horizon, ESA is preparing the Sentinel-3 Next Generation Optical (S3NGO) mission. Ewa went through what will be provided by S3NGO: advanced OLCI (AOLCI) with hyperspectral bands and spatial resolution doubled to max 150 m. NASA's PACE-OCI instrument is an important reference for S3NGO development. In addition, EUMETSAT operates the geostationary Meteosat satellites. These were not developed with OC considerations, but they have been prototyping ocean colour applications to show the value and demonstrate the need for a dedicated OC instrument on a geostationary platform over the European continent and Africa.

Work on in situ FRM continues. The data are used for system vicarious calibration. EUMETSAT manages activities to develop OC-SVC infrastructure on behalf of the EC Copernicus Programme. A European node will be established and standardized with NOAA's MOBY and NASA's MarONet. The review of proposals to start phase 4 of this activity is almost completed. When developed the infrastructure will have a free and open policy. For validation, EUMETSAT is implementing Phase 2 of FRM4SOC (Phase 1 was implemented by ESA). This focused on above-water radiometry and implementing a complete FRM framework for two types of hyperspectral radiometers that are the most commonly used in the community. Many calibration labs have adopted detailed guidelines, and new labs are being established. We are now at the stage where we can assign a metrological quality label to in situ data, and this opens up ocean colour to new applications in policy, regulatory reporting, and legal compliance. Ewa shared the breadth of EUMETSAT data services and user support resources and invited anyone who has issues or needs support to contact the helpdesk.

5.2. ESA (European Space Agency)

Marie-Hélène Rio gave an update on ESA's ocean colour activities. She indicated that a previous IOCS recommendation had been taken to have Sentinel-2 (S2) reflectance dedicated to the aquatic domain, and this is now available as a stand-alone algorithm within SNAP version 13, but will become part of L2A products.

For future missions, S2-Next Generation (S2NG) will ensure enhanced continuity of services for S2 products. ESA is preparing for the expansion mission with CHIME, which will be hyperspectral. A number of projects are active to explore future applications. These include one focused on EarthCARE, which is active LiDAR dedicated to monitoring clouds and the radiative budget. The Project OCEAN (Ocean Colour EarthCARE ANalysis) focusses on seeing how data from EarthCARE could be used for ocean optical properties at 355 nm. FLEX, set for launch in 2026, will measure in the visible to infrared for application to photosynthesis and vegetation stress. Other projects are part of the EO for Society programme to advance understanding of scientific processes within the Earth's system that have societal application. More than 40 projects are active and many are using ocean colour radiometry (OCR). You can explore the full list at eo4society.esa.int/projects/.

Marie-Hélène gave examples of projects where OCR is used to develop useful products for International European Policy frameworks. She also highlighted the ESA Climate Change initiative, and the cross-links with the IOCCG Task Force on Harmonizing Global Ocean Colour for Long-term Climate and Ecosystem Monitoring, for which ESA-ECSAT in the UK is hosting the secretariat. There is now also a new CCI Phytoplankton essential climate variable (ECV), which aims to give climate quality time-series data from 1997 to 2025.

She highlighted the Ocean Carbon Project, which tries to take the global picture of the pools, fluxes, and processes of carbon in the aquatic environment. The Ocean Carbon from Space workshop, which was hosted by ESA and which continued at the IOCS in the Ocean Carbon sessions, is part of these initiatives. All recommendations from these meetings are important for developing the CEOS Aquatic Carbon Roadmap, due in 2026. It is the aquatic component that supports the CEOS strategy paper on carbon that shows how EO data can best support the global carbon stocktake, and is part of the guiding vision that space agencies need for the next 15 years to support science and policy needs.

5.3. NCEO (UK National Centre for Earth Observation)

Steve Groom presented virtually, and gave an update on the UK National Centre for EO (NCEO) and the work they do using ESA OC Climate Change Initiative (CCI) and PHYTO-CCI, which are projects led by NCEO colleagues at the Plymouth Marine Lab (PML), UK. The aim of OC-CCI is to create a long-term dataset that merges multiple sensors. As each sensor has a finite lifetime, and some tend to degrade closer to the end of their life cycle, a merged product is needed in order to get a complete record for climate analyses. Merging is done by band-shifting sensors to a reference, and taking inter-sensor bias corrections to reduce the differences between the sensors and harmonize the different approaches. A common atmospheric correction is used, where possible, and bias correction to a reference sensor is conducted. The current OC-CCI time series goes from 1997 to 2025. Products are available at 1 km (reduced set) and 4 km resolution, with daily, weekly, monthly and annual frequency. Included are also 14 optical water classes. Over 100 peer reviewed publications now use OC-CCI.

Planning for a new phase of CCI has just started, as well as work on the next generation of CCI, version 7. Updates in CCIv7 include new in situ data, re-evaluated system vicarious calibration, and the launch of new round-robins for in-water algorithms and atmospheric correction schemes. There are plans to investigate adding in NOAA-20 VIIRS and possibly re-integrating Aqua MODIS, which was not used beyond 2019.

Regarding the in situ database, 3 versions have been published, with the most recent in 2022. The database has now been extended with data to 2025, and additional data sources have been added. Steve showed the additions that had been made to the dataset as well as comparisons with updated OC-CCI v6 match-ups against in situ HPLC, which showed improvement. Additional bands are being added based on OLCI sensors (400, 620, 681 and 709) as part of the requirements under PHYTO-CCI, along with the 6 traditional bands.

New missions are being investigated to add into future OC-CCI versions, in consultation with the various space agencies, including SGLI-GCOMc, VIIRS-NOAA21, OCM-OceanSat3, and OCI-PACE. Multi-sensor integration is the aim of a new IOCCG Task Force, and is vital for long-term ocean-colour climate records. More will be discussed in the dedicated breakout session (#10). Steve summarized by adding that OC-CCI now delivers almost 28 years of consistent climate-quality data, and bias correction and harmonised processing continue to support cross-sensor consistency.

5.4. CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia)

Thomas Schroeder gave an update on key ocean colour activities and cal/val infrastructure in Australia. Australia has regional access to Copernicus data through the Australia-Asia regional data hub that provides free and fast access to all the Sentinel missions (www.copernicus.gov.au). The data supports a wide range of national OC activities, predominantly using S3-OLCI. CSIRO partnered with SmartSatCFC (a consortium of universities and other research organizations along with industry that has been funded by the Australian government) on AquaWatch to build an integrated and observational system. Developments continue under this integrated coastal in-land and in-water network, with several pilot sites around the country to test use cases. There are discussions about a potential hand-over to a national partner for some of the activities. Thomas shared the AquaWatch dashboard, with examples.

Also included in his update were ocean colour activities that are being led by others in the region, including in-water optical sampling as part of Australia's Integrated Marine Observing System (IMOS); MarONet (Marine Optical Network) that supports SVC for PACE; a recap of the Southern Ocean Bio-optics workshop that was held in November 2025 to unite bio-optical scientists with the phytoplankton photophysiology community; sampling at the Darkwater Inland Observatory Network (DION) which is fixed in freshwater at a high CDOM and low TSS site; bio-fouling detection for in-water sampling; and sampling from a coastal validation site with HyperOCR and SeaPRISM as a reference. Upgrades to infrastructure will occur in 2026, and this includes an upgrade to the SeaPRISM T-model to avoid on-platform observations and significantly increase the number of AERONET-OC observations.

5.5. JAXA (Japan Aerospace Exploration Agency)

Hiroshi Murakami gave an update on JAXA's ocean colour research and applications. SGLI was launched in December 2017, with data available from January 2018. The mission is now in its extension phase until 2030, including a controlled deorbit. This will facilitate long-term environmental monitoring and contributions to climate issues. However, currently the next mission is not planned, and is to be determined.

The target for SGLI-data and products has shifted more to applications, and to contributions to the IPCC and the global stocktake. He showed the global average of CHL by many sensors including SGLI, indicating that after bias correction the data was looking good, and these comparisons are important for continuity and potential product merging. The latest product version (v3) for GCOM-C is available through JAXA's G-Portal (https://gportal.jaxa.jp/gpr/), which is open and accessible to the scientific public. The data are available in HDF5 format. Hiroshi showed that application of GCOMC data goes beyond OC to include air quality; wild fire detection; sea state, including sea ice conditions; and volcanic islands, including ocean colour change as a result of volcanic eruptions.

JAXA is contributing to Japan's *Basic Plan on Space Policy*, under which the following priority theme related to ocean research was identified: marine monitoring and maritime domain awareness - to strengthen the integrated monitoring of Japan's surrounding seas and sea lanes via satellite networks, and support the *Free and Open Indo-Pacific* vision and expand market opportunities. They are also working on establishing other targets, including a climate science and climate resilience target, for which ocean colour data will also be needed.

Of specific focus at the moment is JAXA's aim to engage with not only the science community but also industry. Thus, a consortium for satellite EO (CONSEO) has been established for stronger collaboration and communication between industry and government. Regarding previous IOCS recommendations, Hiroshi showed a number of recommendations aimed at space agencies that have been actioned or addressed by JAXA, and shared the current and future line-up of all of JAXA's missions.

5.6. KIOST (Korea Institute of Ocean Science and Technology)

Jongkuk Choi gave an update on the current status, validation, and applications of the GOCI-II mission, launched in 2020. GOCI-II has a mission lifetime of 10 years, with 12 spectral bands and revisits in local areas 10 times/day, and outside areas once/day.

KIOST is in charge of generating L2 products, and transferring them to the Korea Hydrographic and Oceanographic Agency (KHOA) for public service and data distribution. Data is available from the National Ocean Satellite Center (NOSC, www.nosc.go.kr) at KHOA from 2021. Data downloads for GOCI-II increased 7-fold from 2021 to 2024 (1.2 million to 8.5 million).

Currently, there is a project to improve the accuracy of GOCI-II data up to 2026, and a new project is being established to improve accuracy until the end of the mission. In situ cal/val measurements are continuing via ships and automated systems (e.g. AEROCET-OC) and a new optical station has been deployed in clear-water. They are also utilizing the international sites of their institute but welcome more international collaboration.

Jongkuk highlighted several new developments that were detailed in posters by team members throughout the meeting, including: new radiative calibration algorithms developed through long-term monitoring of solar diffusers; improvements to atmospheric correction algorithms using AMI (Advanced Meteorological Imager) and GEMS (Geostationary Environment Monitoring Spectrometer) data on water vapour, ozone, and NOx in the same geostationary orbit as GOCI-II; system vicarious calibration from many optical water classes and in situ data from AERONET-OC; comparisons of good consistency in Rrs between the first years of GOCI and GOCI-II; improvements to IOP algorithms via machine learning which reduced QAA uncertainties; updates to GOCI-II regional Chl-a algorithm, including with water quality considerations; and applications of data to phytoplankton phenology during a marine heatwave.

Preparations are now underway for GOCI-III (budget pending for the start of development). Some of the spectral band widths and band centers have been adjusted, with some designed for polarization. Spatial resolution and coverage will remain the same as for GOCI-II. The plan is that GOCI-III will be launched on GEO-KOMPSAT-6 along with a GEMS sensor in 2033, but the team is worried about potential gaps between GOCI-II and GOCI-III. The team is also developing Level-3 algorithms for both GOCI-I and GOCI-II, to provide long-term time-series data.

5.7. NOAA (National Oceanic and Atmospheric Administration)

Menghua Wang presented virtually and gave the agency update on behalf of NOAA and the NESDIS Center for Satellite Applications and Research (STAR). NOAA's Joint Polar Satellite

System (JPSS) series provides operational data. Three VIIRS sensors continue to provide data, on the SNPP (2011-present), NOAA-20 (2017-present) and NOAA-21 (2022-present) satellites. NOAA-22 is planned to be launched in September 2027, with the next launch planned to follow 5 years later, in ~2032. Due to dramatic policy changes, ocean colour has been descoped from the next-generation geostationary satellite program, Geostationary Extended Observations (GeoXO).

VIIRS data is available through [NOAA OCView]() and L3 products through [NOAA CoastWatch]() along with MOBY in situ data.

Menghua showed results from new system vicarious calibration approaches applied equally to SNPP, NOAA-20 and NOAA-21, with surprising results for NOAA-21. A new global water transparency product (secchi depth) has also been developed, and he showed a map of the resulting global climatology. NOAA continues to produce daily, gap-free data for the community using the three VIIRS-sensors, and separately, a 5-sensor method that also includes OLCI-S3A/3B. Products produced are Chl-a, Kd(490), SPM and secchi depth (Z_{SD}). They have started application of the daily gap-free data to eddy detection using other parameters (e.g. SST) and neural networks.

Cal/val cruises continue, with 10 dedicated cruises from 2014-2025 and support from routine MOBY in situ measurements. Cruise reports are published as part of the NOAA NESDIS Technical Report Series.

5.8. NASA (National Aeronautics and Space Administration)

Laura Lorenzoni gave an overview of the NASA satellite missions. There have been many changes within the agency and a renewed push for deep space exploration, which is currently driving agency priorities and budgets. Earth science is still central to everything that the agency does, and so there is commitment to understanding the biology and biogeochemistry of the Earth better. Laura explained the goals and aims of the Ocean Biology and Biogeochemistry (OBB) program, and that satellites, airborne, and in situ measurements as well as modeling approaches are applied to meet these goals. OBB also works closely with the biodiversity program.

Planned missions include GLIMR (Geostationary Littoral Imaging and Monitoring Radiometer) which will assist as OC is descoped from GeoXO. Although the satellite will be completed by 2026, a launch date is still pending. Also planned is a collaboration with the Italian Space Agency on Luce, which is a space-based LiDAR mission (Cloud Aerosol LiDAR for Global Scale Observation of the Ocean-Land-Atmosphere System) to address some of the most important questions posed in the last US decadal survey.

Laura congratulated ESA on the launch of Sentinel-6B, which launched in Nov 2025. NISAR launched before that, in July 2025, and is a collaboration between NASA and ISRO to examine how the solid Earth changes using radar, and this includes coastal subsidence. EMIT on the international space station can be used to look at atmospheric gas pollutants, and that data is available at high spatial resolution. SWOT, launched in 2022, and gives data on sea surface height and in-land waters. PACE, launched in 2024, is the long-awaited hyperspectral ocean colour mission, and Laura was pleased to see the number of projects and science involving PACE data at the IOCS. She acknowledged the field teams (24 of them) doing in situ measurements for understanding and validating PACE data, and the 14 science and application teams working on developing new products and refining algorithms. NASA just selected 16 teams to examine the ground-breaking science of PACE that span land ecosystems, cryosphere, ocean, and atmosphere. She showed some of the surprising applications of PACE data for science advancement and societal application. Many products are now available through NASA's website.

Other updates were on additional science being explored. Laura reminded everyone about the Research Opportunities in Space and Earth Sciences (ROSES), and thanked reviewers, including the international reviewers of proposals they receive under ROSES. She indicated that the next US Decadal Survey will focus on observables rather than missions and is being worked on at present. She mentioned a new project, FORTE (Frontlines Of Rapidly Transforming Ecosystems), which has been selected to go forward, and the many collaborative training opportunities with other agencies that NASA has participated in over the past year (Ocean Optics Class, Ocean Training Course, FICE25, etc.). NASA also supports SVC systems (HyperNAV and MarONet) and lunar calibration through the Air-LUSI project, which will end in winter 2026. She stressed the collaborative nature of the community, how impactful it is for science, and how important this is moving forward.

5.9. SIO (Second Institute of Oceanography, China)

Xianqiang He presented on progress in China's ocean colour satellite missions and remote sensing application technologies, on behalf of the Second Institute of Oceanography, Ministry of Natural Resources in China. He gave an update of the HY-1 series ocean colour satellite currently in orbit, including: HY-1C and HY-1D, launched in 2018 and 2020, respectively; HY-1E, an experimental satellite launched in 2023; and HY-1F operational satellite, currently under approval. HY-1E and F have three payloads: an updated Ocean Color and Temperature Scanner (COCTS2), a Programmable Moderate Resolution Imaging Spectroradiometer (PMRIS), and an updated Coastal Zone Imager (CZI2). The number of bands and spatial resolution are much improved compared to HY-1C and D. He showed examples of satellite images and daily Chl-a product from HY-1E. A merged daily Chl-a product has also been created with HY-1C/D/E since 2024. Data from the HY-1 series is freely accessed through the National Satellite Ocean Application Service (NSOAS).

China has planned geostationary ocean colour missions with the Geostationary Ocean and Coastal Zone Imager, with highest spatial resolution at 25m, and the Geostationary Ocean Color Imaging Spectrometer with lower spatial resolution of 200 m, but with two modules, one multispectral and one hyperspectral. There is also a Geostationary Atmospheric Differential Absorption Spectrometer, to monitor air pollution in coastal areas.

In addition to the traditional satellites, China has also launched SmallSats specific for ocean colour observation (HiSea-II), and BlueCarbon-I SmallSat for local observations.

Xianqiang showed cal/val results of the HY-1 missions, and indicated that they have now established a Long-term Ocean and Atmosphere Simulations Observation Network (LOASON) with many time series stations along the whole Chinese coastal area for cal/val of Chinese and international ocean colour satellites. They have done validation for HY-1E using AERONET-OC and in situ data in the East China Sea and South China Sea, and have developed in situ OCR instruments: HOC (Hyperspectral Ocean Color Radiometers), Triplet-R AOP, HyperOPS, and Airborne AOP.

For applications, two large projects have been supported: 1) the marine carbon sink monitoring project to observe the long-term change in the carbon sink in the China Seas using time series, and monitor global pCO2 and air-sea CO2 flux using the HY-1 series; and 2) the active and passive integrated remote sensing technology and equipment development project to develop a new technique that will combine LiDAR with passive sensors. Satellites have now been used within China to operationally monitor water quality, including river water quality, eutrophication in bays, and suspected pollution in coastal areas. The scientific community has released GLOSS (Global, Long-term, Ocean-color Synthesis Series, led by ZhongPing Lee) that has higher effective coverage. A Marine Satellite Data Online Analysis Platform has also been released online and has been used widely since 2016, with associated training courses.

Xianqiang introduced the Journal of Remote Sensing (JRS), which is an open access science partner journal published by the Aerospace Information Research Institute, Chinese Academy of Sciences (AIR-CAS) and distributed by AAAS (American Association for the Advancement of Science). He welcomed submissions https://spj.science.org/journal/remotesensing.

5.10. ISRO (Indian Space Research Organisation)

P V Nagamani presented ocean colour science and applications at the Indian Space Research Organisation (ISRO). ISRO aims to enable national development, improve the quality of life of citizens, build a resilient society and facilitate enhanced understanding of the Earth system. She shared the context and history of remote sensing capabilities at ISRO, which includes remote sensing for natural resource and disaster management, weather forecasting, and climate studies, in addition to ocean and atmosphere.

The main ocean colour mission is Oceansat, equipped with the Ocean-Colour Monitor (OCM). Previous missions were Oceansat-1 (1999-2010) and Oceansat-2 (2009-2021). Oceansat-3 was launched in September 2022 and is currently in orbit, with 13 spectral bands from 412-1020 nm including spectral bands for fluorescence line height and bloom detection. Standard products are available for Oceansat-3: Chl-a, TSM, AOD(870), Kd(490). Nagamini indicated procedures for post launch calibration, which is on-going, as well as the sites, methods, and results for satellite data validation, including from coastal observation facilities and BCG-Argo. She also showed comparisons between the global daily Chl-a OCM3 product and Chl-a from ESA OC-CCI, as well as global monthly composites. Similar comparisons were shown with S3-OLCI, with OCM-3 capturing seasonal dynamics well. Work will continue on bias correction and harmonization of processing using in-situ observations, as well as on cal/val activities for improving data quality.

The launch of Oceansat-3A (with OCM, OSCAT and SSTM sensors) is planned for the first quarter of 2026 with the same 13 spectral bands and daily global coverage at 1 km resolution. This mission, with the presence of the SSTM sensor, should also allow for the study of sediment dynamics. For other future work, ISRO is involved in the generation of long-term ocean colour data with multi-sensor integration, as part of the IOCCG Task Force on Harmonizing Global OC for Long-Term Climate and Ecosystem Monitoring. Nagamani indicated that ISRO would like to collaborate on cal/val activities as well as the development of new sensors and sites in their region with the collaboration of other agencies, to, among other things, help to provide long-term in situ data for climate applications for the global community.

5.11. CNES (French National Centre for Space Studies)

Aurelien Carbonniere presented virtually and gave an update on the Earth observation program at CNES with a focus on ocean colour. He outlined the four strategic priorities of CNES and all the missions in which CNES is involved, including within themes of ocean and hydrology, infrared sounding, optical imagery, carbon, satellite altimetry and the Earth's magnetic field. He focussed on the SWOT mission, which was launched in 2022, joint with NASA. The primary drivers of the SWOT mission are hydrology and oceanography, but there have been applications to other fields (coastal altimetry, cryosphere, etc.).

Regarding future mission development in the marine domain, he outlined three upcoming missions: The TRISHNA mission (French-Indian collaboration), which has coastal 60m resolution every 3 days with many applications to water quality; ODYSEA (French-US), expected by ~2030 and will look at winds and surface current velocity variables that are not currently being assessed; and S3-NG-Topography which will directly follow from SWOT.

He gave a recap of the UNOC'25 and the creation of the Space4Ocean Alliance. The Alliance brings together all marine stakeholders to work towards common objectives. These include the development of advanced ocean indicators, and new and innovative space missions; assessment of current gaps in knowledge and observations; and promotion of the delivery of operational services, especially to countries that do not have space missions. The Alliance exists as a place to build trust among all marine stakeholders, and to work together to design new mechanisms of funding, etc. Aurelien encouraged the group to use the Alliance as an opportunity to advance many of the IOCS recommendations and suggestions regarding cross-collaboration with stakeholders.

Looking forward, the main priorities of CNES in the next 5 years includes high resolution applications to salinity and soil moisture, as well as exploring the land-sea continuum, and ocean colour from geostationary orbit. CNES is also funding a global initiative on LiDAR. They have used LiDAR since 2022 to study ocean colour activities and are invested in the launch of the Luce mission in ~2032, as marine LiDAR is one of their key priorities. He highlighted several projects that CNES has funded: COUL-PNP focussed on spatio-temporal variability in particulate organic matter to constrain calculations of global biogeochemical cycles; HYPERVAL to develop a new algorithm for S2 reflectance in optically shallow coastal waters; two projects in Canada, to improve estimates of Arctic primary production and estimate under-ice radiation; and INVASEA to map intertidal invasive macroalgae.

Aurelien highlighted the ODATIS Ocean Data Cluster web interface (https://www.odatis-ocean.fr/). ODATIS is the marine component of the larger digital infrastructure called DataTerra. The expert group on ocean colour is part of ODATIS and has recently enabled the generation of satellite OC products at 1.3 km spatial resolution along the entire French coastline. Targeted users are large research consortia that can use the information for better insight about variations on bio-optical and biogeochemical properties in French coastal waters for the past 25 years.

5.12. CONAE (Argentina National Space Activities Commission)

Carolina Tauro presented virtually and gave an update of the status of the SABIA-Mar mission being led by CONAE. The SABIA-Mar mission is an ocean colour mission with an expected launch for 2027. The main objective of the mission is to obtain ocean colour data in the open ocean, and mainly South American coastal zones. It is expected to have a 2-day revisit in Argentinian coastal waters, with a ground station in Córdoba, Argentina. The team is working towards two scenarios: global resolution of 800m, and regional resolution of 200-400m. The satellite will cover VIS-NIR-SWIR with spectral resolution of 15 bands from 412-1610nm. Also aboard the satellite will be a panchromatic high sensitivity camera for night-light detection, a data collection system receiver, and a GNSS (Global Navigation Satellite System) receiver compatible with on-board computers.

CONAE is currently also developing their own algorithms for cal/val activities. Carolina showed details of the expected products (from L0 to L3, regional and global) that will be developed from the spectral bands, with the expectation to have the data freely available from the CONAE website. She showed the expected applications resulting from community engagement to meet user needs: water quality, fisheries and aquaculture, land-use monitoring, and sea surveillance and navigation support in Argentinian and surrounding waters (gained from night light monitoring). Several workshops have been hosted for

SABIA-Mar users, and meetings with the Brazilian community for application to Brazil as well. The satellite is being assembled in Argentina, and most of the pre-launch calibration has been completed. There have also been workshops on cal/val through collaboration with other institutions and agencies. Carolina thanked all those from the community who have helped to contribute thus far to the mission.

5.13. Community Town Hall and Q&A with Space Agency Representatives, Moderator: Shubha Sathyendranath

Panelists:
Ewa Kwiatkowska (EUMETSAT, Germany), Hiroshi Murakami (JAXA, Japan), Jongkuk Choi (KIOST, South Korea), Marie-Hélène Rio (ESA, Italy), Thomas Schroeder (CSIRO, Australia), Xianqiang He (SIO/MNR, China), Laura Lorenzoni (NASA, US), P V Nagamani (ISRO, India), Online: Menghua Wang (NOAA, US), Aurelien Carbonniere (CNES, France)

A panel discussion with the IOCCG agency representatives was organized on the final day of the IOCS meeting, with questions to the panel taken solely from IOCS participants in the audience. Shubha welcomed the panel and opened the floor for questions.

Bror Jönsson (U. of New Hampshire) asked about international collaboration on ocean colour. He wanted to know what systems we could use to advance working together. In other areas, there are funding calls where agencies require a collaboration, and the funding for the collaboration is joint from the agencies so that money doesn't cross borders. Can something similar occur for ocean colour as well?

- Laura indicated that NASA and ESA have tried. However, when calls are released specifically with collaborations involved, there have been little to no responses for these interdisciplinary funding calls. So there seems to be a barrier that prevents researchers from submitting proposals, and Laura asked the audience what this barrier might be.
- Shubha asked the audience how many know whether these calls exist. There were a few hands, so knowledge of the funding calls could possibly be one barrier.

Gemma Kulk (PML, UK) indicated that she knows of calls for ESA funding where 10% of the funding can be used for US-based scientists, but argued that 10% was insufficient to cover the cost of an international collaborator. Shubha asked whether a 10% leeway is what the agencies had in mind.

- Marie-Hélène indicated that indeed the community may not have been fully aware of the funding calls, and that communication about the call could be improved. Shubha indicated that IOCCG could help to advertise such calls.
- Marie-Hélène confirmed that 10% can be for countries that are not EU Member States, and acknowledged that the amount is limited. However, she clarified that what Laura mentioned was a joint call that would allow ESA to fund EU Members, and NASA would match and fund the US consortium, specific for in situ campaigns and activities. Yes,

this was only one call between ESA and NASA, and so we should consider activities in common with other agencies.
- Ewa indicated that within Copernicus there are calls for outreach and collaboration, and these are also available for cooperating countries. On the science side, if projects exist with common goals across countries and the possibility for collaboration, they find ways to make it work. She gave the example of the FRM activities that have benefited greatly from these types of collaborations.

Maycira Costa (U. Victoria) indicated that ESA supports Canadian scientists, but that the application process is one barrier because it is complicated from the Canadian side. Additionally, after the University overhead, the amount remaining is usually not worth the effort to submit an application to ESA and creates a block to working with colleagues from Europe. She indicated that collaborators that try to get their own funds domestically tend to work more successfully.
- Marie-Hélène indicated that Canada has contributed to Europe's science budget specifically so that Canadian scientists can be PIs on projects, so it is important to understand why Canadians believe the process to be complicated and how this can be improved to increase collaborative applications for funding. Maycira suggested she would speak with Marie-Hélène directly to give more details that would be helpful towards this goal.

Victor Martinez-Vicente (PML) asked whether there was a way to be strategic about datasets as a collaborative development (e.g. SeaBASS for ESA), to coordinate across agencies to collate and compile in situ data that is essential for cal/val. Shubha added that the need for in situ data is always highlighted at meetings, can the space agencies collaborate with their science counterparts that fund in situ data collection (as it directly benefits cal/val activities) to have a joint in situ data pool?
- Ewa acknowledged that this request has been made many times throughout the meeting, and there are actions on the IOCCG agencies to collate in situ data access points or projects on the IOCCG webpages. She agreed that, beyond availability of links, it would be good to establish partnerships, and acquire more fundings for in situ data collation, as it is important for space agencies to ensure the quality of the in situ data and FRM generated by the community for cal/val and algorithm development.
- Hiroshi agreed that the purpose of satellite agencies is to produce good data, and this includes in situ data. Japan encourages the sharing of in situ data because there are existing good datasets, and yes, we could advertise the portal for access to this, and we encourage this.
- Jongkuk suggested that there could be a collaborative project to collate all the cal/val data so that others can use it for their own data needs. This could be collaborative across all satellites from all the represented countries.
- Marie-Hélène agreed that access to in situ data is always requested. Maybe we can agree on a common roadmap for in situ data collation. She encouraged the agencies,

through IOCCG or CEOS, to discuss a way forward. It is an agency challenge but also a science community challenge because national programs at-sea sometimes do not make their data open-access, so something needs to happen collectively to solve this issue.

- Thomas indicated that CSIRO is not a space agency but they put a lot of effort into collating in situ data. Under IMOS (Integrated Marine Observing System) Australia, a database is available for the larger Australia/Asia/Antarctica region for validation and algorithm development. This is part of their contribution to the space agencies and the community.
- Xianqiang indicated that China does not have an in situ database like SeaBASS, but they are moving forward to establish a network in the Chinese coastal ocean. In the future they will be happy to share their in situ datasets with the community.
- Laura indicated that this has always been a challenging issue, especially on metadata. IOCCG has played a big role in developing protocols for intercomparable data quality. We are fortunate to have SeaBASS, which collects more than just validation data. It is an open database. There is a possibility to do a good data mining effort with SeaBASS. She understands that each country has their mandate for their data, and questioned whether it is feasible to have a database where all the data gets logged. She suggested maybe just linking all the databases would be helpful. She suggested revisiting the IOCCG website to ensure the community can find the data that they are looking for and that the links are available and active.
- Nagamani indicated that ISRO has a mandate for cal/val of sensors and products, and so they have the required data for the Indian Ocean and their own database in their institution. She said that it is only a policy matter, and they are happy to share data within the limitations of the space agencies.
- Menghua indicated that NOAA's mandate is that they must make data from MOBY, etc., publicly available. This data is in near-realtime for MOBY and can be downloaded from NOAA CoastWatch. NOAA also contributes data to SeaBASS, and this is available. AERONET-OC makes a lot of data contributions to NOAA and this is also available. NOAA contributes data operationally, but NASA contributes for data processing, making it available to all of the community and it is easy to access. This model is very useful so anyone can access the data, and it is consistent so that everyone knows where to find data.
- Aurelien indicated that they have been launching French ocean observing systems, aiming to combine all the different types of observations into one repository. The aim is to have satellite, in situ, and modelling data all at the same place to ease assessments. This is a structuring initiative that takes a long time, but they are trying to combine all the research and infrastructure initiatives. He suggested trying a geographic case study where all agencies put into practice the collation of data for a location. He acknowledged that it might be difficult to choose which location, but they could try to find a place that is of interest to all.

- Laura mentioned that we cannot share what we do not have, and that the community cannot access what is not shared. She said a lot of funding and time goes into data curation, so the data that the community submits needs to follow the protocols that are established. She implored the community to make their data available.
- Marie-Hélène indicated that, at the European level, the Ocean Pact was launched in June 2025, and included discussions around European marine infrastructure. The problem of an in situ database was advanced with the EC. Antarctica InSync (International Science & Infrastructure for Synchronous Observation) initiative in the Southern Ocean brings together all the scientists collecting in situ measurements to address the challenges. ESA is strongly involved and many agencies could also be interested.
- Regarding one in situ database, Thomas suggested that maybe it doesn't matter if each country has their own database if we could develop a simple interface that can query all the databases to surface the information from the different databases to the user.

Hervé Claustre (CNRS/Sorbonne University) is the co-chair of BGC Argo and indicated that they collect from everywhere, including China, India, Japan, etc. They have a common view to share the data in realtime, and the dataset is accessible to all. He suggested that we could set up a subset of the general BGC Argo fleet dedicated to serve the interest of the agencies and scientists to contribute to dedicated cal/val to reach FRM status. He indicated that this can be done with support from all the agencies, because they are trained in France to work with CNES and every agency that contributes to Argo has the ability to share the data for the benefit of all. Shubha thanked Hervé for this contribution, which was very helpful.

Anne-Gaëlle Bretéché (Shom) asked whether there were initiatives from agencies to study the impact (positive and negative) of satellites on the environment.

- Laura indicated that the impact of science-based missions are not significant, and especially in light of the scientific results they provide. Even so, when satellites are deorbited, the process is done with extreme care so that the safety and wellbeing of natural ecosystems are accounted for.

Gemma Kulk (PML) asked about the urgency of our science, and whether the satellites that will help us see the biggest changes will be launched too late. Can this be sped up or made quicker?

- Marie-Hélène indicated that we already have all the observations we need to know that we need to act, and we have been discussing about ensuring this knowledge goes to decision makers. It is complex but we need to progress our communication towards society rather than focus on the timeline of satellites, as these do indeed have long timelines for construction and launch.
- Laura indicated that she was more worried about continuity, when there are gaps in observations. She said no single country can fill observation needs. When we lose

instruments that are not going to be replaced, that's a problem. Consistent observations are critical and greater coordination is needed, especially for instruments/missions that we lose, to help to fill gaps. The criticality of these measurements need to be highlighted in media and other avenues so that those in charge of funding can ensure that missions and data continue to be collected where it is needed.

Paula Bontempi (URI) asked if the panelists could comment on workforce. She was impressed by the number of early career scientists, and of posters focussed on artificial intelligence (AI) and machine learning (ML) which are powerful tools, but she worried whether the community was losing the skillset to do the truly grinding and pioneering work done on basic IOPs, AOPs, radiative transfer theory, etc. She said that this is interfaced with what takes so long to develop a new mission concept, and asked for input on where the field might be headed.

- Laura indicated that it's an important problem as we are failing to capture some of the brightest young minds to do research as they go to the private sector where salaries are higher. Perhaps salaries need to scale to attract these minds.
- Ewa agreed with Paula, that the fundamental skills of the pioneers are so crucial to keep and nurture in the community, and develop further. She indicated that recent training and outreach activities are for this purpose, and agencies can and should support this. She indicated that it is not just who is in the agencies, but also the colleagues in science, as this is how the expertise is harnessed. We should all, even within industry, ensure diligent knowledge of physics, biogeochemistry, etc.
- Marie-Hélène was optimistic as she had seen a huge number of excellent studies being done in the poster sessions. This included with AI and ML, but also interest in understanding the fundamentals, and was confident that this curiosity would remain and the knowledge would not be lost.

Jutarak Luang-on (JAMSEC) indicated that she's originally from Thailand, and during her PhD she got instruments and data analysis assistance from JAXA. She indicated that she would love to be a representative for South-East Asia because she also wants to collect good in situ data according to protocols, but they do not have the instruments or the budget for this. She asked what the space agencies recommend for the collection of in situ data in coastal regions in south-east Asia? Shubha added that there is a large data gap in the tropics and other areas, so she included a question of how we can get data where it is most needed.

- Ewa indicated that there was a recent call for submissions of proposals issued within the FRM4SOC to collect in situ data with a rental of fully calibrated and characterized radiometers to support these activities, and training on how to acquire this high quality data. It was advertised on the IOCCG mailing list. Hopefully there will be similar calls in the future, and that representatives from south-east Asia will apply, as this initiative was put in place specifically to support the community, and especially those areas and groups that do not have access to instruments and protocols.

- She indicated that there is an ocean colour community in South-East Asia and they may not know much about the advertisement, so she would be happy to help to disseminate this information in the region.

Kevin Ruddick (RBINS) commented, on the topic of situ data sharing, that the AERONET-OC model was extremely effective in providing essential variable validation data, and so HYPERNETS was set up following that model, but for hyperspectral data. This data is now publicly available for hyperspectral algorithm validation. He thanked all the agencies that have supported—initially the EU and ESA, but now also NASA, KIOST, CSIRO, and EUMETSAT contributes a match-up tool and a BRDF tool. He plugged the WATERHYPERNETS Data Users meeting that would take place following the close of the IOCS meeting, open to all interested.

Premkumar Rameshkumar (INCOIS) indicated that much work has been put towards developing water quality parameters from remote sensing, but they are not always available across the globe. He suggested that there could be an online platform with information that makes it easier for anyone to be able to access data and information for applications.

- Shubha indicated that a lot of this information is indeed available online, but it might be a matter of better communication and identifying the gaps.

As the session concluded, Shubha thanked the panelists and the participants for their enthusiastic participation in the session, and indeed throughout the week of the IOCS meeting, which she described as inspirational and thought provoking.

6. Breakout Workshops

A total of 10 breakout workshops (4 parallel sessions on Monday, and 3 on Tuesday and Wednesday) occurred as follows:

- ***Monday 1 December (Breakout Workshops 1 – 4)***
  - **Breakout 1.** Inland & coastal waters: current status & future directions in the correction of adjacency effects
  - **Breakout 2.** In water radiometry on autonomous profiling floats in support of satellite ocean colour validation activities
  - **Breakout 3.** Priority list of marine biodiversity metrics to observe from space: synthesis and planning for next steps
  - **Breakout 4.** Ocean Colour Satellite Sensor Calibration
- ***Tuesday 2 December (Breakout Sessions 5 – 7)***
  - **Breakout 5.** Blueprint for large-scale, operational, EO-based systems for Harmful Algal Blooms monitoring
  - **Breakout 6.** SI-Traceable in situ Aquatic Radiometry: Bridging the Gap Between Different Measurement Methodologies
  - **Breakout 7.** Challenges on Optical Remote Sensing for Marine Litter and Floating Matter

- ***Wednesday 3 December (Breakout Sessions 8 – 10)***
    - **Breakout 8.** Ocean Carbon from Space
    - **Breakout 9.** Water Quality Demonstration
    - **Breakout 10.** Merged, long-term ocean-colour products

A summary of each workshop is given below, including new community consensus recommendations that were developed during the meeting to address key issues and provide advice for the space agencies, the IOCCG or the ocean colour science community. Detailed reports of each session as submitted by the session chairs is available on the IOCS-2025 archive website.

6.1. Breakout 1: Inland & coastal waters: current status & future directions in the correction of adjacency effects

Chairs: Barbara Bulgarelli (EC-JRC, Italy), Alexandre Castagna (Ghent University, Belgium)

6.1.1. Summary

Standard algorithms for the processing of satellite data assume an infinite water surface, thus neglecting the presence of nearby land when inland and coastal waters are imaged. As a consequence, the radiance reflected by the land and then propagated by the atmosphere in the field-of-view of a satellite sensor observing a water target represents a perturbation leading to uncertainties in satellite products. This phenomenon, called adjacency effects (AE), always occurs in the presence of a scattering medium overlaying a non-homogeneous surface, while its impact varies over space and time. This session aimed at gathering the scientific community to review state-of-the-art knowledge on the quantification of AE in satellite imagery from inland and coastal waters to: identify potential gaps/opportunities for its operational correction; identify areas of collaboration; provide recommendations to enhance the quality of satellite water products in complex but critical inland and near shore coastal waters. The session featured several presentations from academia and industry (consultancy companies) covering theoretical foundations, algorithm development, operational implementations, and validation of AE correction methods, followed by open discussion.

6.1.2. Recommendations

The group identified 8 existing recommendations relevant to the topic, with 1 directly covering AE. No changes were made to these recommendations.

The gathered community agreed on the following new recommendations defining a roadmap to support the future operational correction of adjacency effects:

1. The community should further develop algorithms for the correction of adjacency effects, which should include i. refined capability to account for atmospheric optical

properties and off-nadir view, ii. capability to account for water surface reflectance anisotropy, iii. evaluation of algorithm uncertainties.

2. The community should collect reference in situ measurements for the validation of adjacency effects correction algorithms (i.e., over small or narrow water bodies, and near-to-the-shore in coastal waters and large inland water basins).
3. Space agencies should support the further development and validation of adjacency effects correction algorithms.
4. Space agencies and IOCCG should promote intercomparison exercises of adjacency effects correction algorithms with reference in situ data and potentially with synthetic data.
5. The community should develop flags identifying satellite data pixels potentially contaminated by adjacency effects.

6.2. Breakout 2: In water radiometry on autonomous profiling floats in support of satellite ocean colour validation activities

Chairs: Vincenzo Vellucci (Sorbonne U., IMEV, France), Nils Haëntjens (U. Maine, USA), Marine Bretagnon (ACRI, France)

6.2.1. Summary

The workshop addressed a central challenge for ocean colour remote sensing: the ocean is difficult and costly to sample using traditional ship-based methods, resulting in persistent global under-sampling of physical and biogeochemical properties. Over the last two decades, autonomous profiling floats have transformed open-ocean observing capabilities. Early attempts to use radiometry-equipped floats for satellite validation started in the 2010s with multispectral upwelling radiance sensors, but these efforts did not transition into operational programmes. More recent developments, such as floats designed explicitly for system vicarious calibration and new BGC-Argo platforms integrating hyperspectral radiometers, have revived the prospect of deploying radiometry in the open ocean, with improved protocols, processing standardisation, and uncertainty characterisation aligned with FRM principles. The objectives of the breakout session were to present the state of the art of in-water radiometry on profiling floats and to discuss how hyperspectral BGC-Argo data could be integrated into satellite validation workflows (including commissioning phases of new missions). The session contained 6 presentations followed by a review of 4 existing recommendations, and open discussion.

6.2.2. Recommendations

Recommendation 2017.05.3 was updated to *Actioned*, as BGC-Argo floats now include several optional sensors in addition to the 6 core variables.

The discussion converged on several priorities to enable reliable radiometry at Argo scale that were summarized into four new recommendations. An additional recommendation emerged from the need to better link satellite OC measurements with particulate backscattering coefficients measured onboard BGC-Argo floats.

1. The community is recommended to follow metrological principles for calibration of radiometric sensors used on BGC-Argo profiling floats. Actions have to be taken 1) to intercompare radiometric measurements on BGC-Argo with other in-water profiling systems (e.g. HyperPro), and 2) to characterise long-term sensor drift by recovering floats, when possible, for post-deployment calibration.
2. Agencies should use BGC-Argo floats for validation of satellite OCR products.
3. The community and agencies need to promote discussion between the BGC-Argo and ocean colour communities through dedicated actions (e.g. working groups and workshops).
4. The community should work towards building a community processor for common in-water radiometric profilers with associated uncertainties complying with FRM protocols.
5. The community should consider the use of shorter wavelengths for bbp measurements (e.g. in the green region) onboard BGC-Argo floats, in addition, or as an alternative, to 700 nm.

6.3. Breakout 3: Priority list of marine biodiversity metrics to observe from space: synthesis and planning for next steps

Chair: Victor Martinez-Vicente (PML, UK), Maycira Costa (U. Victoria, Canada)

6.3.1. Summary

The breakout session was proposed to discuss progress on metrics for marine biodiversity following workshops held at IOCS 2023 and ESA's BIOSPACE25 (Feb. 2025). A need to coordinate efforts to identify which products are fit-for-purpose and their maturity was highlighted, and the session aimed to address this need by identifying indicators for addressing national and international agreements, such as the Convention on Biological Diversity Kunming-Montreal Global Biodiversity Framework. The session was attended by over 80 participants and was designed with most of the time dedicated to discussions. A second meeting was organised during the week of the IOCS with those interested in a working group, and there was consensus to immediately focus on a community paper.

6.3.2. Recommendations

Three previous recommendations were reviewed, with 2 updated: **2023.07.1**: *Ongoing, plan in place to deliver in the short term-2026*; **2023.07.3**: *Actioned, ESA has funded PHYTO-CCI for phytoplankton. Missing coastal pelagic phytoplankton and seabed habitats.*

The following new recommendations were proposed in the session:

1. Space agencies to promote development of satellite Earth Observation with higher spatial resolution (~ 2-5m) and revisit frequency, with good signal-to-noise and more spectral bands in the long term (constellation?) and lidar.
2. The community (specialists on atmospheric correction) with the support from the Space agencies need to consider the atmospheric-bottom reflectance challenge in the medium term (~5 y).
3. Space agencies should support (within 5 y) research to upscale from field, drone, airborne data to satellite, and differentiate species distribution.
4. The community should aggregate in situ coastal habitat datasets into repositories along with satellite-derived labelled data for machine learning training within 1-2 years, as part of the tasks from a new IOCCG working group.
5. The community should better understand the management requirements for marine biodiversity metrics from satellite Earth Observation, educate managers, and communicate uncertainty within 1-2 years.
6. Space agencies should support GLIMR and/or studies with other geostationary sensors already deployed to investigate high frequency dependence of plankton diversity within ~5 years.
7. The community should (within >10 years) complement passive remote sensing with active and other methods for vertical extension of ocean colour, noting the challenge of extending vertically over the continental shelf, where BGC-Argo floats do not currently operate.
8. Space agencies should support (within ~5y) regional algorithm development and in situ data collection in coastal areas in the presence of different levels of other optically active substances.
9. Space agencies should support (within ~5 years) the collocation of high spatial resolution in situ (as a minimum hyperspectral Rrs) and laboratory optical data for algorithm development.
10. IOCCG to promote the adoption of the Essential Biodiversity Variables Framework by the satellite Earth Observation community working in the marine environment through the activities of a new IOCCG WG/TF within 1-2 years (e.g. through workshops).

6.4. Breakout 4: Ocean Colour Satellite Sensor Calibration.

Chairs: Gerhard Meister (NASA, USA, Remote), Ewa Kwiatkowska (EUMETSAT, Germany), Hiroshi Murakami (JAXA, Japan)

6.4.1. Summary

This session was a meeting of the IOCCG Task Force on Ocean Colour Satellite Sensor Calibration, which supports exchange of calibration methods and ideas and is composed of calibration and characterization experts from space agencies. The Task Force presented recent advances and challenges in the pre-launch and on-orbit calibration of ocean colour satellite sensors, and focused on the delivery of highly accurate top-of-atmosphere radiances (or reflectances) based on direct instrument calibrations.

The session facilitated virtual participation, which was extremely important due to travel restrictions for several speakers. The overarching topic of the session was ‘lessons learned’. For the first time, the session included presentations related to the calibration of polarimeters as well as lunar irradiance models. Other discussions centered around lessons learned from solar diffuser calibration, benefits of redundancy, and the importance of establishing traceability for every mission. The session focused mostly on radiometric calibration issues.

6.4.2. Recommendations

There were no updates made to the existing recommendations, and the following new recommendations were proposed **to the space agencies**:

1. On-board solar diffusers should be characterized prelaunch as close to on-orbit conditions as possible (‘as-you-fly’). High BRDF accuracy should be achieved at a reference solar geometry, which can then be used as a baseline for relative BRDF characterization via spacecraft rotations on-orbit. Characterization efforts must continue on-orbit with sensor temporal trending.
2. Increased focus should be dedicated to the prelaunch characterization of the SWIR bands at low level radiances. This is because the dynamic range between the top-of-atmosphere radiance over ocean and the calibration radiance (prelaunch or on-orbit) is typically even larger in the SWIR than in the visible spectrum.
3. Agencies are encouraged to support GSICS and CEOS/WGCV IVOS, which are undertaking activities to reduce uncertainties and achieve absolute calibration of lunar irradiance models with a goal to facilitate using the moon for on-orbit absolute calibration.

6.5. Breakout 5. Blueprint for large-scale, operational, EO-based systems for Harmful Algal Blooms monitoring

Chairs: Ilaria Cazzaniga (EC-JRC, Italy), Krista Alikas (U. Tartu, Estonia), Jeremy Kravitz (Pixxel Space Technologies, USA)

6.5.1. Summary

The objective of this breakout session was to propose recommendations leading to an agreed blueprint for large-scale, effective, operational EO–based systems for monitoring Harmful Algal Blooms (HABs). The session aimed to reach consensus on a clear definition of HABs applicable in the EO context, to clarify the scope of these systems, and to support the choice of proper methods and their harmonization. The session also aimed to identify a strategy to reconcile diverse methods, and to supersede the regional/empirical character of HAB-related approaches, as well as relate them to a more formal framework based on first principles. Three presentations were made, followed by open discussion.

6.5.2. Recommendations

A list of 13 existing recommendations from previous IOCS meetings and extracted from IOCCG Report 20 (Observation of Harmful Algal Blooms with Ocean Colour Radiometry) were reviewed. A set of new recommendations were suggested and discussed, as follows:

➔ Bloom definition: between observable discolouration of the water surface and a population-dynamics informed distinction of bloom, there is persistent confusion on how a bloom is to be defined. The harmful nature of a bloom is usually not discernable and rather follows from expert insight. The frequent inclusion of cyanobacteria as algae may further confuse practitioners.

1. The community and space agencies should identify bloom definitions and thresholds together with users, considering regulatory policy instruments and applying an eco-region-specific approach.

➔ Chl-a concentration alone is not enough for HAB monitoring systems.

2. The community and space agencies should use additional information (based on spectral features, pigment absorption, PFT, etc.) to support bloom monitoring.
3. The community and space agencies should define threshold and anomaly criteria for HAB monitoring through long time series analyses that depend on the type of application.
4. The community and space agencies should take vertical mixing conditions into account when informing on the severity of blooms, particularly in regard to cyanobacteria.
5. The community and space agencies should implement the recommendations of Water-ForCE for multivariate, multi-mission service development (see especially chapter 3 and 5).

➔ Temporal, spectral and spatial gaps still limit the applicability of EO data for management purposes.

6. Agencies should increase observation frequency and observation capabilities for inland waters, particularly for small lakes.
7. Agencies should consider constellations of multiple twin sensors that may support increasing temporal coverage and near-real-time services for HAB monitoring.
8. The community should address observation gaps through robust methods for trend fitting or develop lake-specific bias corrections.
9. The community should use multivariate datasets and hybrid observation-model approaches to support the identification and characterization of different bloom types and conditions.

➔ In situ data collection and sharing are key to success for algorithm calibration and system validation

10. Agencies and IOCCG should fund and coordinate systems for data curation, which are essential to support continued in situ data collection, harmonization, quality control and sharing.
11. Agencies and IOCCG should make a coordinated, curated effort to integrate existing datasets, map the measured parameters, highlight gaps in data availability, and assess spatial coverage to guide future data collection.
12. Agencies and IOCCG should implement the recommendations of Water-ForCE for data collection, sharing, and new in situ measurements (see section 4).
13. The community should combine in situ data with EO data to confirm bloom characteristics (e.g., toxicity).

6.6. Breakout 6. SI-Traceable in situ Aquatic Radiometry: Bridging the Gap Between Different Measurement Methodologies

Chairs: Agnieszka Bialek (NPL, UK), Carol Johnson (NIST, US, Remote), Giuseppe Zibordi (NASA, US)

6.6.1. Summary

All aquatic in situ radiometry instrumentation and methods require a robust link to SI units, entailing knowledge about instrument non-ideal performance, measurement protocols, data reduction and quality assurance/control schemes, and open-for-scrutiny processing. The most critical element for all in situ radiometry methods is the modelling of correction steps, such as glint correction for above-water methods, extrapolation to the surface and above for in-water methods, and the correction of bidirectional effects for all. The goal of the session was to define the priority when addressing existing discrepancies between the aquatic radiometry methods.

Key discussion points focussed around protocol expansion for new methods (autonomous profilers and UAVs are emerging techniques that should be supported by protocols shared through living documents to accommodate advances. Any new, dedicated implementation requires clear documentation, such as a peer-reviewed publication to ensure transparency and to support reproducibility. Aquatic radiometry protocols in coastal and fresh waters require incorporation of land surface reflectance contributions and may benefit from collaborations with land or atmosphere communities); modeling challenges (sea-surface reflectance factor sparked the most debate, highlighting its impact on radiometric products and uncertainty and suggests a need for focused actions on modeling implications and uncertainty quantification); best practices & training (continued adherence to established protocols and best practices is essential. Ongoing training and collaboration with instrument manufacturers were emphasized, particularly to support their efforts in providing uncertainty with absolute calibration).

6.6.2. Recommendations

Three existing recommendations on the topic were reviewed (all previously actioned) and the following added:

1. IOCCG and agencies should continue support for global training initiatives with coordinated and coherent approaches to radiometry to ensure that participants fully understand protocols and measurement uncertainties with hands-on experience (i.e. no decrease in training with time).
2. The community should increase dedicated efforts in sea-surface reflectance factor modelling and comparisons and with summarized uncertainty evaluations, preferably in a dedicated breakout session at the next IOCS meeting, in 2027.
3. Regular (every 3-5 years) inter-comparisons should be supported by the agencies with funding available for participants, including uncertainty workshops and participant involvement in the planning phase, which should lead to a number of intercomparisons planned and executed by international teams.

6.7. Breakout 7. Challenges on Optical Remote Sensing for Marine Litter and Floating Matter

Chairs: Shungu Garaba (U. Oldenburg, Germany), Victor Martinez-Vicente (PML, UK),

6.7.1. Summary

The breakout workshop was coordinated by the members of the Task Force on Remote Sensing of Marine Litter and Debris (RSMLD). The main scope of interest in this field includes developing methodologies to better distinguish the diverse floating materials found in the natural environment and apply these methods to relevant monitoring efforts. The workshop session aimed to discuss the strengths, limitations and future directions. Discussions covered multi-modal remote sensing technologies relevant for multiscale and multi-platform monitoring of floating and slightly submerged matter in all aquatic environments. Floating matter discussed included anthropogenic materials (mostly plastic waste) as well as *Sargassum* and a diverse array of mixed material that accumulate at sea or in in-land water systems. Participants put emphasis on the use of alternative sensing techniques that are valuable in resolving gaps in capabilities of standard techniques, in line with stakeholder priorities. A few presentations to set the stage and understand related on-going research were shared prior to open discussion with the participants.

6.7.2. Recommendations

A total of 5 recommendations from the previous IOCS meeting of the RSMLD Task Force were reviewed and refined into new community recommendations as follows:

There is a need to have continuous support (with funding) for scientific groups to understand the advances and challenges associated with the monitoring of marine litter and debris (including exploring multimodal technologies on multiscale platforms, and sustaining scientific field campaigns) to help define the roadmap for the way forward.

1. Space agencies should support continued research on remote sensing of floating matter to understand the challenges and opportunities associated with the detection of floating matter to help define the roadmap for the way forward.

The community needs to continue to foster improved collaboration of diverse expert communities (e.g., citizen science, ocean colour, numerical modelling, industry, civil society, non-profit organisations, environmental agencies) for holistic remote sensing solutions.

2. IOCCG and the community should continue to foster improved collaboration of diverse expert communities (e.g., citizen science, ocean colour, numerical modelling, industry, civil society, non-profit organisations, environmental agencies) for holistic remote sensing solutions for marine litter and debris.

There needs to be sustainable support for dedicated FAIR-adhering resources of marine litter and debris that can consolidate in situ and above-water imagery, with metadata, and concurrent satellite overpass, and be accessible and available to all scientists, including for citizen science.

3. The community, supported by the space agencies, should support a dedicated FAIR resource (e.g., OceanScan) of marine litter and debris that can consolidate in situ and above-water imagery, with metadata, and concurrent satellite overpass, and be accessible and available to all scientists, including for citizen science.

For application of the detection of marine litter, especially after extreme weather events (e.g., tsunamis, flooding) and for dedicated field campaigns, satellite data providers should expedite tasking or new acquisition requests by the community and extend quota allocation for commercial multimodal satellites to establish open-access representative datasets documenting diverse floating matter.

4. Space agencies should expedite tasking or new acquisition requests by the community and extend quota allocations for commercial multimodal satellites to establish open-access representative datasets documenting diverse floating matter, especially after extreme weather events (e.g., tsunamis, flooding) and for dedicated field campaigns.

6.8. Breakout 8. Ocean Carbon from Space

Chairs: Gemma Kulk (PML, UK), Bob Brewin (U. Exeter, UK), Juan Ignacio Gossn (EUMETSAT, Germany), Laura Lorenzoni (NASA, US), Cecile Rousseaux (NASA, US, Remote), Roberto Sabia (ESA, Italy), Shubha Sathyendranath (PML, UK), Jamie Shutler (U. Exeter, UK, Remote).
Rapporteurs: Javier Concha (ESA, Italy), Elin Meek (PML, UK), Marie-Hélène Rio (ESA, Italy)

6.8.1. Summary

The breakout workshop formed part of the second Ocean Carbon from Space workshop, and addressed three key questions that emerged from this latter workshop: 1) What are the critical gaps in our current satellite observing capabilities that prevent us from accurately quantifying the ocean carbon cycle, and how can we prioritise filling these gaps? 2) How can we improve our understanding of the physical, chemical, and biological processes that govern the ocean carbon cycle, and assess how climate change affects carbon flow through marine ecosystems? 3) What specific, actionable steps should the international research community and space agencies take to ensure satellite-derived ocean carbon data can effectively inform climate model evaluation and policy decisions?

6.8.2. Recommendations

One previous IOCS recommendation was reviewed and discussed but could not be closed. New IOCS recommendations related to observing the ocean carbon cycle from space were developed and are listed below.

1. Within 1-5 years, the research community should resolve carbon pools and fluxes at the regional scale across key environments, including tropical, polar and coastal regions, inland waters (lakes) and in the deep ocean, using integrated observations, models and synthesis approaches. Ocean carbon budget assessments should explicitly include Blue Carbon components (e.g., mangroves, seagrasses, salt marshes). Progress should be assessed by tracking the number and proportion of peer-reviewed publications on regional ocean carbon assessments.
2. Within 1-5 years, the research community should develop and validate tools to detect change and the rate of change in the ocean carbon cycle, enabling identification of potential tipping points. Progress should be measured by the number of peer-reviewed publications and publicly released datasets demonstrating the use of these tools, including documented methodologies and case studies showing detection of significant change events or trends.
3. Within 1-5 years, space agencies should support efforts to generate robust evidence on the impact and effectiveness of marine Carbon Dioxide removal (mCDR). Progress should be measured by funding projects that specifically target mCDR from satellite observations (or integrate observations with models), with publicly accessible datasets and methodologies to inform timely decision-making.
4. Within 10-20 years, space agencies should continue to maintain and improve the accuracy and stability of primary observables needed for ocean carbon research by sustaining robust cal/val activities and implementing advances in atmospheric correction. Progress should be measured through regular, publicly reported assessments demonstrating reductions in calibration bias and uncertainty, and documented improvements in atmospheric correction performance across satellite data products.

5. Within 1-5 years, the IOCCG should promote the inclusion of ocean carbon from space in existing and new training activities. Progress can be tracked by noting the number of training events that incorporate ocean carbon topics, the participants engaged and the availability of openly accessible training materials and resources.
6. Within 1-5 years, the IOCCG is encouraged to assess and address the latency between science and policy, including evaluating the uptake of key ocean carbon research information in decision-making. The use of 'knowledge brokers' or knowledge hubs should be considered to bridge the gap between science and policy. Progress can be tracked through the preparation of a guidance document within the next few years.

6.9. Breakout 9. Water Quality Demonstration

Chairs: Tiit Kutser (U. Tartu, Estonia), Bridget Seegers (NASA, US), Hubert Loisel (U. Littoral Côte d'Opale, France), Jongkuk Choi (KIOST, South Korea). Rapporteur: Ewa Kwiatkowska (EUMETSAT, Germany)

6.9.1. Summary

Industry has demonstrated that there is a large market for water quality services using satellite data. Space agencies and environment/water management institutions have showcased a variety of successful operational water quality tools and products, but there are far more ways to utilize satellite observations to create water quality applications and services that reach the broad range of user needs. The roadblocks for expanding remote sensing applications include a lack of awareness and trust in the potential of satellite data, lagging policy regulations that rely on sparse in situ sampling, legal issues, and few guidelines, as well as spatial, spectral, and temporal limitations of current satellite data for the desired water quality applications in coastal zones and inland waters. The ultimate goal should be operational satellite services for water quality monitoring and forecasting, similar to services for weather forecasting. These services would provide measurable benefits to human health, national economies, businesses and water ecosystems. The aim of the session was to discuss these roadblocks and the lessons learned, and identify potential solutions, priorities, and actions to further unlock satellite observations for water quality applications.

6.9.2. Recommendations

The following recommendations emerged from the session discussions:

1. *Space agencies and the community should engage all stakeholders in developing satellite services for water quality*, to build trust, understand the needs, support policy and guideline definitions, and deliver the relevant data products and services. The stakeholders include the space agencies, national environmental or water authorities, regulatory institutions, relevant international organizations, private and commercial sectors, economists, as well as local communities and decision makers. Engage early from the beginning, persistently, and in their own language.

2. *Space agencies should implement sustained operational missions with specifications suitable for coastal and inland water quality applications*. Only sustained availability of satellite data with suitable specifications warrants the long-term investment needed in downstream services. In particular:
    - Dedicated OC sensors are required from geostationary satellite platforms (the value of diurnal monitoring and improved coverage in catching sudden or evolving Water Quality events).
    - PACE to be followed by PACE II mission (for service continuity).
    - S3NGO and S2NG to uphold their specifications, currently tentative, for coastal and inland waters (e.g. S3NGO 150m hyperspectral).
    - Operational satellites that perform well like S2A and S3A, to not be decommissioned (the value of stable platforms for long-term time series, and increased coverage).
3. *IOCCG and the space agencies should coordinate across the space agencies to deliver data products and services suited for water quality applications*. Water quality data needs may be different from typical water products from the space agencies, and these needs should be established through direct engagement with the stakeholders, as recommended in point 1. Some data examples include GeoTIFF images, presence/absence flags, or water quality indicators as used in reporting. Although many of these data specifications may be different across countries and applications, some commonalities will exist and should be coordinated.
4. *IOCCG and the space agencies should coordinate across the space agencies to collect in situ measurement holdings suited for water quality applications*. To improve algorithm performance for water quality applications, FRM-quality in situ data are required in coastal and inland waters across different bio-optical regimes. IOCCG was already recommended to coordinate access to in situ data holdings from the space agencies and the community. Here, the agencies are recommended to provide long-term sustained maintenance of in situ datasets for the community. Furthermore, IOCCG is recommended to identify optical water types not covered through in situ data collection across inland and coastal water types and to coordinate agencies to acquire such data or leverage from existing programs. Ideally, FRM-quality radiometry should be collected together with water constituents and IOPs. In parallel, IOCCG should support training to collect good FRM quality data.

6.10. Breakout 10. Merged, long-term ocean-colour products

Chairs: Robert Frouin (Scripps Institute of Oceanography, US), Liz Atwood (PML, UK)

6.10.1. Summary

This breakout session aimed to engage the broader ocean colour user and producer community in the activities of the newly established IOCCG Task Force on Harmonizing Global Ocean Colour for Long-Term Climate and Ecosystem Monitoring. The goal was to solicit community input to help shape the Task Force's priorities and activities, ensuring that the resulting multi-sensor, long-term ocean-colour products are scientifically robust, practically useful, and widely adopted. Eighteen countries were represented across the audience: Australia, Belgium, Bulgaria, Canada, Chile, China, France, Germany, India, Korea, Portugal, South Korea, Spain, Sweden, Tanzania, the United Kingdom, the United States, as well as international organizations (e.g., EUMETSAT). Research spanned 24 fields, with the top three common areas being ocean color remote sensing, climate change and trend analysis, and water quality monitoring. When asked which long-term time series (LTTS) products they currently use, OC-CCI had 18 responses, GlobColour had 8 responses, and 6 responded that they use none, which reflected both the importance of existing merged products and the need to broaden adoption and accessibility.

6.10.2. Recommendations

A total of 6 existing recommendations related to the topic were reviewed, and 5 continue to remain open. The new recommendations emerging from session are intended to operationalize and extend the IOCS 2023 guidance, moving the community from problem identification toward coordinated implementation. They define a pathway toward transparent, traceable, and climate-quality long-term ocean-colour records, grounded in robust calibration, explicit uncertainty characterization, regional awareness, cautious use of new technologies, and sustained international collaboration.

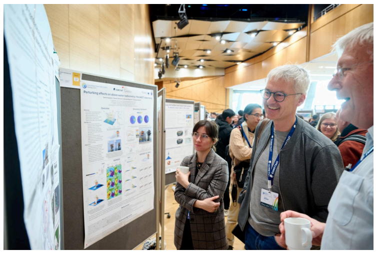
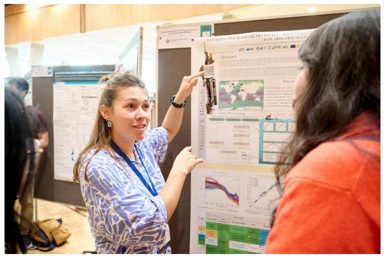
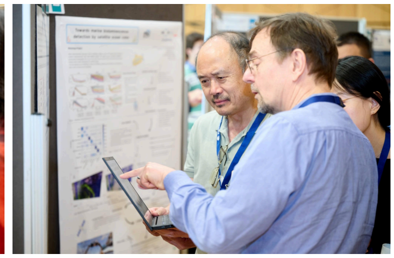
1. *Agencies and the community should deliver a single blended LTTS product with regionally informed adjustments.*
   Develop one unified, blended long-term ocean-colour record that supports optional regional adjustments where required by physics and optics, while avoiding multiple competing global products. Regional tuning should be documented, traceable, and applied only where justified, without forcing artificial consistency across regions.
2. *The community should define climate-quality requirements with quantified uncertainty thresholds.*
   Establish explicit, variable-specific climate-quality criteria, including uncertainty thresholds that are demonstrably smaller than the trends being investigated. Define minimum record lengths required for robust trend detection (e.g., 35 years for chlorophyll), recognizing that requirements differ by variable and application.
3. *Agencies should provide flexible access to intermediate and derived products.*
   Ensure users can access intermediate products (e.g., pre-SVC, sensor-specific fields) alongside merged products, enabling users to apply application-specific uncertainty tolerances, regional analyses, or alternative merging strategies where appropriate.
4. *Agencies and the community should strengthen coordination through shared calibration and processing infrastructure.*
   Establish and sustain coordinated local-regional-global networks for calibration, validation, and processing, building on existing international frameworks. Support shared investments in calibration sites, matchup databases, processing tools, and documentation to ensure long-term continuity.

5. *Agencies and the community should expand and qualify in situ observations for validation.*
   Address gaps in global in situ coverage, particularly in under-sampled regions (e.g., high latitudes, monsoonal systems, optically complex coastal waters). Explicitly quantify and document regions where in situ uncertainty exceeds satellite uncertainty, and incorporate this information into validation and uncertainty frameworks.
6. *Agencies and the community should ensure traceable cross-calibration and account for SVC variability.*
   Maintain traceable cross-calibration chains across missions, including assessment of gaps in geostationary coverage. Explicitly account for site-to-site variability in SVC gains in merged products rather than relying on indiscriminate averaging, and document how SVC differences are handled.
7. *Agencies should implement robust, scalable merging frameworks.*
   Design merging frameworks that explicitly accommodate different numbers of contributing sensors (e.g., two-sensor versus multi-sensor merges). Provide metadata indicating which missions contribute at each time step, and implement safeguards to avoid regional artifacts caused by gap-filling under aerosols, dust, or persistent cloud cover.
8. *The community should define acceptable temporal gaps by application.*
   Develop community guidance on acceptable data gaps and compositing windows (e.g., daily versus 7-day products), recognizing that tolerance for gaps varies across climate, ecosystem, and operational applications.
9. *Agencies should integrate artificial intelligence (AI) and machine learning (ML) methods with clear physical and uncertainty constraints.*
   Encourage innovation using AI/ML while requiring that such methods be traceable, physics-aware, and uncertainty-quantified. Ensure AI-based approaches do not introduce spurious or non-physical features, mask real variability, or create false temporal continuity in long-term records.
10. *Agencies should provide multi-scale uncertainty characterization.*
    Deliver pixel-level uncertainty estimates alongside methods for deriving regional and ensemble uncertainties, recognizing that aggregation reduces random error. Provide uncertainty PDFs or ensemble-based representations to characterize extreme behavior (tails), and document impacts of data gaps or regional data-sharing constraints on uncertainty.

7. Poster Sessions

Poster sessions were held each day to allow participants to discuss and share their research with colleagues. Each session started with poster lightning talks, where presenters shared the main point of their research with the audience within 35 seconds. The lightning sessions served as an advertisement for the posters ahead of the viewing sessions, while the viewing session allowed for in-depth discussion of the work with colleagues.

A total of 224 posters were presented, grouped into four main themes: continued research in ocean colour science, carbon and climate, water quality, and biodiversity. All accepted poster abstracts are available in the *Book of Poster Abstracts* on the IOCS-2025 meeting website, and the poster lightning slides presented each day are available at iocs.ioccg.org/iocs-2025-meeting/iocs-2025-presentations.

8. Social Programmes

Two social activities were planned and sponsored by EUMETSAT & ESA. An icebreaker reception was hosted at the meeting venue at the end of day 1 on Monday, 1 December, sponsored by ESA, and a conference dinner at Orangerie Darmstadt, hosted by ESA & EUMETSAT.



Appendix

Scientific Planning Committee

Shubha Sathyendranath – IOCCG Chair, Plymouth Marine Lab (PML), UK
Ana Dogliotti – IAFE/CONICET, Argentina
Áurea Maria Ciotti – Universidade de São Paulo, Brazil
Aurelien Carbonniere – CNES, France
Cara Wilson – NOAA-NMFS, USA
Chuanmin Hu – University of South Florida, USA
Claudia Giardino – CNR/IREA, Italy
Corinne Bourgault-Brunelle – CSA, Canada
David Antoine – Curtin University, Australia
Emmanuel Devred – Bedford Inst. of Oceanography, Canada
Ewa Kwiatkowska – EUMETSAT, Germany
Frédéric Mélin – EU Joint Research Center, Italy
Hiroshi Murakami – JAXA, Japan
Jeremy Werdell – NASA GSFC, USA
Jongkuk Choi – KIOST, South Korea
Laura Lorenzoni – NASA, USA
Marie-Hélène Rio – ESA/ESRIN, Italy
Mark Baird – CSIRO, Australia
Menghua Wang – NOAA, USA
Nima Pahlevan – NASA, USA
Paula Bontempi – University of Rhode Island, USA
Raisha Lovindeer – IOCCG, Canada
Robert Frouin – Scripps Institute of Oceanography, USA
Steve Groom – NCEO, UK
Tim Malthus – CSIRO, Australia
Vittorio Brando – CNR, Italy
Wonkook Kim – Pusan National University, South Korea
Xianqiang He – Second Inst. of Oceanography, China

Organising Committee

Ewa Kwiatkowska – EUMETSAT, Germany
Sylwia Miechurska – EUMETSAT, Germany
Beatriz Fornos, EUMETSAT, Germany
Marie-Hélène Rio – ESA/ESRIN, Italy
Raisha Lovindeer – IOCCG, Canada
Shubha Sathyendranath – PML, UK

IOCS Rapporteur

Lisa Sonke – intern, EUMETSAT, Germany

Plenary Session Chairs

Welcome & Closing Sessions: **Shubha Sathyendranath** - IOCCG Chair, PML, UK
Oral Session 1 : In situ Data: **Giuseppe Zibordi** – NASA, US/Italy
Oral Session 2: Ocean Carbon: **Marie-Hélène Rio** – ESA/ESRIN, Italy
Oral Session 3: Reports: **Hellen J. Kizenga** – U. Bologna, Italy / U. of Dar es Salaam, Tanzania
Oral Session 4: Water Quality: **Milton Kampel** – INPE, Brazil
Oral Session 5: Reports: **Wonkook Kim** – Pusan National U., South Korea
Oral Session 6: Biodiversity & Reports: **Laura Zoffoli** – CNR-ISMAR, Italy

Breakout Session Chairs

Breakout 1: Inland & coastal waters: current status & future directions in the correction of adjacency effects:

Barbara Bulgarelli - EC-JRC, Italy
Alexandre Castagna - Ghent U., Belgium

Breakout 2: In water radiometry on autonomous profiling floats in support of satellite ocean colour validation activities:

Vincenzo Vellucci - Sorbonne U/IMEV, France
Nils Haëntjens - U. Maine, USA
Marine Bretagnon - ACRI, France

Breakout 3: Priority list of marine biodiversity metrics to observe from space: synthesis and planning for next steps:

Victor Martinez-Vicente - PML, UK
Maycira Costa – U. Victoria, Canada

Breakout 4: Global carbon budget for the land to ocean aquatic continuum (LOAC) from remote sensing:

Gerhard Meister - NASA, US (Remote)
Ewa Kwiatkowska – EUMETSAT, Germany
Hiroshi Murakami – JAXA, Japan

Breakout Breakout 5. Blueprint for large-scale, operational, EO-based systems for Harmful Algal Blooms monitoring:

Ilaria Cazzaniga - EC-JRC, Italy
Krista Alikas - U. Tartu, Estonia
Jeremy Kravitz - Pixxel Space Technologies, USA

Breakout 6. SI-Traceable in situ Aquatic Radiometry: Bridging the Gap Between Different Measurement Methodologies:

Agnieszka Bialek - National Physical Laboratory, UK

Carol Johnson - NIST, US (Remote)
Giuseppe Zibordi - NASA, US/Italy

Breakout 7. Challenges on Optical Remote Sensing for Marine Litter and Floating Matter:
Shungu Garaba - U. Oldenburg, Germany
Victor Martinez-Vicente - PML, UK

Breakout 8. Ocean Carbon from Space:
Gemma Kulk - PML, UK
Bob Brewin - U. Exeter, UK
Juan Ignacio Gossn - EUMETSAT, Germany
Laura Lorenzoni - NASA, US
Cecile Rousseaux - NASA, US (Remote)
Roberto Sabia - ESA, Italy
Shubha Sathyendranath - PML, UK
Jamie Shutler - U. Exeter, UK (Remote)
Rapporteurs: Javier Concha, Elin Meek, Marie-Hélène Rio

Breakout 9. Water Quality Demonstration:
Tiit Kutser - University of Tartu, Estonia
Bridget Seegers - NASA, US
Hubert Loisel - Université du Littoral Côte d'Opale, France
Jongkuk Choi - KIOST, S. Korea
Rapporteur: Ewa Kwiatkowska - EUMETSAT, Germany

Breakout 10. Merged, long-term ocean-colour products:
Robert Frouin - Scripps, US
Elizabeth Atwood - PML, UK
Rapporteur: Jing Tan - Scripps, US