International Ocean Colour Science Meeting 2023

Advancing Global Ocean Colour Observations

Proceedings of the
2023 International Ocean Colour Science Meeting (IOCS-2023)

University of South Florida, St. Petersburg, FL, USA
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Convened by the International Ocean Colour Coordinating Group (IOCCG)
Sponsored by NASA, NOAA, USF, and OCB

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1. Overview

1.1. Background

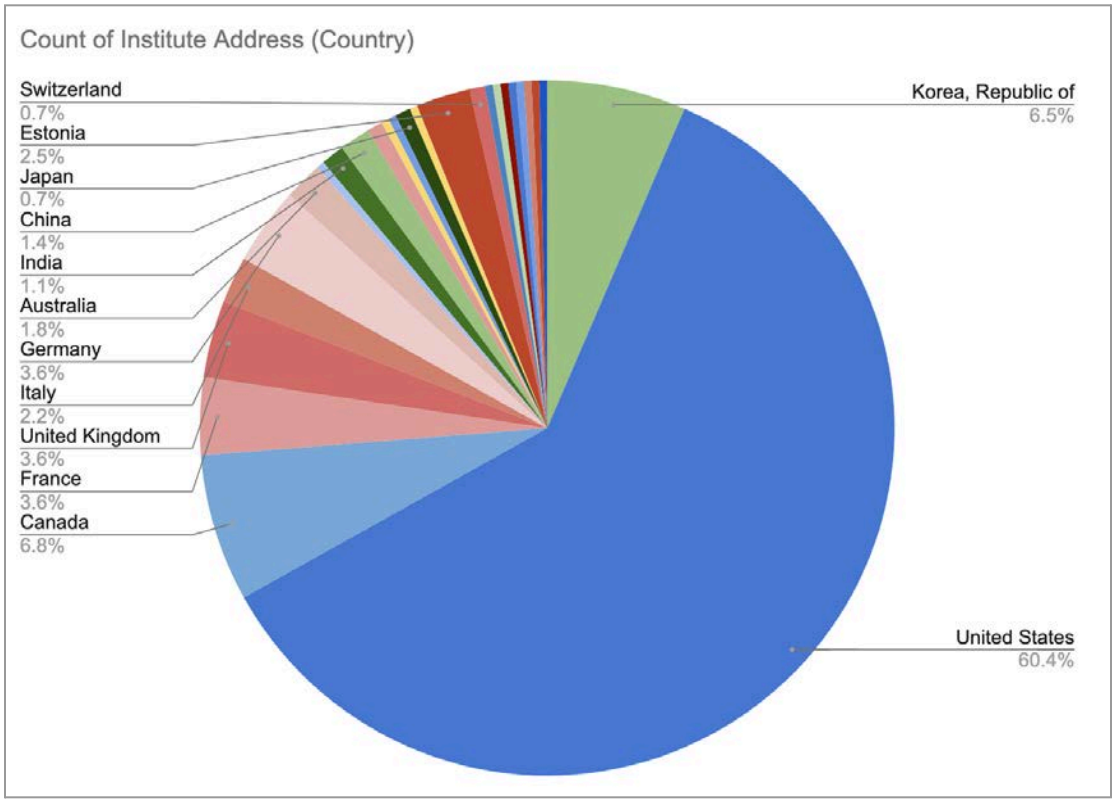
The fifth International Ocean Colour Science (IOCS) meeting was convened by the International Ocean Colour Coordinating Group (IOCCG) in partnership with the University of South Florida (USF), NASA, and NOAA, and took place from 14-17 November 2023 at the USF St. Petersburg campus in Florida, USA. Travel support for participants to the meeting was additionally provided by the Ocean Carbon & Biogeochemistry Project (OCB), which is gratefully acknowledged. IOCCG also gratefully acknowledges the outstanding support of many volunteers from USF as well as Dr. Chuanmin Hu and his lab for organizing USF as the host of the meeting. Thanks also to the Organizing Committee and the Scientific Planning Committee, for their hard work in helping to structure the programme, and in planning the logistics for the meeting. IOCS-2023 was preceded by the GEO AquaWatch Biennial Meeting and six training events. See the meeting website at: https://iocs.ioccg.org/ for further details on these events.

The overarching theme for IOCS-2023 was *Impact and Value of Ocean Colour Observations in a Changing World: Water in all its Colours* with the overall goal of nurturing a strong global user community for ocean colour science and applications, and fostering exchange between the ocean colour research community and international space agencies with an interest in ocean colour science.

1.2. Participants

A total of 278 researchers from 26 different countries participated in the four-day meeting. This included ocean colour research scientists and students from Australia, Bangladesh, Belgium, Bermuda, Brazil, Canada, Chile, China, Costa Rica, Croatia, Estonia, France, Germany, India, Ireland, Italy, Japan, Republic of Korea, Mexico, Peru, South Africa, Spain, Switzerland, Uganda, United Kingdom, and the United States. Also included were representatives from major space and research agencies with an interest in ocean-colour radiometry: CONAE, CNES, CSA, CSIRO, ESA, EUMETSAT, ISRO, JAXA, KIOST, NASA, NOAA, NCEO, and SIO.

The IOCS meeting was an excellent venue for networking but also helped to facilitate direct communication between the ocean colour research community, program managers and representatives from international space agencies. The meeting fostered interesting discussions during the nine breakout workshops, as well as a lot of very helpful feedback to the IOCCG. All the space agencies as well as the IOCCG Committee were very receptive to the comments, suggestions, and recommendations from the scientific community, which will help to advance the science of satellite ocean colour remote sensing and help the IOCCG with their strategic planning for the coming years.



Distribution of participants at the IOCS-2023 meeting.

1.3. Programme

The IOCS-2023 programme included six invited keynote talks, updates from several agencies, two panels discussions, nine breakout workshops (three sessions in parallel on each of three days), and two talks from the IOCCG Committee, including an overview of the IOCCG's activities and a status update of recommendations made at previous IOCS meetings. In addition, several poster sessions were held, each consisting of exciting poster lightning talks where presenters used 35 seconds to advertise their poster, and then ample time for poster viewing and discussion. The program also included three optional social activities: an ice-breaker reception on the first evening of the meeting with live entertainment from a local band, a happy hour organized by GEO AquaWatch and sponsored by SeaBird Scientific, and a

two-day public art exhibition of satellite ocean colour images (*The Ocean on Canvas*) sponsored by IOCCG and NASA. The full meeting agenda can be viewed here. Presentations from all plenary sessions and the summary reports from the breakout workshops can be viewed at iocs.ioccg.org/iocs-2023-meeting/presentations, and the Book of Poster Abstracts here.

2. Opening Session

Shubha Sathyendranath (IOCCG Chair) opened the meeting by welcoming everyone, and giving a brief history and overview of the IOCCG. She shared that the idea for the IOCCG came from Robert Frouin when he was at NASA, and acknowledged the previous chairs of the Group (Trevor Platt, James Yoder, David Antoine, Stewart Bernard, and Cara Wilson), as well as Venetia Stuart, the previous coordinator of the IOCCG Project Office who retired at the end of 2022, and Raisha Lovindeer, the current IOCCG coordinator. She gave an overview of the activities of the IOCCG through the past year, which included the 2022 Summer Lecture Series, the launch of the IOCCG Trevor Platt Memorial Scholarship, and a recent collaboration on an online+in-person training course on satellite-based tools for investigating aquatic ecosystems held earlier in 2023. The IOCCG continues to promote scientific excellence through its working groups and task forces, and maintains strong ties to international groups and organizations, such as the Committee on Earth Observation Satellites (CEOS), Scientific Committee on Oceanic Research (SCOR), Group on Earth Observations (GEO), and others. She highlighted that the IOCS meeting is part of the way IOCCG serves the community, showcasing the international coordination and collaboration that the IOCCG strives towards, and providing a forum for exchange of ideas. She warmly welcomed everyone to the meeting and thanked USF for graciously hosting, the people who helped and volunteered towards the planning of the event, the meeting sponsors, as well as the IOCCG sponsoring agencies that make the meeting possible. Shubha then thanked and welcomed the USF Chancellor Christian Hardigree, to take the stage and address the audience. The USF Chancellor gave a rousing welcome to the meeting, expressed her sincere gratitude for the presence of a large international audience on the USF St. Petersburg campus, and shared a bit about the campus's spirit and activities with the audience.

3. Previous IOCS Recommendations – A status update

Cara Wilson (IOCCG Immediate Past-Chair) started her presentation with an update on the scientific activities and accomplishments since the last IOCS meeting, including the publications of IOCCG Reports 18 - 20, and four new protocols in the IOCCG Ocean Optics & Biogeochemistry Protocols Series. Three new working groups had been established, and four new task forces, to handle scientific questions ranging from how to conduct benthic reflectance measurements, to how to get integrated measurements of ocean carbon from remote sensing. Over the four previous IOCS meetings (2013, 2015, 2017, and 2019), 34 breakout workshops across 20 themes generated 159 separate recommendations. The majority of the

recommendations were technical in nature (48%), with another 36% about data access and sharing, and 15% about users of ocean colour data. Most of the recommendations were geared at the general ocean colour community (56%), while 32% was aimed at space agencies, and 12% at the IOCCG. A total of 22% of the recommendations were deemed completed, with 62% in progress. The remainder were either not yet fulfilled (8%), not able to be measured (7%), or the recommendation was made as a statement with no action outlined (2%). Going forward, Cara urged the chairs of breakout workshops to ensure that their emerging consensus recommendations are **s**pecific, **m**easurable, **a**chievable, **r**elevant, and **t**ime-bound (SMART), so that recommendations will not be deemed unmeasurable or unactionable in the future. Chairs were also urged to examine previous recommendations under their topics, and use their breakout workshops to assess the status of those previous recommendations to decide if they have advanced, are still relevant, or are completed.

The presentation was much appreciated by the audience. Participants thanked Cara and the IOCCG for shedding light on the status of the previous recommendations.

For recommendations that emerged for IOCCG to form a working group or a task force, as these are volunteer-led groups, audience members suggested that IOCCG could send out a call for proposals to the community around the recommended topic. This would help researchers to know where the priorities lie when forming new scientific groups. It is often the case that those who have the time or interest to lead such groups may not be aware of the gaps.

Questions emerged around the long list of recommendations that will compound after each meeting, how they might be handled, and if there were a way to update or merge existing recommendations. It was suggested that, for each topic, the existing recommendations would be evaluated by the breakout workshop before adding new ones. This was the case for the current recommendations, as they were distributed to previous session chairs and space agency representatives for them to evaluate the status, as well as distributed to current session chairs to discuss within their sessions.

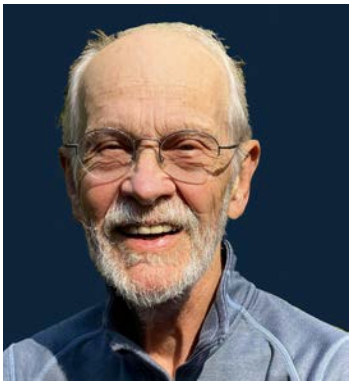
Frank Muller Karger requested that the IOCCG Committee consider discussing how the ocean colour community can be part of the decade survey for NASA, to ensure that ocean colour is included as part of the agency's mission planning.

All past and present IOCS recommendations, and their current status, are now available on the IOCCG website at https://iocs.ioccg.org/iocs-recommendations/

4. Keynote Addresses

4.1. Keynote 1: Howard Gordon (U. Miami)

The first session was chaired by David Antoine, who introduced Howard Gordon and welcomed him to give the opening keynote talk. Howard was unable to be at the meeting in-person, and presented his keynote virtually.



Howard R. Gordon received his B.Sc. in physics from Clarkson College of Technology (now Clarkson University) in 1961 and Ph.D. from the Pennsylvania State University in 1965. After 2 years as Assistant Professor of Physics at The College of William and Mary he moved to the University of Miami in 1967, where he began contemplating satellite remote sensing of ocean properties in the early 1970's and where he carried out research in oceanic and atmospheric optics for 48 years. In 1975 he became a member of the Nimbus-7 Coastal Zone colour Scanner (CZCS) experiment team, and later served on the science teams for the follow-on ocean colour sensors: SeaWiFS and MODIS. Professor Gordon was awarded the Public Service Medal by NASA in 1982 for the development of methods for recovering phytoplankton pigment concentrations from CZCS imagery. He was elected Fellow of the Optical Society of America (OSA) in 1977 and Fellow of the American Association for the Advancement of Science (AAAS) in 2004. He received the Jerlov Award from The Oceanographic Society (TOS) in 2004, and was appointed Distinguished Professor of Physics at the University of Miami in 2005, and Distinguished Professor Emeritus following his retirement in 2016.

Howard's opening keynote of the meeting was entitled *Ocean Colour Remote Sensing - the Beginnings: CZCS.* He took the audience through some of the early developments of ocean colour remote sensing, and provided a historical retrospective. Through his presentation, he managed to convey the highs and lows of the early exploration into ocean colour science. His talk was very well received, with an appreciative standing ovation from the audience upon its conclusion. The slides are available on the IOCCG website: https://iocs.ioccg.org/wp-content/uploads/2023/11/keynote1-howard-gordon.pdf.

4.2. Keynote 2: Astrid Bracher (Alfred-Wegener-Institute)

The second day of the IOCS meeting started with a keynote talk from Astrid Bracher under the theme of new technology. She was introduced by Emmanuel Devred, who chaired the session.

Astrid Bracher is professor at the University Bremen (UB) and a senior scientist at the Alfred-Wegener-Institute Helmholtz Centre for Polar and Marine Research (AWI). She obtained her PhD at the UB in Biological Oceanography focusing on biooptics of the Southern Ocean, and worked as research associate at the German Advisory Board for Global Change and as a PostDoc on ENVISAT Atmospheric Sensor satellite validation at UB. In 2007 she was elected as Helmholtz-University Young Investigator to found the PHYTOOPTICS Group at AWI, which currently focuses on the bio-optical in-situ sampling / techniques in the global and coastal ocean and inland waters, and on algorithm development with a special focus on hyperspectral retrievals, including coupled ocean-atmosphere radiative modelling. Dr. Bracher is co-chair of the international "Phytoplankton Functional Type (PFT) algorithm inter-comparison 2nd round-robin" working group as well as the IOCCG Hyperspectral Remote Sensing Task Force. She has been appointed to the Environmental Mapping and Analysis Program (EnMAP) Science Advisory Group, the Sentinel-3 Next Generation Optical/IR mission Ad Hoc Expert Group (S3NGO-AHEG) and its Mission Advisory Group (S3NGO-MAG), and the Scientific and Technical Advisory Committee for Copernicus Marine Service.

The title of Astrid's talk was *Hijacking other thematic satellite sensors for ocean colour application.* She gave a brief overview of the common sensors made and used for ocean colour application, and then delved into atmospheric sensors used for ocean colour application. Sensors included ESA Envisat's Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY), NASA Aura's Ozone Monitoring Instrument (OMI), EUMETSAT Metop series' Global Ozone Monitoring Experiment-2 (GOME-2), and ESA Sentinel-5P's TROPOspheric Monitoring Instrument (TROPOMI). These instruments have been used to derive CDOM and UV-absorbing compounds in the ocean, and assist with better quantifying ocean primary production and carbon, including via phytoplankton fluorescence and photophysiology. The slides from Astrid's talk are available on the IOCCG website: https://iocs.ioccg.org/wp-content/uploads/2023/11/keynote2-astrid-bracher.pdf.

4.3. Keynote 3: Steven D Miller (Colorado State U.)

Continuing with the theme of new technology, the afternoon session on Wednesday 15 November started with Steven Miller, who gave a keynote on the application of night-time technology for remote sensing. He was introduced by Jessie Turner, chair of oral session 3.

Steven Miller is a professor of atmospheric science at Colorado State University (CSU) and director of the Cooperative Institute for Research in the Atmosphere (CIRA) in Fort Collins, colourado. He received his BSc in Electrical and Computer Engineering from the University of California at San Diego in 1995, and his MS (1997) and PhD (2000) from CSU's Department of Atmospheric Science, studying atmospheric radiation theory and satellite-based remote sensing of clouds. In 2000 he joined the Naval Research Laboratory in Monterey, where he designed algorithms for detection and characterization of aerosol, cloud, and surface parameters, supporting Coalition forces in the wake of 9/11. In 2007 he rejoined CSU as deputy director of CIRA, and in 2021 became CIRA's 4th director. He specializes in satellite-based environmental visualization and applications. His imagery tools are used widely by forecasters and the national media. His research passion centers on unique phenomena and associated visible light signals of the nighttime environment. His work with the NOAA's Day/Night Band sensor has enabled several research pathways, including pursuit of nocturnal retrievals of clouds and aerosol via moonlight, study of atmospheric gravity waves in nightglow, and exploring a rare marine bioluminescence phenomenon known as milky seas.

Steven's talk was entitled *A Glow from Below: Bioluminescent Milky Seas and their Role in the Earth System* and was a fascinating exploration into the history of studying oceanic bioluminescence, and the application of low light sensors to observe the phenomenon. He told the audience of the interesting story of finding a large-scale bioluminescent sea in the Indian Ocean that was finally observable in the day/night band files on Suomi-NPP and NOAA-20, and other encounters thereafter. The slides from Steven's talk are available at https://iocs.ioccg.org/wp-content/uploads/2023/11/keynote3-steven-miller.pdf.

4.4. Keynote 4: Srinivasa Kumar Tummala (INCOIS)

Oral session 4 on Thursday 16 November started with a keynote talk from Srinivasa Kumar Tummala. He was unfortunately not able to make the meeting in-person and presented his talk virtually. He was introduced by Alison Chase who chaired the session.

Srinivasa Kumar Tummala holds a PhD in Marine Science and has made impactful contributions to the field of operational oceanography and coastal multi hazard early warning systems. Working at the Hyderabad-based Indian National Centre for Ocean Information Services (INCOIS) of the Ministry of Earth Sciences (MoES) since 2004, he was responsible for implementing several important projects including the Potential Fishing Zone Advisories, Multi Hazard Vulnerability Mapping, Coral Reef Bleaching Alert System, Satellite Coastal and Oceanographic Research, etc. Post the 2004 tsunami, he coordinated the successful establishment of the Indian Tsunami Early Warning System, as a multi-institutional project. The tsunami early warning centre, based at INCOIS is identified as one of the Tsunami Service Providers under the Indian Ocean Tsunami Warning and Mitigation System (IOTWMS) framework of the Intergovernmental Oceanographic Commissions (IOC) of UNESCO. Between October 2016 to August 2020, he worked with the IOC-UNESCO as Head of the IOTWMS Secretariat in Perth, Australia, where he was instrumental in strengthening the regional tsunami early warning system in active collaboration with 28 Member States. He started his scientific career with a brief stint at the Indian Space Research Organisation (ISRO), and is currently the Director of INCOIS. He is also Vice Chair of the IOC for Region IV, Co-chair of the IOC–WMO Joint Collaborative Board, and Chair of the Ocean Decade Tsunami Programme Scientific Committee.

Srinivas gave a talk titled *Societal application of ocean colour to fisheries information service*. He gave an overview of the ocean value chain and the crucial application of ocean data, including ocean colour, to fishing communities, and the management of coastal states, ports, harbours, and offshore shipping in India. He gave examples of ocean colour data applications, mainly from the Oceansat missions and ISRO/CNES SARAL (Altimeter in Ka band) Altika, to help identify habitats suitable for fisheries, that are then translated into maps and other forms that fishers can digest. Data is validated using search times for fishing. Such habitats might include the identification of clear, low turbidity water, which tuna prefer; identification of frontal systems and associated productivity or hotspots; and detection of Jellyfish aggregations. In addition to marine fishery advisory services, satellite ocean colour data is also used by INCOIS for water quality services, including pollution and algal bloom alerts; organic carbon fluxes and cycling; and ecosystem modelling. Slides from Srinivas's talk: https://iocs.ioccg.org/wp-content/uploads/2023/11/keynote4-srinivasa-kumar.pdf

Audience members raised the point about making data from India and the Oceansat missions open and accessible, so that others may benefit from the data. For example, the ESA data portal and NCEO's NERC Earth Observation Data Acquisition and Analysis Service (NEODAAS) are open and accessible and can be used by those in the region. In regards to a question

about connecting with fishers, Srinivas indicated the very strong collaboration in the region with the fishing community. This includes an annual users workshop that helps to improve products and to gain understanding of the species-specific requirements of the community.

4.5. Keynote 5: Marina Marrari (FECOP)

The Thursday afternoon session was chaired by Srinivas Kolluru, who introduced Marina Marrari to give a keynote talk under the theme of application of ocean colour in ecosystem function, community development and citizen science.

Marina Marrari attained a BSc in Biological Sciences from the National University of Mar del Plata, Argentina, and continued her studies in the USA as a Fulbright scholar. She obtained her PhD in Biological Oceanography from the University of South Florida (USF), College of Marine Science in 2008 and did postdoctoral work at NASA Goddard Space Flight Center. During her research at USF, she was introduced to the use of ocean colour satellite data as a tool to examine remote conditions affecting reproductive success of Antarctic krill. Some of her later work included examining trends in environmental conditions in large marine ecosystems around South America and the characterization of conditions for successful recruitment in fish along the Patagonian shelf. She joined the Costa Rica Sportfishing Federation (FECOP) in 2018 where she currently serves as executive director. FECOP is a non-profit dedicated to promoting responsible fishing practices and the conservation of marine organisms through science and education, with a special focus on species of tourist interest that support the development of coastal communities through marine tourism. Dr. Marrari's interests include using satellite data for studies of environmental variability, marine conservation, the use of technology for capacity building and community involvement, and science as a tool for public policy advocacy.

The title of Marina's talk was *Ocean colour In Latin America, Ecosystem Function, Citizen Science, and Community Development*. She showed the application of satellite data to the development of mobile apps in South America that assist fishers with accessing near-real-time data for identifying relevant ocean features, and even alerting them to their proximity to marine protected areas. The main app, pezCA, used in Costa Rica, gets temperature and chlorophyll data from MODIS Aqua/Terra, and currents from the NASA OSCAR model, in addition to satellite data for sea level anomalies and thermocline depth. The pezCA app is part of the PACE Early Adopter Program, with application to red tide and harmful algal bloom monitoring. Marina also gave examples of the many capacity building opportunities and citizen science initiatives that the development of this application has facilitated. The slides from Marina's talk are available on the IOCS-2023 website: https://iocs.ioccg.org/wp-content/uploads/2023/11/keynote5-marina-marrari.pdf

4.6. Keynote 6: Ajit Subramaniam (Columbia U.)

The morning session on the final day of the meeting was chaired by Paula Bontempi. She introduced Ajit Subramaniam to give a keynote talk under the theme of the economic value of ocean colour, prior to a panel discussion on the topic.

Ajit Subramaniam is a Lamont Research Professor at the Lamont Doherty Earth Observatory of Columbia University. He has a BSc in Physics from The American College in India, and an MSc in Marine Environmental Science and Ph.D. in Coastal Oceanography from SUNY, Stony Brook. He is interested in advancing our ability to observe the ocean and expand our understanding of how the marine ecosystem works and can be managed. He has served as the Program Director for the Marine Microbiology Initiative at the Gordon and Betty Moore Foundation and a program director in the Biological Oceanography Program at the U.S. National Science Foundation. He has worked for the National Oceanic and Atmospheric Administration Coastal Services Center in Charleston, SC, the University of Maryland in College Park, and the University of Southern California in Los Angeles. He was elected as a Member at Large of the Board of the Association for the Sciences of Limnology and Oceanography in 2018 and reelected to this position in 2021. He was awarded a Mercator Fellowship by the University of Rostock and the Baltic Sea Research Institute, Germany in 2017 and the Climate and Life Fellowship at LDEO in 2021.

The title of Ajit's talk was *Monetizing Ocean colour?* It was a provocative dive into the costs and potential earning power of ocean colour data and its applications. Ajit argued that costs should include the value that cannot be accounted for in dollars. In situ sampling would take ~11 years to create the equivalent of 1 satellite scene. Some areas have no in situ data, but have satellite observations. He showed a study that uses these comparisons to quantify the value of information gained from satellite data. But are all communities served? Some quantifications of the value of ocean colour data use the impact of harmful algal blooms. These calculations include costs associated with human health (exposure to toxins) and with reductions in restaurant/supermarket and lodging revenue for foods and places affected by blooms. Other impact-related examples were detection of Sargassum blooms in the Atlantic Ocean and Caribbean Sea, and oil spills, both associated with high clean-up costs. Remote sensing is also used in management and response plans of national agencies. Ajit argued that the ocean colour community is poised to play a role in carbon capture mechanisms, to ensure that implementation, if any, is done after thorough research and investigation. He raised questions about the inclusion and incorporation of data from unmanned aerial vehicles (UAVs) which are increasing in use, as well as cubesats and small sats in addition to the work with satellite missions. There is a gap between data providers and users. He understands that space agencies will focus on their missions, but urged the community to talk about how ocean colour is used to expand its application. He proposed that the IOCCG could engage local agencies that could use satellite data to find out what they need to help to fill the gap.

He raised the idea of a working group on the use of UAVs, and a working group on how ocean colour data can be used for measurement of marine carbon dioxide removal. Ajit's slides: https://iocs.ioccg.org/wp-content/uploads/2023/11/keynote6-ajit-subramaniam.pdf

5. Economics of the Ocean - Panel Discussion

Following the final keynote talk by Ajit Subramaniam, Paula Bontempi moderated a panel discussion on the economics of the ocean. Panel speakers were Ajit Subramaniam, Jim Sullivan (Blue Green Algae Task Force for Florida State, Ocean Florida Alliance, Indian River Lagoon (IRL) National Estuary Program), and Žarko Kovač (Physicist with interest in economics, University of Split, Croatia).

The panelists introduced themselves. Žarko got into economics because of the similarity between the mathematical structure of primary production and economics. Jim is a local Floridian and his work depends on ocean colour remote sensing. He stressed that these programs are worth billions of dollars to the state, and remote sensing is used to judge the success of projects. Ajit indicated that he makes money off ocean colour.

Paula started by giving an anecdote, highlighting that the Cyanobacteria Assessment Network (CyAN) Project had been selected as one of the projects highlighted at an event at the US White House, to indicate the impact and opportunity of remote sensing. She kicked off the discussion by raising Ajit's statistic in his talk about the comparison between in-situ sampling and satellite data. After discussion, it was clear that both are needed. Satellite data helps in-situ sampling to be more efficient (you can know where to go to sample a bloom, for example), but also measures a much wider swath of the surface ocean at a much faster pace, and in many more remote locations.

With regards to some of the value to fisheries highlighted in previous talks, Žarko raised that using remote sensing to optimize fisheries might lead to overfishing, so this should be counted as a cost against that benefit, which needs to be managed. Emmanuel Devred (Fisheries & Oceans Canada) gave examples of how satellite data can be used to help with fisheries management, catch quotas, and fisheries economics.

Joaquin Chaves (NASA-GSFC) raised that the benefits of ocean colour are not only economic, but are also societal and cultural. We probably need to collaborate with economists or anthropologists to probably inaugurate the field of *ocean colour anthropology or economics* so that we can quantify all the values to those who determine future funding and economic policies. Gemma Kulk (PML) added social justice to the conversation. Satellite remote sensing allows for a holistic view of the globe, and to better serve underserved communities, and this should also be added to its value.

Menghua Wang (NOAA) asked how we could better sell the importance of OC data to the public. Water and air are priceless, but we need to think about how to sell the value of the work that we do. Some ideas were:

- Kimberly Hyde (NOAA Fisheries) indicated that we could look at the value of measured products to its applications (e.g. the value of phytoplankton to fisheries). They do work with economists and anthropologists in their center.
- Jim shared that we should communicate the costs of getting data without satellites when talking to politicians and economists.
- Laura Lorenzoni (NASA) agreed and added that we need to better communicate the precision and uncertainties needed for the community level, which might be less strict than for climate science, so we can find that middle ground, and help people make better decisions.
- Paula agreed, and raised that we should engage with our government officials.
- Rick Stumpf (NOAA Federal) indicated that the EPA was invited to the White House, and chose the CyAN project because it was helping to solve a problem. Other information about satellites and their cost is only relevant supporting information when communicating the value, as many see the true value in helping to solve whatever is the problem they are having. He also noted that every new sample costs the same as the last one once a satellite is already in orbit, making it a very economical choice for sampling.

Bror Jönsson (PML) raised that the science community is not really profiting from the economics of ocean colour or finding the value add. Is there a way to package the data for society (entrepreneurs etc) to turn into a financial business?

- Ajit mentioned that he does make money from ocean colour data.
- Cara Wilson (NOAA) indicated that others do package products in the private sector, but that there are differences internationally for using and profiting from public data.
- There was a recommendation that space agencies push and fund new technologies, including UAVs for ocean colour applications. UAVs are mostly for land at the moment and if we push for more ocean sensors then we can develop cheaper technologies for the community.
- Vittorio Brando (CNR-ISMAR) indicated that Copernicus is attached to industry with a stated purpose to save money for Europe. It is built around satellites and core services, and the downstream products are meant to make money. There are reports on how much money is used and how much money is saved. There is a lot more saving and income generated from innovation. Copernicus is geared towards smaller users and companies.

Shubha raised that there is a cost to doing science as well, and there is a carbon currency that we could use for determining the economics. Are there costs/savings in carbon currency by doing satellite measurements? Are there strategies on the economics of carbon towards moving to net zero? Space debris adds a cost as well.

- Žarko indicated that the valuation of ecosystem services is difficult, and we need to consider present value over future costs and benefits. Economists discount the future, which is a critical problem in how to put a number on the future cost or benefit. Human minds are in the scale of the present but not the scale of 10-30 years in the future, which is needed for economic valuations that involve the climate.

Frank Muller-Karger (USF) raised that we all value information, and there is a lot of exploration and discovery that has an undiscovered value that we may need to incorporate. Bob Brewin (U. of Exeter) asked whether social scientists are involved in the valuation of beaches, and in incorporating the psychology of seeing the ocean, and whether we should be putting an effort towards this. Ajit supported this question, indicating that we plan our vacations around beaches. Jim indicated that using satellite data to determine when, and if, someone can safely go to the beach is invaluable. Harmful algal bloom alerts and Sargassum warnings for beach attendance are often based on satellite data.

Nima Pahlevan (SSAI/NASA GSFC) raised that when stakeholders are savvy with the current data, they will want more satellite products. Can we predict their needs 10 years from now, to be prepared?

- Jim suggested geostationary, with much better temporal coverage, would be an awesome thing to help prepare for future needs.
- Ajit indicated that within the US, work is forbidden at spatial resolution smaller than 10m because of industry competition and defense, but that seems to be the resolution that people need. He raised the adjacent question that if satellite images are made available for free, what value does it have? If people really need something, how much will they be willing to pay for it?
- Long term data records is one way to justify more satellites and sensors as an investment. But then we need to consider calibration of past data for the long term record to ensure we can measure how climate has changed within 50 years etc.
- Hayley Evers-King (EUMETSAT) asked whether we couldn't borrow concepts or methods from other communities to be able to evaluate the value of ocean colour. Example, the EUMETSAT weather community does analysis (and land remote sensing as well) to assign value to their data. Perhaps we could liaise with these communities to gain insights on how to value our own data. This could perhaps be incorporated in future meetings.
- Stacie Flood (South FL Water Management District) indicated that, regarding what should be available in 10 years, there are gaps that currently exist in data. She indicated that the data is currently used to the extent that they can be used, but that satellite data is not reliable in some areas (small spatial resolution, blooms occurring in the winter when there is too much cloud cover, turbidity too high, etc). So there are many caveats to using satellite data, and managers need data they can actually use for the purposes they require. Forecasting tools need to be the right resolution for monitoring and mitigation. Stacie presented these as opportunities for the community

to meet the needs of managers, and she embraces UAVs and other small satellites as they have the potential to provide the required resolution. Products need to meet managers at the level of their need, and help supplement field monitoring.

A participant asked whether there might be copyright laws for building commercial products, and whether there is a time limit that then allows the data to be free to the public (e.g. Planet). Paula indicated that she has negotiated end-user licence agreements, and commercial companies need to make money from their data. They might make it available in certain circumstances (e.g. emergencies) but these are on a case-by-case negotiation. Žarko indicated that, from his experience, they can only publish processed data, and will not give out their raw data. Frank Muller-Karger agreed with this and indicated that data from governments are free to use and you cannot sell that data, but you can derive products.

Eric Hochberg (BIOS) raised that there is a lot of money being invested in climate finance (insurance, mitigation, etc). Many within that field do not have a good understanding of what the OC community can offer, and he believes there is a good opportunity to have climate finance people in the room, to show what we can quantify. Companies and governments are investing billions of dollars now, and will be doing so for decades.

Sara Rivero-Calle (UGA Skidaway) indicated that SeaHawk/Hawkeye cubesats are a non-commercial satellite that has been in orbit for 5 years. All the data is freely available. Cubesats disintegrate upon re-entry. They capture 120 m resolution and have a SEAWiFS-like sensor. Currently this is a proof of concept mission, but there have been posters comparing the data to large missions (MODIS and VIIRS) as well as comparisons to in situ data from AERONET-OC. There is a lot of potential for cubesat technology to be able to meet some of the needs of the users and managers.

In final thoughts, Žarko raised that we are at 422 ppm and when he started studying it was significantly less. We can calculate primary production but emissions are not going down, and this is a problem. Ajit wanted the group to think about what aspects of ocean colour we are currently not counting, but have infinite value. Jim indicated that the economic value of satellites is indispensable because without satellites we are blind to see what is happening. He called for the community to better sell the importance to the public and politicians so that we can secure continued funding. Paula thanked the panel and the audience for their valuable input and discussion. She indicated that we did not get to dive into the role of satellites in climate financing, but it will be important to the continued discussion.

6. Agency Updates

6.1. NASA (National Aeronautics and Space Administration)

Laura Lorenzoni gave an overview of the NASA satellite missions. She showed the expansion of satellites in orbit over the past decades that now includes smaller satellites (such as cubesats) and many commercial satellites. She gave an overview of some of the active missions, including those that are not dedicated ocean colour missions but that can be (and have been) used for aquatic applications. These include the Earth Surface Mineral Dust Source Investigation (EMIT) that can be used to image coastal environments, and SWOT which is a collaborative mission to survey surface waters, including rivers and lakes. The following field campaigns and projects were highlighted, with updates on each: EXPORTS, BioSCape (biodiversity survey of South Africa's Cape Floral Region) , ASTraL/EKAMSAT (air-sea interface exchange in the Arabian Sea), in situ measurement sampling support (e.g SOCCOM), and Arctic-colourS (land-ocean interactions in the Arctic coastal zone).

Laura also gave an overview of NASA's Science Mission Directorate and Ocean Biology and Biogeochemistry program, indicating some of the highlights and changes that can be expected in the coming months. She thanked the community for their role and help as reviewers of NASA projects, and called for others to participate if desired. She also called for the community to give their feedback to help identify and reduce barriers to proposing to NASA research programs as well as NASA's Decadal Survey, for which the aquatic sciences community needs to be involved. Laura highlighted funding opportunities under NASA's Research Opportunities in Space and Earth Sciences (ROSES), which is released annually in mid February.

6.2. NOAA (National Oceanic and Atmospheric Administration)

Menghua Wang gave the agency update for NOAA on behalf of the NOAA Ocean Colour Science Team and CoastWatch. The NOAA-21 satellite was successfully launched on 10 November 2022, with the first global true colour image generated on 6 December 2022. The satellite was fully operational in NOAA's fleet of polar-orbiting satellites on November 8, 2023.

NOAA's next-generation geostationary satellite program Geostationary Extended Observations (GeoXO, a collaboration with NASA) has been approved and is now entering the development phase of the mission. Among other things, NOAA plans for GeoXO to add nighttime visible imagery and ocean colour observations. Proposals for the implementation of the GeoXO Ocean colour (OCX) Instrument are being requested from industry. The contract will provide a hyperspectral, ultraviolet through near-infrared passive imaging radiometer that analyzes ocean data and is planned to fly on the NOAA GeoXO program series of geostationary satellites. GeoXO is expected to begin operation in the early 2030s.

NOAA now produces three-sensor, global, daily, gap-free, Chl-a, Kd(490), and SPM products and images (in both 2 km and 9 km resolution). VIIRS-SNPP, VIIRS-NOAA-20, and OLCI-S3A are merged to improve data coverage and the Data Interpolating Empirical Orthogonal Function (DINEOF) is used to produce global daily gap-free products. The products are distributed through NOAA CoastWatch. Menghua also highlighted some of the applications and economic benefits of the CoastWatch products and collaborations.

6.3. CSA (Canadian Space Agency)

The update for the CSA was given by the new CSA representative to the IOCCG, WaterSat Mission Manager Geneviève Gariépy, who was unable to make the IOCS meeting in-person and delivered the update virtually. She highlighted Canada's ocean colour and inland water-related activities and missions. This included the SWOT mission, which will focus on surveying Earth's surface water to improve water resource management and to help adapt to climate change, and the smartWhales initiative, the tracking of right whales using satellite data. CSA is revisiting Canadian mission concepts in light of new and planned missions through stakeholder and science community engagement, and continues to explore international partnership opportunities (e.g. with AquaWatch).

Hyperspectral field campaigns have been funded in the St. Lawrence River in eastern Canada that will provide simultaneous in situ radiometric measurement and bio-optic properties of the water column and remote sensing via flight with the WISE instrument—a hyperspectral sensor (380 – 970 nm spectral range, ≤5 nm sampling, and 118 spectral bands). This includes *WISE-Man* in the Manicouagan Peninsula (2019-2020), which took measurements of bathymetry, water constituents, and bottom type mapping, and for which data is available online (catalogue.ogsl.ca); and Algal-WISE (2022-2024), which will measure microalgae, macroalgae, and phytoplankton functional types. The higher resolution DICE instrument is now in development. This instrument will have 360 – 910 nm spectral range, ≤1.25 nm sampling, and 440 spectral bands. Flights with the DICE instrument are expected between 2024 and 2025. CSA is working to have an integrated processing chain for developing algorithms, products and services, and demonstrating applications, while also building core expertise. Also ongoing, is an assessment of land-focused hyperspectral imagers for ocean colour applications, e.g. PRISMA and EnMAP.

6.4. CONAE (Argentina National Space Activities Commission)

Carolina Tauro, who also presented virtually, gave an overview of the status of the SABIA-Mar mission and other ocean colour applications at CONAE. The aim of the SABIA-Mar mission is to gain ocean colour information over open ocean and coastal zones of South America, with 2-day revisits over Argentinian coastal waters. The visible and near infrared camera (412 - 865 nm) will have both regional and global application at 200 m and 800 m spatial resolution, while the near infrared and short wave infrared camera (750 - 1640 nm) will only have regional application at 400 m spatial resolution at nadir. Secondarily, a panchromatic high sensitivity

camera will enable detection at night. The mission's Critical Design Review was approved in April 2023 and the mission has moved into Phase D. Pre-Launch tests have begun, and the next milestone will be the Mission Operations Review. The mission is scheduled for launch in 2025.

CONAE also launched SAOCOM, Argentine Synthetic Aperture RADAR in 2020. Products are available at argentina.gob.ar/misiones-satelitales/acceso-los-productos. Products have helped to monitor icebergs and track boats in Argentinian waters, among other applications.

6.5. SIO (Second Institute of Oceanography, China)

Xianqiang He gave a pre-recorded presentation on the progress in China's ocean colour satellite missions & remote sensing application technologies. China's ocean colour satellites HY-1C and HY-1D were launched in 2018 and 2020, respectively, and are successors of HY-1A (2002-2004) and HY-1B (2007-2016). Both instruments have the *China Ocean colour and Temperature Scanner* (COCTS, 10 bands, 1.1km - 3000 km global resolution) and the *Coastal Zone Imager* (CZI, 4 bands, 50 m - 1000 km resolution), and the *Ultra Violet Imager* (UVI, 2 bands, 550 m - 3000 km global resolution). Data products from HY-1C/1D are freely available at osdds.nsoas.org.cn. China has two new generation polar-orbit ocean colour missions. The experimental satellite, HY-1E, scheduled for launch in November 2023, and the planned operational satellite, HY-1F. They will have three major payloads: a **new** Ocean colour and Temperature Scanner (COCTS2) with 18 bands from UV to thermal infrared, and smaller spatial resolution of 500m; Programmable Moderate Resolution Imaging Spectroradiometer (PMRIS), and a **new** Coastal Zone Imager (CZI2) with 8 bands, 20 m resolution, and 1 panchromatic at 5 m resolution. China has also planned geostationary ocean colour missions with the GEO Ocean and Coastal Zone Imager, with highest spatial resolution of 25 - 200 m in the visible and near infrared.

Some achievements regarding ocean colour product applications were highlighted. This included an advancement in atmospheric correction (AC) algorithms at high solar zenith angles (>70°), improving applications of geostationary satellite observation at dawn and dusk, and the polar-orbit ocean colour observation at high latitude during the winter using the PCOART-SA model (He et al., RSE, 2018) and a machine learning method. Other notable achievements included improving AC for absorbing aerosols, detecting oil slicks, and improved satellite retrieval of benthic reflectance.

China also held their SatCO2-V International Training Workshop, for which 22 students attended. SateCO2 is a freely distributed Marine Satellite Data Online Analysis Platform developed to provide convenient access and efficient utilization of marine satellite remote sensing data, and promote the application of such data. Online users can access efficient computation and 3D visualization for large remote sensing, in-situ, and model simulation datasets, and can conduct interactive analyses between remote sensing and in-situ data.

6.6. ISRO (Indian Space Research Organisation)

P V Nagamani from the National Remote Sensing Centre at ISRO joined the meeting virtually and gave an update on the EOS-06 satellite mission as well as other ocean colour science and applications at ISRO. She showed the EOS-06 Ocean Colour Monitor (OCM-3) sensor products, and their detection accuracy, and gave many examples of the accurate detection of algal blooms and sediment loads in both regional and global oceanic and coastal waters. Product validation via in situ measurements are on-going. The OCM-3, in combination with the EOS-06 Scatterometer (SCAT-3) have also assisted with cyclone monitoring in the region, as well as other operational applications such as shoreline, harbour and port management; and oil spill and pollution management. Data for the mission is available from Bhoonidhi, ISRO's Earth Observation Data Hub at https://bhoonidhi.nrsc.gov.in/bhoonidhi/home.html. Hosted within that site is Vista (https://bhoonidhi.nrsc.gov.in/vista/index.html), which allows for near-real-time access to full resolution images, and Upagrah (https://bhoonidhi.nrsc.gov.in/upagrah) the live satellite/orbit tracker. Future activities for the mission includes the continuation of calibration/validation (Cal/Val) activities from global in-situ sites, BGC-Argo, and cruises. Oceansat-3A is the continuity mission for EOS-06 and will help to increase the availability of advanced research, development and evaluation products for the region and the global ocean.

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

Mark Baird presented in conjunction with and on behalf of Tim Malthus, and gave an update on the Australian ocean colour activities. There is continued funding for ocean colour research under Australia's Integrated Marine Observing System (IMOS) through the National Collaborative Research Infrastructure Strategy (NCRIS) until 2027. Under this funding, the IMOS Ocean Colour Sub-facility (led by CSIRO and Curtin University) are continuing their Cal/Val activities and development of satellite ocean colour products for the Austral-Asian region. This includes validation activities for the EnMAP and PRISMA missions. Data access is via the AODN Portal (https://portal.aodn.org.au). Regarding data application, Mark highlighted the expansion of the *eReefs* multi-agency project focused on the Great Barrier Reef (https://www.ereefs.org.au/) and the incorporation of remote sensing data from the project into a coastal biogeochemical model for the region. Mark also noted the spin-up of the AquaWatch Australia Mission for water quality monitoring and management. National and global pilot (2021-2026) sites have been identified for in situ data, with many active sites around the coast of Australia as well as in Malaysia, Italy and the UK. Other sites are planned within Asia and the Americas. Feasibility studies are being conducted for AquaSAT-1 with NASA JPL.

6.8. JAXA (Japan Aerospace Exploration Agency)

Hiroshi Murakami gave an update on the JAXA GCOM-C mission launched in 2017. The mission is now in its data application (post routine operation) phase. In this phase, the focus is on monitoring Earth system changes, and practical and operational applications. Product development and evaluation supporting these applications will continue. Hiroshi showed the many on-going projects using GCOM-C data. Version 3 standard products (Level-1, 2, and 3 HDF5 format) are open and available to the public via JAXA's data portal, G-Portal (https://gportal.jaxa.jp/gpr/). Hiroshi detailed the SGLI calibration system as well as data validation. Validation is via in-situ observations as well as other satellites, and validation results are available at https://suzaku.eorc.jaxa.jp/GCOM_C/data/validation.html. He ended with a summary and details of some of the major environmental SGLI observations over the five years of data acquisition.

6.9. 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. The mission is now in the public product release phase. The National Ocean Satellite Center (NOSC) established a new website (www.nosc.go.kr) and began public distribution of products in January 2023. Currently, there is a project to improve the accuracy of GOCI-II data at the international level, and Cal/Val standardization has been established to achieve this goal. Jongkuk highlighted other work being done, and this included improving the GOCI-II radiative calibration algorithms, updates to atmospheric correction algorithms, and improvements to IOP estimation using machine learning approaches. The team is also developing Level-3 algorithms for both GOCI-I and GOCI-II, to provide long-term time-series data.

6.10. ESA (European Space Agency)

Marie-Helene Rio presented remotely and gave an update on the ocean colour research and applications at ESA. She gave an overview of the ESA-developed Earth observation missions, as well as the over 35 on-going ocean science and applications projects within the categories of ocean carbon, ocean extremes, climate, land/sea and air/sea interactions, and ocean health and biodiversity. Of note were projects that have expanded their in situ data collection in anticipation of hyperspectral missions, and those supporting the CEOS aquatic carbon roadmap, which was endorsed at the CEOS Plenary, during the same week as the IOCS, on Wednesday 15 November. Marie-Helene highlighted relevant calls for project funding that might interest members of the ocean colour research community, and invited the community to join the Ocean Science Cluster mailing list in order to stay updated (https://esacontact.esa.int/ocean-science-cluster-newsletter-subscribe/)

6.11. NCEO (UK National Centre for Earth Observation)

Steve Groom also presented virtually, and gave an update on ocean colour activities at NCEO. NCEO is the UK research centre funded by the UK Natural Environment Research Council. Steve gave an overview of the on-going ocean-colour-related projects within NCEO. Many focussing on global and regional carbon cycles, and climate change, as well as the classification of optical water types. The UK EO Climate Information Service (EOCIS) co-funds work in the ESA Ocean Colour Climate Change Initiative (OC-CCI) project, and some of the projects within the initiative were highlighted. NCEO also oversees the NERC EO Data Analysis and Artificial Intelligence Service (NEODAAS) which provides services that support the Earth observation community by providing operational satellite and airborne data processing, artificial intelligence services, new data products, support, and training.

6.12. CNES (French National Centre for Space Studies)

Hubert Loisel gave the update for CNES on behalf of Aurelien Carbonniere. He gave a brief overview of CNES Earth Observation program and activities, which contribute to the ESA, Copernicus, and EUMETSAT programmes. Several collaborative missions are in various stages of preparation, and others in development, including the TRISHNA (Thermal InfraRed Imaging Satellite for High-resolution Natural resource Assessment) mission, scheduled for launch in 2026. He also highlighted the CNES/NASA SWOT mission, which was successfully launched on 16 December 2022. The mission aims to provide global ocean circulation at high resolution, an inventory of surface water storage and its evolution, including freshwater and coasts. The SWOT satellite is currently in scientific orbit, with a 21-day revisit after completing a 6-month Cal/Val phase in a dedicated orbit. Hubert presented some of the first results from the mission. He also highlighted other on-going projects funded through CNES's TOSCA funding calls: BIOFRONT (estimation of Chl-a increase over fronts in the Gulf Stream), PLANKTOSAT (long-term gap-free 4D PAR dataset to model plankton distribution in North Atlantic), HYPERVAL (autonomous cal/val of satellite-derived products on HYPERNETS water sites), COUL-PNP (optical proxies for particulate organic nitrogen and phosphorus), and high resolution ocean colour products, available on https://hydroweb.next.theia-land.fr.

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

Juan Ignacio Gossn presented on the current status and future outlook of ocean colour products and services at EUMETSAT. EUMETSAT delivers quality ocean colour data services to users and provides data access through https://data.eumetsat.int. The Sentinel-3 OLCI Collection-3 is currently in operation and there is high consistency between OLCI-A and OLCI-B. Open water chlorophyll is within mission requirements, and there are improved product retrievals over turbid waters. The Collection-3 documentation is available online at https://www.eumetsat.int/media/47794. New OLCI IOP products (v. 3.04) are in operation from

January 2024. There has also been development of a OLCI TOA-radiance Fluorescence Peak Height product (https://www.eumetsat.int/S3-OLCI-FLUO). There are now developments towards OLCI Collection-4 with a full mission reprocessing, tentatively for Fall 2024. Community collaboration on algorithm validations is welcome.

The Copernicus Ocean Colour System Vicarious Calibration (OC-SVC) activities are managed by EUMETSAT on behalf of the European Commission and is currently in phase 4 (engineering design, technical definition, and specs). Fiducial Reference Measurements (FRM) for Satellite Ocean Colour (FRM4SOC2) is in phase 2, which is coordinated by EUMETSAT. FRM4SOC2 provides the community with easy procedures, guidelines, and tools for collecting FRM-quality radiometric measurements. There is also development of ocean colour demonstrative products from geostationary Meteosat SEVIRI (Spinning Enhanced Visible and Infrared Imager) and FCI (Flexible Combined Imager) instruments.

7. Breakout Workshops

A total of 9 breakout workshops (3 parallel sessions per day from Tuesday - Thursday) occurred as follows:

- ***Tuesday 14 November 2023 (Breakout Workshops 1 – 3)***
    - **Breakout 1:** Beyond Chlorophyll-a: New trophic state indicators for optically complex waters
    - **Breakout 2:** Remote sensing of aquatic litter and debris
    - **Breakout 3:** Inventory of current ocean colour mission validation activities

- ***Wednesday 15 November 2023 (Breakout Sessions 4 – 6)***
    - **Breakout 4:** Global carbon budget for the land to ocean aquatic continuum (LOAC) from remote sensing
    - **Breakout 5:** The Value of Ocean colour for the Benefit of Society: status and change in water quality and ecosystems
    - **Breakout 6:** Ocean Colour Satellite Sensor Calibration

- ***Thursday 16 November 2023 (Breakout Sessions 7 – 9)***
    - **Breakout 7:** Priority list of marine biodiversity metrics to observe from space
    - **Breakout 8:** Achieving long-term consistency in cross-sensor ocean colour data products
    - **Breakout 9:** Lidar applications for ocean colour

The full description of each breakout workshop along with the agenda and a full report from each is available on the archived IOCS-2023 meeting website at https://iocs.ioccg.org/iocs-2023-meeting/breakout-workshops/.

A summary of each workshop is given below, highlighting the community consensus on key issues addressed by each workshop, and providing advice for the space agencies, the IOCCG or the ocean colour community.

7.1. Breakout 1: Beyond Chlorophyll-a: New trophic state indicators for optically complex waters

Chair: Daniel Odermatt (daniel.oderma-@eawag.ch)
Co-chairs: Michael Sayers (mjsayers@mtu.edu), Astrid Bracher (astrid.bracher@awi.de)

7.1.1. Introduction

New remote sensing sensors and platforms, as well as improved understanding of observables such as phytoplankton fluorescence, are enabling new indicators for assessing trophic status or carbon fixation in aquatic environments. This includes, for example, the determination of primary production, different phytoplankton functional types, harmful algal blooms, carbon particle fractions, aggregated trophic mass or indirect estimates of nutrient availability. The specific potential uses, required methods, and reference databases require clarification. By discussing these requirements, we aim to identify research priorities that can range from consensus protocols for fiducial measurements to robust algorithms for global applications.

The session aimed to stimulate broad discussion of novel ecosystem indicators for optically complex waters that could complement established chlorophyll-a products, highlight the state-of-the-art and potential uses for each, and also address challenges and identify research gaps and priorities.

7.1.2. Session Summary

The session included a suite of presentations from the research community.

The algal bloom monitoring application EOLakeWatch (www.eolakewatch.ca) was presented by Caren Binding. It reports on blooms in Lake Erie, Lake of the Woods and Lake Winnipeg by means of weekly email bulletins and annual summary reports, using MERIS, MODIS and OLCI data. The main challenges in this task are first to define the essence of blooms in a way that is both locally relevant and transferable, despite contrasting definitions in water quality monitoring guidelines. Second, long- term assessments require the homogenization of multi-mission products. Promising opportunities are identified in the improvement of phycocyanin retrievals using PACE, and in the development of bloom forecasting methods using EO data.

The combined use of EO products and hydrodynamic models in the ESA AlpLakes project (www.alplakes.eawag.ch/) was presented by Daniel Odermatt. The talk focused on an

Uroglena bloom in Lake Geneva in 2021 and it described how Sentinel-2 images and forward and backward tracking of particles in a 3D hydrodynamic model helped to understand the hydrometeorological conditions enabling the first bloom of this kind since 1999. The upscaling of such models requires robust Secchi depth (transparency) input data and simplified 3D model parameterization technique. On the other hand, they can enable improved gap-filling methods for EO products or improved EO algorithm parameterization (e.g., using Lagrangian IOP models).

Methods for estimating aquatic primary production in the Great Lakes and worldwide were presented by Mike Sayers. This presentation detailed phytoplankton primary production annual estimates from 2003-2018 for the 11 largest lakes of the world using a combination of ocean colour remote sensing data (MODIS) along with an empirically derived carbon fixation model. The annual time-series data revealed significant increasing trends in production for large arctic lakes (Great Bear and Great Slave Lakes) likely driven by climatic changes. Challenges in this work include the adequate calibration of semi-analytical ocean colour algorithms to account for dynamic spatio-temporal variability in optical properties in large lakes. Additionally, refined methods using more in situ data to estimate phytoplankton-specific carbon fixation rates would make the approach more robust (i.e., better accuracy, lower uncertainty) across variable phytoplankton community composition. Finally, in order to promote the use of such products, more incubation measurements should be taken for validation purposes.

The detection of phytoplankton functional groups in optically complex waters was summarized by Hongyan Xi. The talk highlighted that understanding the diversity and composition of phytoplankton in optically complex waters is critical because phytoplankton play a key role in the aquatic ecosystem with respect to the major biogeochemical processes, carbon transport, water quality, and harmful algal bloom (HAB) monitoring. The talk detailed why the detection of phytoplankton groups (PGs) in these waters using ocean color techniques is still very challenging due to many influencing factors (such as high sediment and/or dissolved organic matter loads, and high dynamics due to tidal influence, etc.). She presented very recent case studies on the application of hyperspectral and multispectral remote sensing data for PG/HAB detection and quantification in various Case-2 waters. It finally opened the discussion on the main challenges we have to tackle, and address potential perspectives we can focus on.

Kelp forest mapping on the coast of British Columbia was presented by Maycira Costa as an example for quantifying benthic primary production. Canopy-forming kelp forests are globally recognized as one of the most structurally complex foundational ecosystems, playing an important role in maintaining marine food webs, buffering shorelines against erosion and contributing to carbon and nitrogen cycling. Today, the cumulative effects of a warming climate and coastal development threaten marine species, including kelps. It focused on British Columbia, Canada, as a case study to highlight the use of remote sensing technologies

with historical data to evaluate the long-term distribution and resilience of canopy-forming kelp forests and associated drivers of change. The talk also highlighted the importance of partnerships with local indigenous peoples, communities and organizations.

7.1.3. Recommendations

The lack of optical satellite sensors optimized for inland and coastal waters is overall the biggest limitation to the potential for remote sensing applications in such waters. Several mission proposals are currently in preparation, namely Aquasat-1 (Bright et al., 2023), the ESA Earth Explorer 12 mission proposal GALENE (Chami et al., 2022) and CSA's WaterSat. We thus recommend:

1. Regardless of the fate of current mission proposals to address the lack of optical satellite sensors optimized for inland and coastal waters, space agencies should develop a strategy for remote sensing of optically complex waters in dialogue with the scientific community within the next two years.

Improving the integration of remote sensing in traditional lake monitoring could strongly enhance the potential for remote sensing in terms of the availability of in situ data (e.g., adaptive monitoring, primary production) or the interpretation and utilization of satellite data products (e.g., algal bloom monitoring). The GLEON working group on remote sensing is a durable effort across discipline boundaries, but a stronger push is needed towards the science policy interface (e.g., Water-ForCE was only temporary). We therefore recommend:

2. Community organisations like IOCCG or GEO Aquawatch should focus more strongly on the science policy interface, than on research and technology, to help improve the integration of remote sensing in traditional lake monitoring.

Traditionally, Earth observation had a leading role in promoting open data and software. However, we noticed that this paradigm was less and less considered as technology matured. We therefore request the following:

3. Space agencies are requested to review and expand the use of FAIR and open source standards in their commissioning processes to promote more open data and software.

7.2. Breakout 2: Remote sensing of aquatic litter and debris

Chair: Madeline Cowell (Madeline.Cowell@ballaerospace.com)
Co-chair: Shungu Garaba (shungu.garaba@uni-oldenburg.de), Chuanmin Hu (huc@usf.edu)

7.2.1. Introduction

The IOCCG Task Force on Remote Sensing of Marine Litter & Debris (RSMLD) has as an overarching goal to coordinate the advancement of current and future remote sensing technologies and techniques that have the potential to provide observations of plastic litter over all aquatic environments. This breakout workshop was coordinated and supported by the RSMLD Task Force. More discussion is needed on the state-of-the-art technology available

for mapping and monitoring floating, and slightly submerged, matter in all aquatic environments. This is true for anthropogenic waste, such as plastic litter, but also for macroalgae, sea snot, pollen, and other materials common in mixed aggregations. Consensus is needed around the identification of essential indicators that could be derived from operational remote sensing, and that would be relevant descriptors for the United Nations Sustainable Development Goals (e.g., Goal 6, which addresses the quality and sustainability of water resources, and Goal 14, which aims to conserve and sustainably use the oceans, seas and marine resources). Discussions are also required to highlight gaps and to recommend ways to better understand marine litter pollution using space-based technology and remote sensing in general.

7.2.2. Session Summary

Presentations within the session covered themes on the relevant advances in instrument technology, algorithms, datasets, and expected stakeholder applications of remote sensing of marine litter. Part of the session was dedicated to a recap and further review of the ESA-NASA Remote Sensing of Marine Litter Workshop that was held in October 2023 at ESTEC, The Netherlands. The session provided a platform for engagement amongst end-users, citizens, policymakers, and upstream experts, including interdisciplinary researchers.

The diversity of stakeholder applications and expected end-products was emphasized. These applications are a key driver of determining the most appropriate remote sensing platforms and sensor requirements. Hyperspectral optical sensors were deemed the most resource-intensive because of fine pixel resolution but high signal-to-noise ratios in the infrared spectrum. A synergy of sensor technologies was proposed as a vital strategy for improved sensing capabilities e.g., microwave radar or lidar. Detection, identification and quantification could be better achieved by combining optical sensors with fluorescence lidar techniques to get the vertical distribution of the litter in the water column, whilst radar has the ability to measure through cloudy conditions.

Attendees all agreed that remote sensing offers a complementary monitoring strategy for all stakeholders. The capabilities have been demonstrated in several studies with the caveat that the current sensors are not well fit-for-purpose, especially for spaceborne platforms. The importance of continued advancements in technologies and approaches in a collaborative open-science approach was echoed as key to further enhance scientific evidence-based understanding of marine debris dynamics, and contribute to effective, well-informed mitigation strategies. A concept satellite mission (MARLISE led by VITO) was discussed as a step towards a space laboratory for observing specific accumulation zones e.g., landfills, beaches and windrows. There is an active community utilizing proxies to help identify accumulation zones, such as windrows. Curated hyperspectral open-access datasets that could be leveraged and adapted for the community were encouraged (e.g. OceanScan2).

The Task Force is working towards restructuring in order to further improve advances on the topic of remote sensing of marine litter, and to engage a wider pool of interdisciplinary stakeholders. Though the TF had four distinct core topics, these will remain as themes, but the resources will be combined to pull together all members contributing to the community, with a goal to increase community engagement. To ensure continued development, there will be the establishment of Tiger Teams to focus on specific actions and deliverables. These smaller teams are meant to provide ownership beyond the TF's steering committee, as resources are strained. Smaller teams are more agile and new teams can be formed if needed. The TF steering committee will remain, and will help guide actions to support the remote sensing of marine litter and debris roadmap.

7.2.3. Task Force Goals Emerging From The Workshop

1. Develop of the remote sensing of marine litter and debris roadmap
    - What: Living open-access document to be reviewed and revised every 2 years.
    - Who: TF-RSMLD with the support of Space Agencies and stakeholders.
    - When: Draft expected April 2024.
2. Develop hyperspectral library and database
    - What: Curated open-access hyperspectral reference library of diverse endmembers for algorithm development and sensitivity analyses from controlled experiments, and in-situ observations with match-ups or reference RGB photos.
    - How: Data mining and community contributions (e.g. OceanScan, TF-RSMLD website).
    - Who: TF-RSMLD with the support of all stakeholders.
    - When: Ongoing and draft version expected October 2024.
3. Define sampling protocol
    - What: Living open-access protocols for remote sensing of floating matter from ships-of-opportunity, citizen science, or upcoming agency campaigns.
    - How: Stakeholder engagement to define essential metadata, and affordable, easy-to-use, and sustainable sensors for databases.
    - Who: TF-RSMLD with the support of all stakeholders.
    - When: First draft expected June 2024
4. Engage stakeholders and downstream users
    - What: Create a published document to communicate the realistic capabilities and limitations of relevant remote sensing technologies with regards to detection, identification, quantification, and tracking applications through community generated infographics and terminology.
    - Who: TF-RSMLD with the support of all stakeholders.
    - When: Ongoing
5. Get priorities from stakeholders
    - Determine the "why?" or "so what?"—why do the stakeholders care?

- Determine how stakeholders want the information, what actions they plan to take from the data products, and their management outcomes, to dictate the level of data/information
- Assess the impact story—determine the stories that can be highlighted to display the effects of science on mitigating pollution impacts.
- What: Expected deliverables could be in the form of an article on the lessons learned from stakeholder interviews.
- Who: The article is anticipated to be generated by the TF-RSMLD
- When: Towards the end of 2024.

7.3. Breakout 3: Inventory of current ocean colour mission validation activities

Chair: Lachlan McKinna (lachlan.mckinna@go2q.com.au)
Co-Chair: Jeremy Werdell (jeremy.werdell@nasa.gov)

7.3.1. Introduction

There are multiple international ocean colour missions on-orbit and in-formulation (e.g., GCOM-C, Sentinel-3A/B, VIIRS, PACE). Each mission has its own dedicated validation program to ascertain data product quality and provide confidence to the user community. Successful validation programs are key to ascertain if prescribed mission requirements are met. There are currently multiple validation programs run concurrently throughout the world with data stored in various data repositories.

As the collective international ocean colour community had not met in-person for several years, this workshop aimed to take an inventory of current validation activities to identify potential gaps and opportunities, and to learn how the community might assist each other (e.g. measurements or instruments that some groups require could be resolved through collaboration). There are also a number of novel technologies, including hyperspectral sensors and in-water autonomous platforms, that lend themselves to validation, but for which the capabilities and benefits may not be broadly familiar.

The workshop is meant to take stock of the activities occurring in the near-term with a focus on biogeochemical measurements (e.g., HPLC, POC, PIC, Kd), apparent optical properties (AOPs, Kd), and inherent optical properties (IOPs). It aimed to identify: (i) gaps in validation campaigns, (ii) geographic domains being sampled, (iii) new technologies, (iv) innovative sampling strategies, and (v) areas of collaboration and/or resource sharing to achieve collective objectives.

7.3.2. Session Summary

A template was provided for institutions to present an overview of their validation objectives, scope, and program(s); geographic regions sampled; measurements to be collected; and a list

of gaps and opportunities. Presenters included NASA, ESA, EUMETSAT, NOAA, JAXA, CONAE, and CSIRO/IMOS, who presented their validation activities according to the template.

The groups then discussed a catalogue for compiling the ocean colour mission validation activities, what it might look like, and which institution(s) would take responsibility for the catalogue. Also discussed were hurdles for collaboration, which included data sharing, locating datasets, instrument sharing, instrument availability, and DOIs/credits for data. It was suggested that the IOCCG could maintain the catalogue of where agencies/countries keep their data and how that data can be accessed.

7.3.3. Recommendations

The following recommendation emerged from the workshop:

1. IOCCG should maintain a living inventory of validation activities, and create an accompanying webtool that seamlessly allows the community to submit their information. This should be accompanied by a data catalogue that indicates where agencies/countries keep their data and how to access it (12 months)

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

Chair: Hubert Loisel (Hubert.Loisel@univ-littoral.fr)
Co-Chair: Claudia Giardino (giardino.c@irea.cnr.it)

7.4.1. Introduction

The budget of global carbon requires an assessment of the respective contributions from all aquatic environments. This includes inland waters (streams, rivers, floodplains, lakes, reservoirs), coastal waters (estuaries, marshes, mangroves, shelves), and the ocean. An assessment across this continuum requires a synergistic approach, as these environments are complex and varied. Such an approach includes in situ observations, models, and remote sensing. In this context, observations from satellite platforms play a central role, providing both temporal and spatial coverage. However, key questions and issues must be addressed. These include a determination of which components of the carbon cycle, with their degree of uncertainties, can (and cannot) be estimated from remote sensing for inland and coastal aquatic environments; laying out the challenges in estimation of carbon pools and fluxes across the continuum from space; figuring out how to merge community practices across varied products, temporal dynamics and spatial scales; and addressing the vertical dimension of the water column using other technologies, such as lidar, models, or in situ observatories.

7.4.2. Session Summary

The breakout workshop was chaired by Hubert Loisel and Claudia Giardino, and had speakers on carbon from lakes (Tiit Kutser, Mortimer Werther) as well as carbon from coastal zones and estuaries (Antonio Mannino). The main objectives of the sessions were to identify the primary advances and limitations in the satellite assessment of aquatic carbon over inland (lakes and rivers) and coastal waters; exchange information on best practices across the inland and coastal water communities for space-based retrieval of carbon related parameters; and identify priority actions over the next decade for monitoring carbon pools and fluxes across the land to ocean aquatic continuum (LOAC) from remote sensing.

Session participants across the two communities identified the following parameters and processes that could be addressed from ocean colour radiometry (OCR):

- Particulate organic carbon (POC)
- Dissolved organic carbon (DOC)
- Particulate inorganic carbon (PIC)
- Partial pressure of CO2 (pCO2)
- Abundance of macrophytes (derived from OCR)
- Primary production
- Photo-degradation (using OCR and Modeling)

The community noted that while POC and DOC estimations are fair to good for coastal waters and lakes, they are fair to bad for estuaries.

7.4.3. Data needs for measuring the LOAC

The following emerged as being important for measuring carbon in the LOAC:

- Intercommunity meetings are helpful for community exchange on measurement protocols for in situ measurements.
- In order to derive Rrs(λ) data, adjacency effects and ice cover have been identified by the communities as a fundamental issue to address. Operational products are not useful unless they also contain per-pixel uncertainties.
- High frequency observations (e.g. via geostationary or constellation) are needed in these highly dynamic systems.
- Other ancillary data is needed, such as LIDAR, which can improve the Rrs(λ) retrieval and provide information about the vertical structure of the water column, and modeling approaches that provide integrated values along the vertical access and information about the physical environment and forcing parameters of a considered water pixel.

7.4.4. Recommendations

1. The community should develop an open-access database of POC and DOC for inland and coastal waters.

7.5. Breakout 5: Value of Ocean colour for the Benefit of Society: status and change in water quality and ecosystems

Chair: Merrie Beth Neely (merrie.neely@noaa.gov),
Co-Chairs: Veronica Lance (veronica.lance@noaa.gov) and Emily Smail (emily.smail@noaa.gov)

7.5.1. Introduction

How do we enhance the value of ocean colour to applications for the benefit of society? While the world's oceans are characterized by their relative inaccessibility, satellite observations provide both focused and synoptic views of this expansive realm. Though we are arguably data rich, a challenge still remains to ease the conceptualization and synthesis of data for the purposes of user accessibility and decision making. This session explored how to leverage new capabilities in technology and algorithm development, while simultaneously working to help provide end-users with actionable knowledge, not simply data. In the age of open science, advanced institutional capacity should be exploited to maximize data accessibility, increase visualization, and create tools to better help communities learn from and connect with data streams that impact their lives. The session aims to highlight stories of successes and failures in this endeavor, and establish priorities for increasing the widespread usability of information derived from ocean colour and associated synergistic measurements.

7.5.2. Session Summary

The session consisted of two 70-minute panel sessions aimed at increasing the science community's awareness of the barriers to using Earth observations for 1) global ocean users, and 2) water quality monitoring at the state and local level.

The first objective was met by an ocean ecosystem panel, moderated by Veronica Lance. The panel featured Juan Ignacio Gossn (EUMETSAT, Germany), Cara Wilson (NOAA Fisheries, USA), Maria Tzortziou (CUNY CREST, The City College of New York/NASA GSFC, USA), Shungu Garaba (University of Oldenburg, Germany), and Anthony Gidudu (Makerere University, Uganda). The panelists represented remote sensing algorithm developers as well as advanced satellite data users. The second was met by a panel, modered by Merrie Beth Neely, of local representatives: Megan Hunnicutt (Office of Agricultural Water Policy, FL Department of Agriculture and Consumer Services), Stacie Flood (South Florida Water Management District's Coastal Ecosystems Section), and Andrew Kamerosky (Applied Ecology, Inc consultant for Brevard County). These panelists represented state, regional and local government water quality users from Florida. Panelists from both sessions presented their current uses and

needs for earth observation information in their respective interest areas of biodiversity and water quality. Discussions reaffirmed that users need higher resolution data, and for coastal areas, require increased confidence in the data delivered in that region. Long-term time-series, gap-free data was also highlighted as a need. Many users were also interested in data from commercial sensors.
Some findings from the session included:

- A lack of knowledge of the events that focus on users of ocean colour data. For example, the Operational Satellite Oceanography Symposium (OSOS), which is a series of symposia to bring visibility to the uses of satellite data for operational oceanographic applications. It was co-created and co-developed by NOAA and EUMETSAT in 2017. The first symposium was held in the US in 2019; the second was entirely virtual in 2021; the 3rd (OSOS-3) was hosted by Korea Hydrographic and Oceanographic Agency in Busan in 2023, and 57% of presentations showed the use of ocean colour data. However, out of the ~50 people in the breakout session, only a handful had heard of the meeting.
- Users want tailored, end-user dashboards for satellite data discovery, leveraging interoperability standards that upstream data providers strive to supply (metadata, interoperability). However, agencies cannot realistically provide *all* of these to *everyone* (e.g., regional datasets and services; curated data acquisition portals for particular user groups which can exploit space agency use of common data formats; etc.)
- There is a widespread need by users of consistent Long-Term Time Series (LTTS) ocean colour data. Consistent (across sensors and missions) LTTS are needed in response to user requirements. IOCCG Report #6 on “data merging” in 2006 set down reasons and approaches. Progress by agencies to recognize the need has been slow and to resource the work, even slower.

7.5.3. Recommendations

Below are five recommendations that emerged from the breakout session, and one that emerged afterwards and was included in the session report:

1. IOCCG should formally endorse and helps to promote the Fourth International Operational Satellite Oceanography Symposium (OSOS-4) to be hosted by EUMETSAT in 2025 (details of this meeting are not yet available) and consider providing international travel support funding for Lower-Middle Income Country (LMIC) scientists to attend as was done for the OSOS-3. While this recommendation was included in the report from the session, IOCCG advertises community events but does not endorse specific events and the recommendation is not carried forward.
2. IOCCG should form a User Engagement Task Force or Working Group to oversee at least these three things to be accomplished in the next 2 to 3 years:
    a. In 2024, draft a list of suggested ocean colour-related topic areas suitable for public-private partnership engagement to bridge the service gaps between

space agencies and end-users. Communicate this list to space agencies for them to consider addressing when releasing calls for proposals.

   b. By 2025, create on the IOCCG website a *quick start guide* for ocean colour data access to complement and better highlight the existing resource links. Use this opportunity to update the existing resource link content.
   c. During 2024 through 2026, develop ocean colour data use-case stories that would enable the novice ocean colour data user to see the value in ocean colour data products for their research or application. Post these stories on the IOCCG website. Do at least 3 (representing different agencies and missions) in 2024 and add at least 4 more by 2026. (A total of 7 in 3 years, which should then be updated and rotated in future years to keep them relevant to the times. These are short, plain language intended to be demonstrative, ideally representative of a variety of sectors.

3. IOCCG should write an open letter to space agencies or publish a policy brief requesting agencies to acknowledge in their mid-to-long range planning that consistent (across sensors and missions) LTTS are needed in response to user requirements, and for agencies to fund efforts for development, production, performance evaluation, validation, monitoring, and reprocessing for operational LTTS data products in the next 2-7 years.
4. IOCCG should form an Ensemble of Models Task Force or Working Group to build community confidence and enhance user knowledge of the relative performance of ocean colour models. Building upon previous IOCCG reports, this might entail hosting an Assessment Workshop in 2024/25. Workshop participants would develop criteria and then identify models appropriate for inclusion. A "host" organization would be sought for routine ensemble processing. The Assessment workshop should result in a report or other documentation for the IOCCG community, but also be incorporated into user-actionable information on the IOCCG website. See GHRSST for example: GMPE GHRSST mean p ensemble https://ghrsst-pp.metoffice.gov.uk/ostia-website/gmpe-monitoring.html
5. The community, spearheaded by the IOCCG in collaboration with representative data users and social scientists, should develop plain language and recommended standards for reporting uncertainties for ocean colour. This is envisioned as a multi-year exercise with intermediate reporting at the next IOCS meeting. Depending on the application, different ocean colour data users need different levels of detail in uncertainty reporting, thus some customization is needed. IOCCG should start by reviewing recommendations in Chapter 7 of IOCCG Report #18, Uncertainties in Ocean Colour and participating work by other relevant groups (Analysis Ready Data; CEOS CARD4L, GEO AquaWatch, MBON, etc.) for relevance and gaps. The final deliverables could include publishing a recommended standards template. It should include members of the user community as well as ocean colour data providers - perhaps co-chairs from each. Here is one example publication on ways to communicate

scientific uncertainties (there are many others and others could be more relevant) https://www.pnas.org/doi/10.1073/pnas.1317504111.

6. In response to conversations during the session (and elsewhere) regarding the needs/uses for optical observations in waters with areas smaller than those covered by current sensors with the full suite of ocean colour bands, the moderators suggest that the IOCCG consider how to treat high resolution optical sensors for water applications (e.g., Sentinel-2 or commercial high-res platforms). The IOCCG Report #17 on Water Quality covers this topic extensively. Clearly, many of the scientists engaged in coastal and inland water use of optics are also members of the ocean colour community and are already producing work. Should, and if so how should, the IOCCG formally recognize this territory within its objectives and terms of reference documentation, (etc.)?

7.6. Breakout 6: Ocean Colour Satellite Sensor Calibration

Chair: Gerhard Meister (gerhard.meister-1@nasa.gov)

7.6.1. Introduction

This session was a meeting of the IOCCG Task Force on Ocean Colour Satellite Sensor Calibration (https://ioccg.org/group/calib-tf/), which is composed of calibration and characterization experts from the space agencies. The task force presents recent advances and challenges in the pre-launch and on-orbit calibration of ocean colour satellite sensors., and focuses on the delivery of highly accurate top-of-atmosphere radiance (or reflectance) products based on direct instrument calibrations. To note, the application of system vicarious gains or water-leaving radiance specific issues are not within the scope of the Task Force.

One of the main objectives of the session was the review of the results of the pre-launch calibration of the Ocean colour Instrument on the PACE mission, which is scheduled to launch in early 2024. The other main objective is calibration issues of current ocean colour satellite sensors such as GOCI-II, MODIS, OLCI, SGLI, and VIIRS. The third main objective of this session was the development of new ocean colour satellite sensors, such as A-OLCI Next Generation, and the associated instrument design and calibration challenges as well as discussions around the new TSIS solar irradiance spectrum.

7.6.2. Session Summary

The meeting started with an introduction by the chair and the search for a new co-chair of the task force. Bertrand Fougnie used to be a co-chair of the task force, but his main interests have shifted away from ocean color sensor calibration, so he stepped down. The current co-chairs are Ewa Kwiatkowska (EUMETSAT) and Gerhard Meister (NASA), the search for a third co-chair is ongoing.

Jack Xiong, in presenting on NOAA-21 reflective solar bands calibration and performance, found that the early mission solar diffuser degradation is similar for all three on-orbit VIIRS instruments, that RSB (reflective solar bands) gain change for NOAA-21 is similar to NOAA-20, and that the SWIR gain is degrading significantly for NOAA-21.

Regarding GOCI-II calibration for long term data stability, Myung-Sook Park indicated trend improvements from the solar diffuser derived gain adjustments.

Hiroshi Murakami indicated improved striping performance for SGLI, with a small bias change. Robert Frouin spoke on the cross-calibration of ocean color sensors using TOA radiances from geostationary sensors, and indicated that a new approach for cross-calibration (after vicarious calibration) shows excellent results for two MODIS instruments. There was a lively discussion about SGLI results.

Previous IOCS recommendations were reviewed by the group, and their status confirmed as follows:

- 2013.12.1 - Calibration teams from each of the current and future ocean-colour sensors are encouraged to join the international collaborative effort GSICS (Global Space-based Intercalibration System) to help intercalibrate TOA radiances for different low Earth orbit sensors. **(Ongoing)**
- 2015.09.1 - The *interpretation* of long-term trends in ocean color products should consider the calibration uncertainty in any assessment **(Partial)**
  This recommendation was assigned to the community, and the task force was unable to give any update on the status, and is it difficult to measure.
- 2017.04.10 - Promote consistency in pre- and post-launch sensor calibration across multiple missions and multiple space agencies to enable robust blending of data products from a constellation of satellites. **(Ongoing)**
- 2019.08.2 - Every mission should evaluate if for a newly launched sensor, a tandem flight is possible to evaluate calibration consistency **(Ongoing)**
- 2019.08.3 - Gain calibration trends should not contain discontinuities that are not clearly supported by calibration measurements **(Completed)**

7.6.3. Recommendations

The science community is starting to move away from the ATLAS-3 solar irradiance spectrum (Thuillier et al., 2004), and towards TSIS (Coddington et al., 2021). There is no consensus among task force participants, as some prefer to keep using ATLAS-3 (also referred to as Thuillier) for existing missions, while some are switching to TSIS

New recommendation:

1. all missions should clearly identify which solar irradiance spectrum they are using to produce their science products.

7.7. Breakout 7: Priority list of marine biodiversity metrics to observe from space

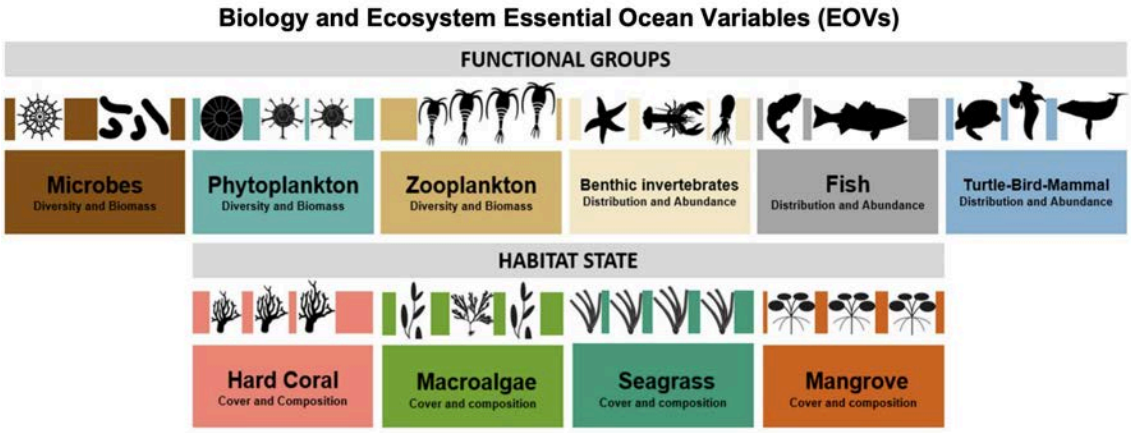
Chair: Victor, Martinez Vicente (vmv@pml.ac.uk)
Co-Chairs: Frank Muller-Karger (carib@usf.edu), Alice Soccodato (alice.soccodato@embrc.eu)

7.7.1. Introduction

Essential Ocean Variables (EOVs) are a fundamental framework to develop time series and maps of interoperable physical, biological and ecological observations. From these, Essential Biodiversity Variables (EBV) have been developed. EBV includes specific indicators for different levels of the ecosystem, and are useful to inform policy and advance biodiversity and ecosystem research. There is an expectation that EOVs and EBVs can serve as indicators to measure progress toward sustainable development and biological diversity targets of international agreements (i.e. the Global Biodiversity Framework (GBF) of the Convention on Biological Diversity, the Sustainable Development Goals, the UNFCCC). The UN Decade of Ocean Science for Sustainable Development (The Ocean Decade) is an opportunity to advance these observations. Marine Life 2030 is a Program of the Ocean Decade that helps highlight relevant indicator work. The aim of the workshop was to advance the use of remote sensing products to generate EOV and EBV products, and specifically to identify practical indicators to develop for national and international use.

7.7.2. Session Summary

The session began with an introduction of the common understanding of the definitions of EOV, essential climate variables (ECV), and EBV, and the movement towards indicators. Other presentations were on EBV class community composition - phytoplankton EOV (Asrtid Bracher); EBV class ecosystem structure - various EOVs (Maria Kavanaugh); species distribution models: Aquamaps (Gabriel Reygondeau); measurement and data of seagrass cover and composition as an EOV, including management standards (Heidi Dierssen); and linkages with models to produce status, trends, and forecast indicators (Camila Serra Pompei).



Many biology and ecology EOVs are now also ECVs adopted by the Global Climate Observing System (GCOS) (https://gcos.wmo.int/en/essential-climate-variables). Discussion and contributions on general EOV/EBVs are that they are the basis for common language to inform policy. They provide a framework to standardize observing (in situ, remote sensing) and to facilitate standardized and interoperable information management.

The current Committee on Earth Observation Satellites (CEOS) focus on remote sensing of biodiversity is largely terrestrial (see https://ceos.org/ourwork/other-ceos-activities/biodiversity/, and CEOS & UNFCCC Global Stocktake https://ceos.org/gst/). The IOCCG has the potential to expand the CEOS focus to include ocean biodiversity variables.

A padlet was created for this session, and the community was invited (and still is invited) to give feedback, as long as the padlet is still active https://padlet.com/martinezvicentev/break-out-workshop-priority-list-of-marine-biodiversity-metr-e2s1xi8bq06txz5m password: IOCS23.

7.7.3. Recommendations

The following recommendations emerged from the session:

1. The IOCCG should develop a biodiversity position paper for CEOS that focuses on remote sensing of ocean biodiversity over the next year, to expand the focus of CEOS biodiversity from terrestrial.
2. The community should summarise priorities (low hanging fruit) over the next year into a paper (derived from the IOCS session and relevant projects) for space agencies to support over the next 5 years.
3. Space agencies should support cross-agency work to engage with stakeholders to refine needs/requirements for essential biodiversity variables (EBV) and essential ocean variables (EOV).
4. Space agencies and the community need to ensure mission continuity and climate relevant datasets for biodiversity

7.8. Breakout 8: Achieving long-term consistency in cross-sensor ocean colour data products

Chair: Brian Barnes (USF)
Co-Chairs: Frédéric Mélin, Kelsey Bisson

7.8.1. Introduction

Detecting long-term trends in satellite observations, including those influenced by climate change, requires timescales typically much longer than that of an individual

sensor or sensor series. While long-lasting missions (> 20 years; e.g., MODIS) may offer some ability to address long-term science questions, dedicated calibration activities are required to achieve and maintain ocean colour radiometry (OCR) consistency, even for a single sensor. With MODIS slated for decommissioning, the duration of the longest continuing single-sensor OCR dataset will soon be halved (> 20 years for MODIS to > 10 years for VIIRS). Combining data from multiple missions is still required to address multi-decadal time scales and to benefit from the enhanced coverage afforded by several sensors.

Several current and future sensors will carry on the OCR legacy (e.g., OLCI on Sentinel-3A and -3B; VIIRS on SNPP, NOAA-20, and NOAA-21; OCI on PACE), but substantial effort is required to ensure continuity of the multi-sensor ocean colour record, and to reduce uncertainties when combining data across platforms. Numerous sensor-specific attributes (e.g., band placement, spatial resolution) and prevailing geometric characteristics (e.g., orbital elements, optical path geometries with consequences on BRDF correction) may individually or synergistically contribute to cross-sensor discrepancies that show non-random spatial and temporal variations. Consideration of these factors is required when merging data from disparate instrument series (e.g., MODIS/Aqua vs VIIRS/SNPP), as well as from sensors of the same series (e.g., MODIS/Aqua vs MODIS/Terra). Recently characterized seasonal biases in OCR datasets further complicate within- and across-sensor consistency. Additionally, higher resolution sensors (e.g., MSI on Sentinel-2A and -2B; OLI on Landsat-8 and -9) are increasingly becoming integral to monitoring of coastal and in-land aquatic systems and present unique intercalibration challenges. Consideration is required to optimally relate upcoming hyperspectral data to existing multi-spectral data records. When assessing cross-sensor consistency using co-located and coincident data from multiple sensors, tandem orbital phases provide the optimal conditions for determination of radiometric consistency, while intersecting orbits allow for more geometric-based continuity assessment. Cross-sensor continuity can also be investigated by comparing multiple satellite sensors to the same in situ dataset(s). In either case, such assessments require accounting for uncertainties of the satellite products (and in situ data).

7.8.2. Session Summary

The session began with an introduction to continuity and merging of datasets by the session chair, Brian Barnes. Other session talks included examples of satellite/in situ matchups in framing continuity (Kelsey Bisson), continuity in the context of uncertainties (Frédéric Mélin), seasonal biases in ocean colour radiometry (OCR, Amir Ibrahim), merging series datasets for climate investigation (Shubha Sathyendranath), and a perspective on coastal zones and freshwater (Nima Pahlevan)

Participants within the breakout workshop highlighted the need to spotlight ongoing work that could help to remediate existing seasonal biases. Areas in the high latitudes, with high cloud cover, and within coastal regions have less consistency across the data. Glint

contributes to a sampling bias in system vicarious calibration (SVC). Some suggested that issues in radiative transfer components in models affect data consistency.

Some of the potential solutions discussed to contribute to improving consistency included coupling geostationary and polar orbiting data to quantify solar geometry dependence; applying trend detection to parameters beyond chlorophyll (phenology, colour, composition); and using consistent atmospheric correction algorithm, flagging, etc. when comparing data from different sensors. Participants also discussed the need for innovation, and longer-term, cheap, stable mission goals that can be applied across missions. Possibly there needs to be broader exposure of adjacent and existing efforts that could assist with ocean data consistency, such as TRUTHS (Traceable Radiometry Underpinning Terrestrial-and Helio-Studies), a joint mission between ESA and the UK Space Agency which aims to establish SI-traceable spectrally resolved measurements and in-flight calibration of Earth observation satellites.

7.8.3. Recommendations

The following recommendations emerged from the breakout workshop:

1. The community needs to conduct more research to identify all sources of discrepancies in merged datasets (beyond time and space, including geometry and other factors) and to quantify and correct them.
2. The community needs to improve description of continuity metrics including reporting of possible extremes (tails), possibly using Probability Density Functions.
3. Space agencies and distribution services (in collaboration with the ocean color and metrology communities) need to prioritize calculating and distributing uncertainties associated with all products (pixel-based and composite), and including propagation through AC and algorithms following metrological practices.
4. The community and IOCCG need to consider revising/updating the 2006 IOCCG report on data merging.
5. Space agencies should advocate for mission design to ensure backwards compatibility to improve confidence in derived trends and ensure overlap between missions.

7.9. Breakout 9: Lidar applications for ocean colour

Chair: Cédric Jamet (cedric.jamet@univ-littoral.fr)
Co-Chairs: Davide Dionisi (davide.dionisi@artov.ismar.cnr.it), Peng Chen (chenp@sio.org.cn)

7.9.1. Introduction

Lidar (Light detection and ranging) is an active remote sensing technique. Active remote sensing of global ocean plankton properties presents a renewed opportunity for overcoming some of the major limitations of passive ocean colour data that have challenged the community for decades. Passive remote sensing of ocean colour observations has revolutionized our understanding of global plankton ecosystems and provide multi-spectral

retrievals at many advantages: multiple wavelength bands, good spatial resolution (300-1000 meters) and on high repetitive cycles (~2 days). However, the ocean colour signal is limited to the very near surface layer, provides no information on plankton vertical structure, is extremely limited in polar regions, suffers from cloud cover and absorbing aerosols, and provides no information on day-night changes in plankton properties. Active remote sensing can address some of these challenges and would provide an exceptional complement to passive observations. Lidar can provide ocean retrievals under thin clouds, between holes in broken clouds, and throughout the polar annual cycle. Lidar measurements can also retrieve plankton vertical structure and information on day-night changes. In the last decade, lidar systems applied to ocean colour have reached maturity thanks to field deployments of multiple airborne and in-situ sensors and to recent studies using lidar measurements from atmospheric satellite missions to obtain significant scientific results in the ocean colour field. These advances make the transition to an ocean-optimized satellite system foreseeable in the next generation of missions.

7.9.2. Session Summary

Approximately 40 participants attended the breakout workshop.

The first part of the session consisted in four short presentations: the current international initiatives and collaborations in lidar (Cédric Jamet); looking at ocean colour through spaceborne lidar measurements: COLOR and CALIGOLA projects (Davide Dionisi); an overview of the ocean capabilities of the space-borne lidars: CALIOP and ATLAS (Yongxiang Hu), and an overview of the in-situ oceanic profiling lidar (Peng Chen/Dong Liu).

The second part of the session focused on discussion, and the community's requirements, including a short survey. While all participants were familiar with lidar applications for ocean colour, only a few had actually explored and utilized lidar data. Participants expressed keen interest in employing lidar for diverse applications, including vertical structure of the ocean, primary production, etc. Despite this strong interest, there is a notable gap in knowledge and training in the ocean colour community regarding the use of lidar.

7.9.3. Recommendations

Discussions were divided into topics—data access, simulations, training, and future space-borne lidar. The emerging recommendations followed this division:

Regarding data and software:

1. The community should to develop coupled atmosphere-ocean simulators for lidar propagation (Hydrolight-like) freely available
2. The community should make open-source tools or codes for processing L1 and L2 CALIOP and ATLAS data freely available

3. Space agencies need to make daily Ocean L1 and L2 CALIOP and ATLAS archives available, with a portal to easily view and download the data (such as oceancolor.gsfc.nasa.gov) as soon as possible.
4. The community needs to share current and past in-situ (shipborne, airborne, fixed platforms) lidar measurements

Regarding in-situ lidar development

5. Space agencies should fund, and the community should develop, in-situ oceanic profiling lidar (measurements up to the euphotic depth, Instruments to measure the back-scattering coefficient at 180°, Multi-wavelength : 355, 470, 532, 560 nm, Fluorescence profiles, Vertical resolution: ≤1 m, Temperature profiles)
6. The community should develop a ground-based network of profiling sensors to validate future ocean spaceborne lidar and passive OC missions
7. The community needs to have better coordination with the atmospheric community for lidar development, scientific objectives and field campaigns

Regarding training in lidar

8. The community should ensure better training on lidar, e.g. session at conferences (Ocean Optics), lectures at the IOCCG Lectures Series and Maine Summer School on fundamentals of lidar: principles, data processing, practical exercises to process the lidar data, courses on the components of a lidar: optics, electronics.

Regarding space-borne oceanic profiling lidar

9. There needs to be an endorsement from the OC Community (agencies, IOCCG, scientists, etc.) on space-borne oceanic profiling lidar (ocean capabilities of CALIGOLA space mission)

8. Community Town Hall

On the final day of the meeting, a community town hall session was held, which was a Q&A with all the agency representatives, chaired by Shubha Sathyendranath. Representatives present were Laura Lorenzoni (NASA), Jongkuk Choi (KIOST), Hiroshi Murakami (JAXA), Menghua Wang (NOAA), Juan Ignacio Gossn (EUMETSAT), joined virtually by Geneviève Gariépy (CSA), Marie-Helene Rio (ESA) and Ewa Kwiatkowska (EUMETSAT).

Cara started by asking the representatives, after hearing all the information during the days of the IOCS, what they thought they could take back to their agencies, and if they had any ideas to share. Laura started by expressing her gratitude to those breakout session chairs and participants that put smart recommendations on their slides, as she was actively engaging with NASA representatives on how to action some of these recommendations. Any recommendations that were stated as actionable will be followed up by NASA. She indicated

that the more expansive summaries of the breakout workshops were also important to give full context, and she awaits those. Laura also requested from the community that as they solidify the discussions that occurred over the four days of the IOCS, that they feel free to reach out directly to the space agency representatives present or the IOCCG Project Office to record their feedback so that they can be actioned if appropriate. She requested that the community continue to challenge the agencies to provide the information that would help them most.

Jongkuk indicated that KIOST is not a space agency, but a research institute and their mission is to research oceans using the remote sensing technique. They develop algorithms and help with the calibration and validation, so their mission is different from agencies such as JAXA and NASA, but they do their best to contribute to the ocean colour community with their research.

Hiroshi (JAXA) expressed his gratitude for the IOCS meeting, especially for the newer breakout sessions on topics like marine litter and debris. Though the ocean colour community is more mature, there are also new missions and capabilities, so the continued discussion is important for future direction planning and support to the space agencies.

Menghua indicated that he appreciated the feedback from the meeting, and especially from the breakout workshops. He indicated that NOAA launches satellites and provides data, but that their role is different from NASA. NOAA's focus is tied to the users, to provide data to the user community and so user feedback is very important. He mentioned some of the missions and how NOAA interfaces with the needs of the missions, and thanked the participants for their feedback.

Juan indicated that he took notes on things to improve for EUMETSAT. This included clarity on the new ways that they disseminate data; feedback that Europe does not have plans for geostationary missions but the problems associated with getting by-in from the member states for a high latitude geostationary mission; and feedback on issues with CCI data.

Marie-Helene indicated that although she was unable to attend the event and hear the discussions, she can ensure that ESA will look at the recommendations emerging from the meeting. It is their priority to try to tackle any applicable recommendations. Next week, there is a one-week event organized for all ocean science and other topics, and many of those topics rely on ocean colour observations to be developed and to advance our science. A few of the IOCS participants will be there and she is sure that some of the discussions and recommendations will already be relayed within the event. Additionally, she also looks forward to the written reports that will be issued.

Geneviève (CSA) similarly indicated that as she was unable to attend, she looks forward to the discussion reports and the recommendations emerging from the meeting to see if any are

applicable to the CSA. She will be discussing these with her colleagues within the government of Canada.

Ewa expressed her regret that she was unable to be at the meeting in-person, and that Juan has wonderfully been a good representative for EUMETSAT. Ewa added that EUMETSAT, like NOAA, is an operational space agency and their major aim is to get the data from satellites and provide the best products to the community. Although there is more improvement to be made with algorithm development, the discussions at the meeting on validation, coordination across the agencies, tools etc, are very helpful. She is happy to hear from many sources that Sentinel 3 OLCI data is widely used for various operational applications, and they aim to improve the products and applications for users. EUMETSAT is now in the process of defining the next generation of Copernicus missions, and community feedback is critical for defining the spatial and spectral resolutions etc. She thanked the participants and looks forward to reading strong recommendations that can be used to carry the missions forward. Sometimes it is a long process to implement user needs but having recommendations on paper from the community makes it much easier to carry them forward.

Frank Muller Karger indicated that he was impressed that so many of the space agencies were represented at the meeting. He asked about the commitment to understand and manage our own activities as part of life on the planet, and recommended that we all have life as the core of our research. Menghua indicated that he believed all the agencies have this goal. For NOAA, the data provided is for this purpose, for users to improve life, and that perhaps agencies could communicate this point through the IOCCG website. Laura indicated that in the Earth Science Division at NASA there is a desire to highlight how EO improves life—keeping ecosystems framed within that interest—but a lot of that focus then goes to land. So she turned the question back to the community. The agencies are indeed focused on life on Earth, but then sometimes that turns around to be life where humans live, which puts the focus on land and atmosphere, so as a community we need to consistently communicate the need for the focus on the oceans as it impacts life. Shubha indicated that every 3 years ESA hosts a large symposium called the *Living Planet Symposium*, so the focus is very much on life on Earth. And when it comes to ocean satellite observations, the living component of the entire symposium is ocean colour, so we are already a key component of that scene. Marie Helene agreed that this is a key topic at the core of ESA initiatives, and explained some of the policies and activities that focus on ocean health.

Susanne Craig apologized for the US-centric nature of her input. She indicated that the ocean colour community is keen to have good representation at the next US Decade Survey (an instrument used by the US government to indicate where funding will be allocated during the next decade). She asked how the ocean colour community can participate in the next Decadal Survey so that we can recommend core observables that pertain to the health of the ocean and the impact of the ocean in climate change. Laura indicated that the community plays a critical role, as it is the community and their input that determines the outcome of the

survey. The needs have to be communicated from the ground-up (grass roots) and so the citizens need to put pressure on the agencies to move things forward. Menghua agreed and reiterated the role of the users, and the need to communicate their needs in response to the survey. Laura also indicated that the power of inter-agency communication should not be underestimated, and that meetings like the IOCS facilitate exactly the type of feedback that is required. She again thanked the participants for their input thus far. Cara indicated that the main input for the Decade Survey are white papers, and that IOCCG could help to coordinate the input so that all aspects of ocean colour observations are included as responses to the survey.

Veronica Lance requested that maybe there could be more interaction between the agencies to have good overlaps of time, resolution, parameters, measurements, calibration (etc) so that there is a longer time series of the data for users. She indicated that in user surveys, long-term time series is the number one request that users have. Menghua indicated that IOCCG currently has various task forces that are working to address this need, handling topics of cross calibration and agency consistency. The topic is very technical, but is currently on-going. Ewa agreed and indicated that it is an important topic. She said that the European Copernicus program focuses on continuity and stability, and making sure that missions will continue into the future. So already some of these continuity recommendations are being implemented by the agencies, who are working to understand how we can ensure the stability and consistency of data across the missions. She thanked all the agencies involved in this collaboration.

Chuanmin Hu expressed amazement at the full spectrum of advances in technology, science, and applications that has been discussed in the past week when compared to 15 years prior. The future is even more amazing (GLIMR, GOCI-III, GEO-XO, PACE, etc), but it seemed as if this was not enough. With an emphasis on societal value, we need meter resolution data, so the commercial sector needs to be involved. NASA has done an excellent job to provide free data to users. He asked the agencies if they have a plan to initiate, continue, or expand collaborations with industry to observe individual lakes, canals, coastal areas, etc., to put more societal value in ocean colour? Ewa indicated that EUMETSAT is pursuing various activities associated with commercial data, though not yet with ocean colour. The European Commission is funding a number of commercial companies to provide Earth observation data into the portfolio. This data includes hyperspectral imagery. There is a responsibility to ensure that commercial data has high enough quality for ocean colour applications, but yes, there is a growing trend in the public sector to include commercial companies, across the various space agencies. Menghua indicated that NOAA management emphasizes commercial companies using their data, and there is a mechanism for commercial companies to propose new methods and instrumentation for data acquisition. Jongkuk indicated that for some applications the spatial resolution of GOCI is not enough, so colleagues have already made an effort to launch low orbit systems with various sensors (e.g. microwave, lidar, etc.), so there is already collaboration with industry/commercial companies in Korea. Hiroshi indicated that

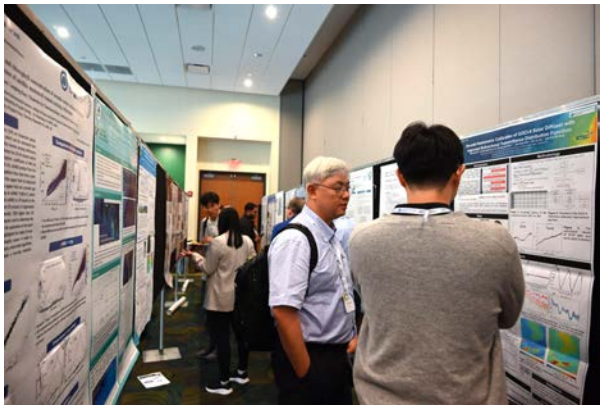
JAXA also does collaborations with industry, through a consortium that comes together for planning and executing new missions. Marie-Helene indicated that at the management level there are connections with new space being investigated, and that commercial satellites are an important player. Laura indicated that NASA and other agencies consistently get requests from higher spatial, spectral, and temporal resolution, and commercial data is critical to satisfy this need. We need a tiered approach to develop platforms with good data that are calibrated and robust enough to do good science at the level that users require. The agencies only have a mandate within a certain level of this tiered system, so they depend on industry and research scientists to help with technology to fill the gaps. She encouraged the community to think big, and think broad.

Shubha thanked the participants for their dynamic input and discussions, and indicated that possibly we could dedicate more time to the town hall discussion in future meetings.

9. Poster Sessions

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

A total of 167 posters were presented, grouped into four main themes: new and emerging technology, examining ecosystem function and change, societal value and impacts of ocean colour, and other research in ocean colour science. All poster abstracts are available in the *Book of Poster Abstracts* available on the IOCS-2023 meeting website at: https://iocs.ioccg.org/wp-content/uploads/2023/11/iocs-2023-book-of-poster-abstracts.pdf. All poster lightning slides are accessible on the IOCS-2023 meeting presentations page https://iocs.ioccg.org/iocs-2023-meeting/presentations/



10. Social Programmes

A series of social activities were planned in conjunction with the IOCS-2023 meeting.

10.1. IceBreaker Reception at the USF Student Center

An icebreaker reception was hosted at the meeting venue at the end of the first day, Tuesday 14 November, sponsored by the IOCCG. The event was held in the pre-function area of the USF Student Center, and commenced promptly at the close of the meeting, which enabled almost all participants to attend. Live music for the reception was provided by a local group, Flamenco Symphony. A selection of hors d'oeuvres were served, and a cocktail ticket provided for each attendee.

10.2. The Ocean on Canvas at The Studio@620

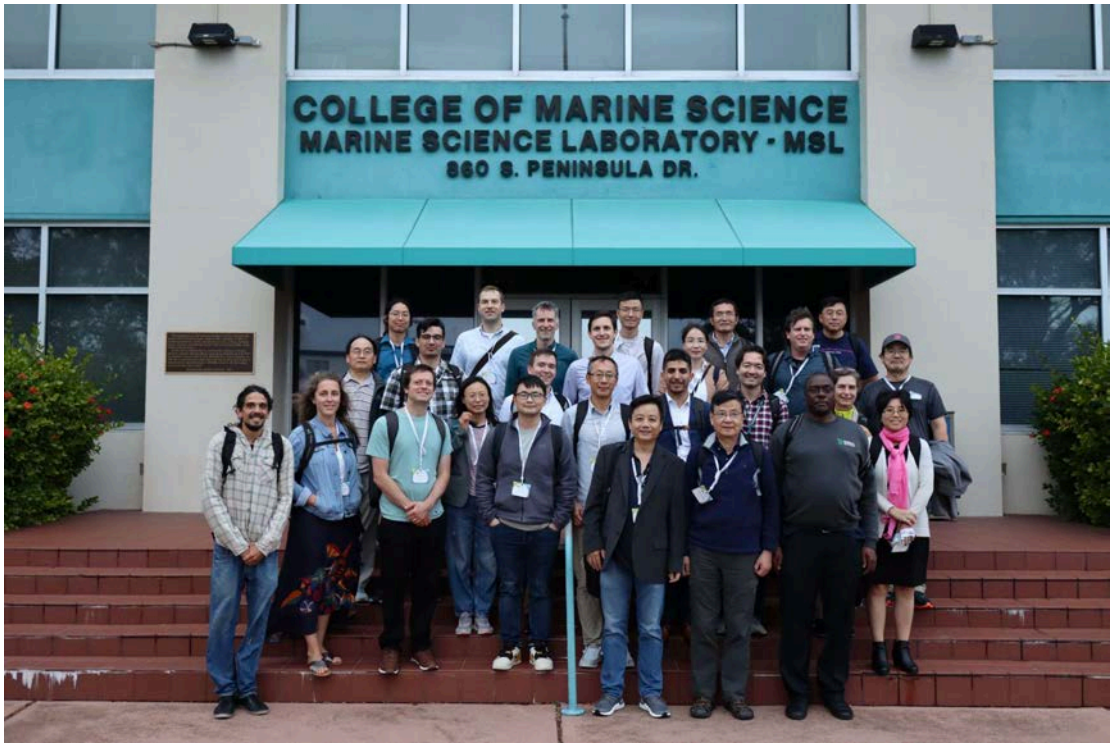
On the following evenings, Wednesday 15 and Thursday 16 November, from 5:30 - 9pm each evening, the IOCCG and NASA hosted a free public exhibition, titled *The Ocean on Canvas*. The event was held at The Studio@620, 620 1st Ave S, St. Petersburg, FL 33701, and featured a captivating collection of satellite imagery contributed by space agencies of the surface of the ocean. The event also featured dynamic photographic art of floating debris, created in collaboration with NASA by Oskar Landi. Light refreshments were provided on both evenings of the event, and drinks were available with a donation to the hosting studio.

10.3. Marine Science Happy Hour at The Hub St. Pete

A Marine Science Happy hour was organized by GEO AquaWatch on the evening of Thursday 16 November, and was sponsored by Sea-Bird Scientific. It was free for all IOCS participants. The happy hour was held at the Maritime and Defense Technology Hub in the St. Pete Innovation District. Complimentary drinks were included. It provided a time to relax and connect with colleagues after the day's proceedings.

10.4. USF Campus Tour

Following one of the day's events, Chuanmin Hu led a tour of the College of Marine Science and his lab, as well as other sites within campus, including the Knight Oceanographic Research Center.



Some of the IOCS-2023 participants at the Knight Oceanographic Research Center (top) and the College of Marine Science (bottom) on the USF Campus.