



**International Ocean Colour Science
Meeting 2019**

Advancing Global
Ocean Colour
Observations

**Proceedings of the
2019 International Ocean Colour Science
Meeting (IOCS-2019)**

Haeundae Grand Hotel, Busan, South Korea

9 - 12 April 2019

Convened by the International Ocean Colour Coordinating Group (IOCCG)

Sponsored by KIOST, NASA, EUMETSAT and Airbus



AIRBUS



Venetia Stuart, IOCCG Scientific Coordinator (vstuart@ioccg.org)
Cara Wilson, IOCCG Chair (cara.wilson@noaa.gov)

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1. Introduction

1.1 Background

The 2019 International Ocean Colour Science (IOCS-2019) meeting took place from 9 – 12 April 2019 in Busan, South Korea, convened by the International Ocean Colour Coordinating Group ([IOCCG](https://iocs.ioccg.org/)) in partnership with, and thanks to sponsorship from, the Korea Institute of Ocean Science & Technology (KIOST), NASA, EUMETSAT and Airbus. IOCCG gratefully acknowledges the excellent support provided by KIOST and their staff in organizing and hosting this meeting in Busan, as well as the support from all the other meeting sponsors. The Scientific Planning Committee is thanked for all their hard work in helping to structure the programme. IOCS-2019 was preceded by the NASA Ocean Color Research Team (OCRT) meeting as well as three training events: a Copernicus marine data stream training course, a SeaDAS training course and the SatCO2 training. See the meeting website at: <https://iocs.ioccg.org/> for further details on these events

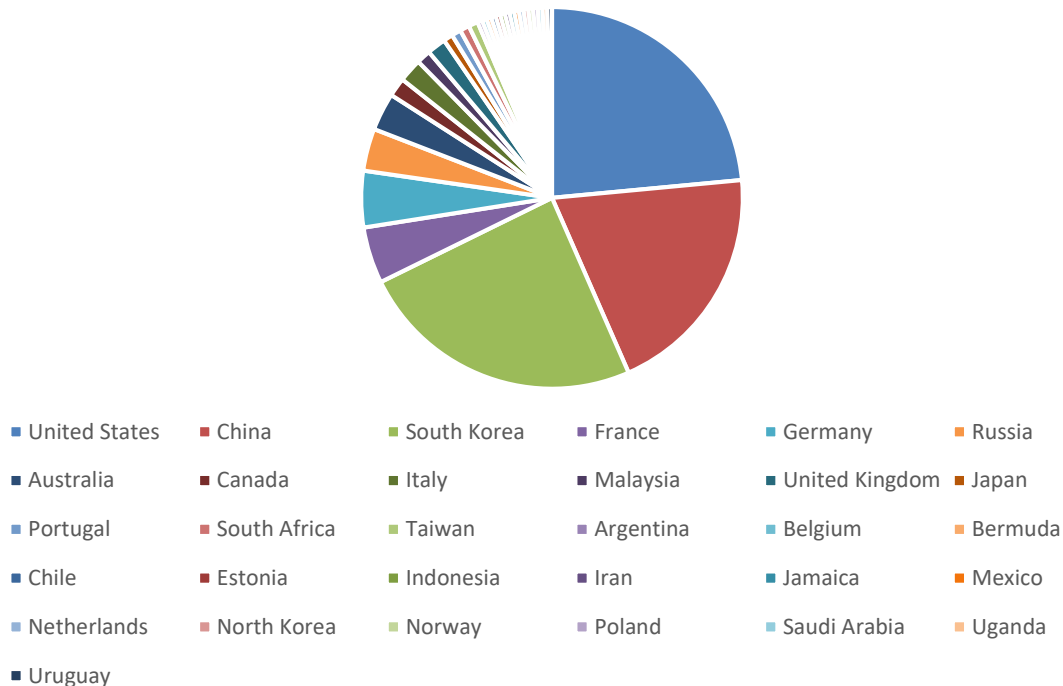
The overarching theme for IOCS-2019 was "*Fostering International Collaboration in Multi-Scale Ocean Colour Science and Applications*" to encourage exchange between the ocean colour research community and international space agencies to build and strengthen the voice of the global user community for ocean colour science and applications. Discussions from the breakout workshops identified advances and challenges in ocean colour remote sensing and the feedback from these sessions and the Town Hall will help the IOCCG in its oversight role with respect to high-level discussions with space agencies.

1.2 Participants

Over 250 researchers from 31 different countries participated in the four-day meeting, including ocean colour research scientists and students from around the world, as well as representatives from all the major space agencies with an interest in ocean-colour radiometry (CONAE, CSA, ESA, EUMETSAT, ISRO, JAXA, KIOST, NASA, NOAA 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. 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.

IOCS-2019 Participant Countries



1.3 IOCS-2019 Meeting Programme

The IOCS-2019 programme included eight invited keynote lectures, several agency talks as well as a special session dedicated to ocean colour remote sensing in Asian waters. Nine parallel breakout workshops (3 sessions of 3 workshops) complemented the plenary sessions allowing participants to discuss current critical challenges in ocean colour science and applications, and provide community feedback to the agencies and to the IOCCG. In addition, four poster sessions were held, consisting of two interactive poster viewing sessions and two very popular “poster lightening” sessions where all poster presenters could share information with the audience quickly and efficiently through short (1 minute) oral presentations about their research. The meeting concluded with a Q & A session where the ocean colour community could directly address space agency representatives. After the first daily session, participants were invited to meet informally at an ice breaker event on Tuesday evening, sponsored by KIOST and Airbus. Pierre Coste from Airbus gave an interesting talk on GOCI-II development, followed by a fascinating performance by the Yulparan ensemble playing traditional Korean instruments. Full details of the meeting programme can be viewed [here](https://iocs.ioccg.org/iocs-2019-meeting/). Presentations from all plenary sessions as well as breakout workshops can be viewed at <https://iocs.ioccg.org/iocs-2019-meeting/>, and all poster abstracts can be viewed at: <https://iocs.ioccg.org/wp-content/uploads/2019/03/poster-abstract-iocs-2019.pdf>.

1.4 Opening Session

Cara Wilson (IOCCG Chair) opened the meeting and warmly welcomed participants to Busan, South Korea. She thanked KIOST for doing such a fabulous job in hosting the meeting and thanked the other meeting sponsors for their support (NASA, EUMETSAT and Airbus). Next, the President of KIOST, Dr. Woong-Sea Kim, welcomed all participants and chairs to the meeting and thanked the Organising Committee for all their hard work. KIOST is a state-run institution that strives to develop cutting-edge scientific technology to acquire new knowledge about the ocean. KIOST Headquarters recently moved to Busan Metropolitan City. They have a well established research division conducting research on ocean resources and related applications as well as marine environment and climate research. The Korea Ocean Satellite Center (KOSC) is responsible for the development of technology for the Geostationary Ocean Color Imager (GOCI) and carries out research on the many applications of GOCI data, as well as providing support for the development of ocean satellite systems. KIOST has a fleet of cutting-edge marine research vessels to conduct research and validation studies.



Cara Wilson provided a brief overview of the IOCCG and the IOCS meetings. Part of the mandate of the IOCCG is to provide a common voice for the ocean colour user community, which is the motivation behind the International Ocean Colour Science (IOCS) meetings. The IOCCG has established several Scientific Working Groups which investigate various aspects of ocean-colour technology and applications, and publish an IOCCG report on the topic (17 IOCCG Reports published to date, five current working groups in various stages of deliberation). The new IOCCG Protocol Series provides updated versions of the NASA Ocean Optics Protocols to encourage broad international acceptance (two protocols published, several more in early writing stages). IOCS meetings help to promote international linkages amongst different communities and provide a forum for discussion on various topics to come up with recommendations and advice for the IOCCG, the community and the space agencies. The relationship between various IOCS breakout workshops from past IOCS meetings and IOCCG activities was reviewed, highlighted the fact that many have resulted in IOCCG reports or protocols. Many of the recommendations from the breakout workshops have also been addressed by the agencies resulting in new applications and/or processing capabilities. It was anticipated that the key recommendations for each of the breakout groups at this IOCS-2019 meeting will provide direction for IOCCG activities over the next few years and possibly feed into agency action.

The meeting programme incorporated reports from international space agencies on the status of their ocean-colour programmes, as well as a special session on “Emerging Applications and Science in Asian Waters”, which included two keynote talks plus presentations on various ocean colour activities in Asian waters. A brief summary of these presentations is given below.

2. Emerging Applications and Science in Asian Waters

2.1 Keynote 1: Young-Je Park (KIOST)

Young-Je Park is a Principal Research Scientist at the Korean Institute of Ocean Science and Technology (KIOST), Busan, South Korea. He received his Ph.D. degree in Physics from the Korea Advanced Institute of Science and Technology (KAIST) for his dissertation on a Lidar system for detection of atmospheric trace gases. Since 1998 when he joined EORC of JAXA as a member of ADEOS-II/GLI algorithm integration team, ocean color remote sensing became his primary research area. His work experience covers validation, algorithm development and applications for ocean color satellite data. He has worked on validation and applications of MERIS products in the North Sea and adjacent seas at the Royal Belgian Institute for Natural Sciences (RBINS), on applications of MODIS imagery to coastal waters, and on high resolution imagery such as QuickBird for mapping shallow waters at CSIRO (Australia). Since he joined KIOST in 2011, his main research activities are related to the Geostationary Ocean Color Imager (GOCI), an ocean color instrument operated on a geostationary orbit providing hourly images during daytime around north-east Asian seas around Korea. He is the PI of GOCI application projects that aim at exploitation of GOCI images for tackling environmental issues around Korean seas. He was also involved in development of the follow-on satellite instrument; GOCI-II, planned to be launched in early 2020, and is leading a project to build a ground system for operation of GOCI-II. He has been involved in international activities, serving as chair of the local organizing



committee of PORSEC (Pan Ocean Remote Sensing Conference) 2018, a member of IOCCG Executive Committee and a member of the scientific program committee for IOCS-2019.

Young-Je Park delivered a keynote talk entitled “Looking back GOCI experience towards the upcoming GOCI-II period and beyond”. The GOCI instrument has been in space since July 2010 and is still delivering good-quality images despite the fact that it is already two years beyond the design lifetime. The GOCI-II successor has been equipped on the GK-2B satellite, and is planned for launch in 2020. It is timely to look back at lessons from the GOCI experience for the new GOCI-II sensor and beyond. GOCI's eight images a day opened up new opportunities for the ocean colour remote sensing. However, GOCI images showed unexpected radiometric artifacts near the bottom of a slot due to stray light intrusion. A baffle was subsequently introduced in the GOCI-II sensor to minimize stray light effects.

Numerous scientific achievements have been published using GOCI data. In particular, diurnal variability was investigated in many coastal or inland water processes including tidal effects in turbid coastal waters, harmful algal blooms in East/Japan Sea and cyanobacteria blooms in Taihu lake. Studies are still underway to capture the weaker signal of diurnal variability in open ocean processes. Also, sub-mesoscale turbulent characteristics have been examined with hourly GOCI chlorophyll data over the East/Japan Sea. On the other hand, practical utilization of GOCI data by providing satellite-based information on various marine and atmospheric issues was the main driver for GOCI development and operation. Those issues include harmful algal blooms, floating macroalgae blooms, low salinity water mass, coastal water quality, oil spill, sea ice, marine fog and airborne fine particles. A research project has just been launched to strengthen practical utilization of satellite imagery by implementing state-of-art technology into a user-oriented data processing system. High spatial anomaly of the red-edge reflectance for floating algae patches has been used to produce a map of floating *Sargassum honeri* blooms in the East China Sea. The spatial anomaly technique with another band combination was tested to detect large-scale ocean debris after the 2011 East Japan tsunami and to detect oil emulsion after the 2011 Bohai Sea oil rig accident, which shows promising results worth investigating for further development. GOCI is one of best sensors for monitoring coastal waters of the northeast Asia. However, higher spatial resolution and more spectral channels are required to deal with complexity of coastal waters. GOCI-II meets some of these demands but is far from ideal. What should be the design of the next sensor after GOCI-II?

2.2 ISRO (Indian Space Research Organisation)

Prakash Chauhan gave a remote presentation on “Ocean Colour Activities in India”. ISRO launched the OCEANSAT-2 satellite carrying the Ocean Colour Monitor(OCM) in 2009. OCM-2 continues to provide quality data even after ten years of operation. OCM data is used operationally to assess marine living resources, primary productivity, algal bloom detection (e.g., floating *Trichodesmium*) and bio-physical coupling studies. Research on river water quality and floating *Sargassum* has been carried out using AVIRIS data and optically active in-water constituents have been investigated off the Mumbai coast using CARTO-2S data. An overview of the new Oceansat-3 satellite, to be launched in early 2020, was also presented.

2.3 JAXA (Japan Aerospace Exploration Agency)

Hiroshi Murakami (Earth Observation Research Center, JAXA) provided an update on the Global Change Observation Mission for Climate (GCOM-C) which carries Second-generation Global Imager (SGLI). The satellite was launched on 23 Dec. 2017 in sun-synchronous orbit at descending local time of 10:30AM. SGLI has a spatial resolution of 250 m to 1000 m, 1150-1400 km swath, 19 bands from near-UV (380 nm) to thermal infrared (TIR) (12 μ m) wavelengths including red and near infrared polarization channels. The SGLI near-UV and polarization bands are expected to improve the aerosol estimation. GCOM-C data including the ocean colour products have been evaluated by *in situ* measurements and other satellite data, and released to the public since 20 December 2018. Vicarious calibration was conducted using MOBY data provided by NOAA. Aeronet-OC data were also used for the confirmation of the vicarious calibration and the aerosol models in the atmospheric correction process. In the first year of GCOM-C/SGLI operations, it was demonstrated that 250-m resolution observations in coastal areas could be used for detection of red tides in the Seto-inland Sea in Japan, floating algae in the East China Sea, river discharge after the heavy rains, Okhotsk sea ice, and so on. Further quantitative applications need more knowledge about the relationship between coastal phenomena and optical characteristics, which will be investigated through collaboration with *in situ* monitoring research institutes e.g., local fishery and environmental institutes.

2.4 Second Institute of Oceanography, State Oceanic Administration (SIO/SOA, China)

Zhihua Mao provided an update of the Chinese ocean colour satellite mission, HY-1C, and derived ocean colour products. China launched its first ocean colour satellite, HY-1A, on 15 May 2002. It was an experimental mission and was successfully operated for about two years. The second ocean colour satellite, HY-1B, was launched on 11 April 2007, while the new HY-1C satellite was launched in September, 2018.. All these missions carry the Chinese Ocean Color and Temperature Scanner (COCTS) and the Coastal Zone Imager (CZI). The status of the missions was presented, together with an introduction to the atmospheric correction algorithm for HY-1C data processing system and validation of the data products.

2.5 KIOST (Korea Institute of Ocean Science & Technology)

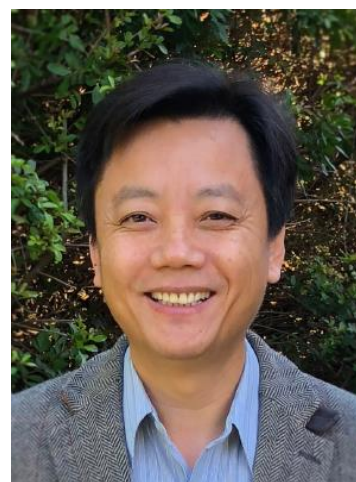
Joo-Hyung Ryu presented the KIOST agency report. The Korea Ocean Research and Development Institute (KORDI) was established in 1973 as the base for ocean science and research in Korea, and it was later re-launched as KIOST, an independent research organization. KIOST's headquarters were moved from Ansan to a new facility located in Busan. At its new Headquarters in Busan, KIOST will be reborn as a global center of marine science and technology. The Korea Ocean Satellite Center (KOSC) is the main operating institute of GOCI. It provides 13 different oceanic environment products from GOCI, 8 times per day, to the related organizations, universities, and other users. KIOST effectively supports the related organizations by providing services for the operational application of GOCI data on various national issues. The official GOCI/COMS operational lifetime is 7 years from the beginning of GOCI normal on-orbit operation and

data distribution service (April 1, 2011). GOCI/COMS operational lifetime will be extended until March 2021 so that GOCI and GOCI-II can acquire data simultaneously for about one year.

GOCI-II, the second Korean ocean colour sensor in geostationary orbit, is scheduled for launch in March 2020. GOCI-II ground segment (G2GS) is under development as a new ground segment system for the GOCI-II. G2GS provides a system operation environment (SOE) and data service environment (DSE) intended for system operators and data users. SOE should generate ocean colour products automatically after receiving GOCI-II sensor data. It has external interfaces for GOCI-II operation, telemetry and re-distribution by satellite. All information generated by G2GS SOE, e.g., GOCI-II Level 1B and GOCI-II Level 2 data, is stored and distributed to users by DSE. GOCI-II data will be uploaded as slot-level NetCDF4 files on DSE storage. When users define those regions of interest, DSE will make new download links for each ROI. Also, the GOCI toolbox (GTBX), which is the GOCI-II data analysis tool similar to the GOCI data processing system (GDPS) for GOCI, will be distributed as a plug-in program on the SNAP framework. GTBX can access GOCI-II data in the DSE data repository. After in-orbit tests of GOCI-II, it is anticipated that various data services will be provided through GOCI-II DSE.

2.6 Keynote 2: Chuanmin Hu (University of South Florida)

Chuanmin Hu received a BS degree in physics from the University of Science and Technology of China in 1989 and a PhD degree in physics (environmental optics) from the University of Miami (Florida, USA) in 1997. He is currently a professor of optical oceanography at the University of South Florida (USA), who also directs the Optical Oceanography Lab. He uses laboratory, field, and remote sensing techniques to study marine algal blooms (harmful and non-harmful, macroalgae and microalgae), oil spills, coastal and inland water quality, and global changes. His expertise is in the development of remote sensing algorithms and data products as well as application of these data products to address earth science questions. He has authored and co-authored >250 refereed articles, many of which have been highlighted on journal covers and by AGU and NASA. His research has led to the establishment of a Virtual Antenna System to generate and distribute customized data products in near real-time, from which unique coastal observing systems have been developed to address specific monitoring and research needs. These include a Virtual Buoy System (VBS) to monitor coastal and estuarine water quality, an Integrated Redtide Information System (IRIS) to provide near real-time information on harmful algal blooms, and a Sargassum Watch System (SaWS) to combine remote sensing and numerical modeling to track macroalgae. Between 2009 and 2014 he served as a topical editor on ocean optics and ocean color remote sensing at Applied Optics, and between 2015 and 2017 he served as a chief editor at Remote Sensing of Environment.



Chuanmin Hu delivered a keynote talk entitled “Rising green tides and golden tides: An oceanographic regime shift?”. Blooms of *Ulva* and *Sargassum* macroalgae, often called green and golden tides, respectively, have been reported in many places around the world. These macroalgae provide important ecological functions in the ocean, but can cause many problems when large quantities are washed ashore. Using satellite data, field and laboratory measurements, and novel macroalgae-specific algorithms, bloom

patterns of *Ulva prolifera* and *Sargassum* were shown between 2000 and 2018 in the western Pacific (Yellow Sea and East China Sea) and tropical Atlantic. While their seasonality indicates algae growth cycles, large quantities detectable in satellite imagery only occurred in recent years. Analysis of environmental conditions suggests that large-scale blooms may become a new norm in these study regions, thus representing potentially a regime shift. How to adapt to such a regime shift and what are its ecological/biogeochemical consequences all remain to be studied, however. Meanwhile, the band-difference algorithm design in these macroalgae studies has led to possibly a paradigm change in ocean colour algorithms, as recent studies show that band-difference has superior performance over band-ratio for retrievals of concentrations of chlorophyll-a, particulate inorganic carbon, and particulate organic carbon in most ocean waters.

3. Agency Reports

3.1 Status of SABIA-Mar Mission and Ocean Applications of CONAE (Argentina).

Sandra Torrusio provided a pre-recorded presentation on Argentina's SABIA-Mar mission, which is primarily an ocean colour mission with 2 day revisit. Regional/coastal acquisitions have 200 m spatial resolution for the measurement bands and 400 m for atmospheric correction bands, while the global scenario has 800 m spatial resolution. Sea surface temperature is a secondary observable (450 m resolution). The main products will include LnW, Chl-a, Kd(490), PAR, turbidity and SST. Data will be available within 24 h (near real time products for Chl-a and SST only). Level-3 products (daily, 8 d and monthly) will also be distributed. Vicarious calibration sites are located in north and south of the equator to get a range of data for calibration. The mission is scheduled for launch in 2023. Various training initiatives and workshops in Argentina were also presented.

3.2 Canada's Ocean Colour Activity Report (Canadian Space Agency)

Laurent Giugni provided a pre-recorded presentation on Canada's ocean colour activities. With the world's longest coastline and close to 10% of the world's renewable freshwater supply, Canada is facing national and global water challenges. In response, Canada invests in protection of the oceans as well as ocean science and innovation to ensure safer, cleaner and healthier oceans. An overview of Canada's recent ocean colour and inland water-related activities was provided including CSA water related missions and initiatives e.g., SWOT, RCM and the proposed CSA hyperspectral WaterSat mission – a satellite to monitor the quality of Canada's coastal and inland waters. Initially, CSA teamed up with NRL to develop the Coastal Ocean Colour Imager (COCI), to be integrated onto the PACE platform, but this was not funded in the last budget. CSA is now exploring national and international partnership opportunities to initiate Phase A of a second version of the WaterSat mission. A summary of various Canadian ocean colour research programs in the Arctic, lakes, nearshore, coastal and marine environments was also presented.

3.3 NOAA Ocean Colour Session

Menghua Wang reported on NOAA ocean colour activities and the production of routine global ocean colour products, including 10 operational standard products e.g., normalized water-leaving radiance, Chl-a concentration as well as 29 experimental products which are now routinely produced e.g., IOPs, Chl-a anomaly and Chl-a anomaly ratio. Since 2014 NOAA has conducted an annual dedicated VIIRS Cal/Val cruise - the fifth cruise will take place in May 2019. NOAA also supports MOBY since high quality *in situ* optical data are required for sensor on-orbit vicarious calibration and for on-orbit sensor performance monitoring. Various applications of VIIRS ocean colour data were also reviewed including the Lake Erie HAB Bulletin, optimization of phytoplankton functional type/size class (PFT/PSC) algorithms, NOAA EcoCast, and NOAA Coral Reef Watch. NOAA and EUMETSAT are sponsoring and conducting the first International Operational Satellite Oceanography Symposium (18-20 June 2019) in Washington DC.

3.4 EUMETSAT Emerging Applications and Science

Ewa Kwiatkowska reported on EUMETSAT emerging applications and science. The Copernicus Sentinel-3A and -3B constellation is now fully operational. Sentinel-3A and -3B flew in tandem phase between 6 June and 16 October 2018 with Sentinel-3B flying 30 seconds ahead of Sentinel-3A on the same ground track. This provided extremely valuable data since similar ocean and atmosphere was observed by both satellites. Currently the differences between the missions (biases, trends etc.) are being analysed and will be used for improving instrument calibration and characterization, and improving knowledge of measurement uncertainties. The final configuration was reached on 27 November 2018 with Sentinel-3B placed in the same orbital plane as Sentinel-3A, with a phase difference of 140°. The status of various Sentinel-3A products was reviewed, most of which meet the Sentinel-3 mission uncertainty requirement at averaged global and temporal scales, apart from water reflectance which does not meet the 5% Sentinel-3 mission uncertainty requirement (ocean colour system vicarious calibration (OC-SVC) is not available). EUMETSAT has been cooperating with ESA, EC-JRC and international space agencies on activities towards establishing Copernicus OC-SVC capability. There are two parallel candidate OC-SVC preliminary designs based on the optical system design of MOBY and BOUSSOLE. Many of EUMETSAT activities follow IOCS recommendations and harness international expertise e.g., improved atmospheric correction for non-negligible water reflectance in the NIR for OLCI, IOP inversion in oceanic and inland waters and advances in phytoplankton fluorescence retrievals.

3.5 NASA Emerging Applications and Science

The session Chair, Tim Moore introduced the speaker, Paula Bontempi and noted that she recently accepted a new position at NASA and is now the Acting Deputy Director of the Earth Science Division, in charge of all NASA Earth Science missions, so she may be leaving our immediate community, but will stay in touch. Paula has led the NASA Ocean Color program for the last 18 years, overseeing and leading the

SeaWiFS, Modis Terra and Aqua, Suomi NPP VIIRS, and PACE science teams as well as many NASA projects that use ocean colour data, including the Ocean Biology and Biogeochemistry Program. She has been a staunch supporter of national and international collaborations between NASA and other agencies, as well as the IOCCG. Her outstanding contributions to the ocean colour community were acknowledged and she was congratulated in her new position. Paula thanked Tim for his kind words and noted that she could do more for the ocean colour community at the Executive Director position.

Paula gave a brief overview of the NASA Earth Science Division, as well as recommended NASA priorities from the recent National Academies Decadal Survey. The NASA PACE mission is scheduled for launch in December 2022, and will carry two polarimeters (HARP2 and SPEXone) plus the Ocean Color Instrument (OCI). There will be two competitions for PACE: ROSES 2019 and ROSES 2022 for pre- and post-launch algorithm and applications development. The post-launch science team will likely be competed through ROSES 2025. There is also an open competition for vicarious calibration – teams will be selected this summer. Laura Lorenzoni will remain the Point of Contact for the NASA Ocean Biology Program.

Paula also addressed the evolution of ocean colour science over the last two decades. Around 2003 the IOCCG was discussing issues such as solar constants, assimilation of OC data in to numerical models, algorithm and data products, data processing and instrument issues. Now the focus is shifting towards validation, vicarious calibration, remote sensing of optically complex and shallow waters, research to operations, atmospheric correction and phytoplankton functional types (PFTs), with more attention being paid to societal benefits, management, policy, economics and coordination among agencies. Regarding validation, *in situ* data collection and sharing is still an issue. Do we need a NOMAD-like database for an R_{rs} match-up data set which is regularly updated (satellite v. *in situ*; IOPs)? Issues regarding technology development (*in situ* or remote), numerical modelling and science were also raised (e.g., promotion of OCR as a necessary input to NWP models, vertical structure of the ocean, quantification and sampling for a carbon inventory, plastics, Lidar etc.). In future, the focus should be on measurements beyond the polar passive multi-band radiometry, support and promotion of geostationary OCR capabilities, other measurements such as hyperspectral spectroscopy, Lidar and polarimetry and multi-platform and sensor data fusion.

3.6 ESA Emerging Applications and Science

Marie-Hélène Rio provided an update on the ESA Sentinel-2 and 3 missions as well as various past and current ESA science projects including Sentinel-2 coral reef monitoring (Sen2Coral), validating Sentinel-3 OLCI on the AMT cruises (AMT4SentinelFRM) and the Ocean Colour Climate Change Initiative (OC-CCI) to produce a long time time-series of Essential Climate Variables (ECV) in support of Climate Research. OC-CCI V4 is ready for release (daily, 4 km maps of OC: Chl -a, R_{rs} , K_d490 , a_{tot} , a_{dg} , a_{ph} , b_{bp} with uncertainty estimation). Other ESA projects are studying the physiological response of phytoplankton global warming, PFTs, characterization of the marine carbon cycle from space, a *Sargassum* monitoring service and marine litter detection from space.

4. Keynote Addresses

A total of eight keynote speakers were invited to give presentations throughout the four-day IOCS meeting: two during the special session on Remote Sensing in Asian Waters (see above) and six during the Plenary Sessions. All keynote presentations can be downloaded from the IOCS-2019 meeting website at: <https://iocs.ioccg.org/iocs-2019-meeting/iocs-2019-presentations/>.

4.1 Keynote 3: - Sandy Thomalla (CSIR, South Africa)

Sandy Thomalla is a principal scientist at the Southern Ocean Carbon and Climate Observatory (SOCCO) at the CSIR, in Cape Town, South Africa. She obtained her PhD in 2007 from the University of Cape Town in association with the National Oceanography Centre, Southampton. Her early research focused on understanding the biological carbon pump through measurements of primary production (^{14}C and ^{15}N) and carbon export ($^{234}\text{Th}/^{238}\text{U}$ disequilibrium), while her postdoctoral research characterised the seasonal cycle of chlorophyll in the Southern Ocean using SeaWiFS to provide a more dynamic understanding of phytoplankton phenology based on underlying physical drivers rather than climatological means. This research continues to play an important role in influencing SOCCO's approach to advancing their understanding of the Southern Ocean carbon – climate system. Sandy's current and future research has expanded into the development and application of ecosystem-appropriate, well-characterised products that translate ocean colour (and in situ bio-optical measurements) into carbon biogeochemistry (phytoplankton biomass, community structure and physiology) allowing new insight into ecosystem function. A key focus is on assessing event, seasonal and inter-annual variability in ecosystem physical drivers and their biogeochemical response, in order to better understand the potential for carbon sequestration at a regional scale. The knowledge and experience gained from her years of research in phytoplankton productivity and carbon export amalgamates well with her expansion into bio-optical approaches that include in situ high-resolution estimates from autonomous platforms such as bio-Argo floats and gliders. Although a jack of all trades and a master of none, Sandy has an unusual combination of experience at the interface of observations, autonomous technology, and ocean colour remote sensing, all centred on phytoplankton primary production and carbon export. Sandy would like to think that this strange multidisciplinary might place her in a unusual position to address the complex problem of understanding the climate sensitivities of the Southern Ocean biological carbon pump.



Sandy Thomalla delivered a keynote address entitled “Do small scales make a big difference? Building a South African Southern Ocean Carbon, Climate research capability”. She joined the Southern Ocean Carbon and Climate Observatory (SOCCO) at the time of its inception back in 2010 and shared the journey from the humble beginnings to a leading research capability that addresses the role of the Southern Ocean in 21st century regional and global climate. As a small group, a niche approach was needed for this grand challenge, which led to the formulation of their underpinning hypothesis that fine-scale ocean dynamics are key to understanding climate sensitivity through their impacts on the variability and trends of carbon fluxes in the Southern Ocean. An emergent aim was to understand and constrain the seasonal cycle as the mode of variability that links ecosystems to climate. This approach required the use of observational and

modelling platforms that could resolve the relevant scales and involved pioneering Southern Ocean robotics experiments, remote sensing and high-resolution modelling. It was a journey fraught with difficulties and the occasional disappointment but ultimately eclipsed by moments of realisation of achieving innovative and pertinent science. Overall, SOCCO continues to make a growing contribution to our understanding of the role that fine-scale dynamics play in shaping the phasing and magnitudes of the seasonal cycle and its inter-annual variability.

Key insights were presented starting with one of their earliest publications which utilized ocean colour to summarise the varying regional response of phytoplankton biomass to different seasonal regimes. This thinking played a critical role in influencing the trajectory of their research and was formative in the development of their high-resolution observational strategy implemented in a number of Southern Ocean Seasonal Cycle Experiments (SOSCEX). Some key realisations emerging from SOSCEX include the important role of small scale variability in driving early blooms in spring and sustained blooms in summer; the seasonal progression of net community production and its sensitivity to fine-scale dynamics; seasonal trends and sub-seasonal variability in chlorophyll to carbon ratios; and the need to subsample at frequencies < 10 and 3 days to characterize intra-seasonal scales of variability in chlorophyll and CO_2 flux respectively. This fine-scale dynamics approach to physical-biogeochemical ocean observations also contributes to reducing uncertainty and biases of empirically derived products of FCO_2 and pCO_2 . Their seasonal cycle lens has enabled them to highlight the mechanisms behind previously underestimated biases in both biogeochemical and Earth system models, with important implications for long term uncertainties in their projections. These results highlight the need for climate models to resolve both meso- to submesoscale and intra-seasonal processes to accurately reflect phytoplankton phenology and understand the sensitivity of primary productivity to climate change.

4.2 Keynote 4: - Alejandro Clément (Plancton Andino, Chile)

Most of Alejandro Clément's career has been in the private sector, but he also carries out applied research on harmful algal blooms (HAB), fjord oceanography, bio-optics and more recently, testing the HABf index, a novel metric to improve communication procedures and early warning of complex biological events. Alejandro was born in southern Chile and obtained his marine biology degree from Universidad de Concepcion. During this time he began studying HABs and obtained his first job at Universidad de Los Lagos, in Puerto Montt, Chile, where he initiated a branch of marine phytoplankton research. Following this, he was hired at Universidad de Magallanes, Instituto de la Patagonia to participate in the red tide monitoring program in Chile's Patagonian fjords. He then decided to further his career by obtaining a Master's Degree from Oregon State University in 1988, studying the use of ocean colour remote sensing data (CZCS) as a tool for monitoring HABs in coastal mid-latitudes. i.e., optically-complex waters with intense aquaculture activities. After a massive HAB outbreak in spring of 1988, the Chilean salmon industry contracted Alejandro to design, develop and run a Phytoplankton Monitoring Program, which was one of the first such programs in South America.



Alejandro resolved to move away from academia into the private sector in 1998, and founded Plancton Andino (www.plancton.cl) a leading company in southern Chile addressing environmental consulting, operational oceanography and R&D, specifically focusing on HAB monitoring, with a team of 21 staff (76 % female). The team uses traditional microscopic analysis in three branch labs: Puerto Varas, Castro and Coyhaique, but more recently they have included bio-optical techniques, such as absorption, backscattering, Chl-a data, algal cell detection and quantification with a flow cytometer (FlowCam), photochemical parameters with FRRf3, and remote sensing data using both the WISP-3 portable water quality spectrometer as well as satellite platforms (VIIRS- Suomi NPP). All these data are compiled, processed and provided to aquaculture industries and authorities via business intelligence and cloud computing.

Alejandro Clément gave a keynote address entitled “HABs, ocean color remote sensing, bio-optical monitoring in fjords and aquaculture activities”, summarising results of several HAB events in optically-complex waters of Chile’s Patagonian fjords, where they applied ocean colour remote sensing and bio-optical methods. It is well observed that many large biomass HABs produce important water colour modifications, among others attributes. However, HAB monitoring and assessing spectral optical properties variability, such as reflectance, backscattering, surface *in situ* chlorophyll a fluorescence, near real-time cells imaging, etc., are not easy tasks, particularly in optically-complex and cloudy coastal waters, such as the Patagonian fjords. The main constituents in the photic water column, are CDOM, re-suspended material, different species and sizes of phytoplankton cells and occasionally glacial silt and ash plumes. The photo-autotrophic flagellate’s cells are subject to much dynamic movement, creating very heterogeneous distributions in stratified water columns, and in many cases generating sub-surface cellular thin layers, which indeed, are the most optically significant layers, as determined using WISP-3 reflectance, absorption, backscattering, cells abundance and Fv.

Under this biologically complex scenario with enormous economic, social and media pressures facing the aquaculture industry, governmental authorities and resource managers need to keep the industry and the public informed of HABs in near-real-time. Fast data processing schemes and near real-time e-cloud data visualization are therefore required. This provides an opportunity to measure and develop algorithms for identification of “bio-optical cellular fingerprint” using *in situ* NRT optical properties and data from satellite ocean colour sensors. In optically-complex waters, improved bio-optical algorithms are required for the identification of phytoplankton functional groups and species discrimination, with additional use of complementary techniques, such as microscopy, cytometric imaging and molecular biology. Some key extreme HAB events were presented, obtained from a 30-year phytoplankton monitoring program that assists the aquaculture sector. During this time period, at least 3 extremes cases were observed; spring of 1988, late summer of 1998 and 2016, respectively. Scientists need to continue modeling and forecasting HAB distributions, but with more focus on an optical species-specific signal rather than only chlorophyll-a based methods. In this way aquaculture users can better mitigate the risk, using an on-line information system similar to the meteorological forecast service.

4.3 Keynote 5: - Jianping Li (Shenzhen Institutes of Advanced Technology, China)

Jianping Li is an optical instrument developer and physicist. He obtained his BSc and M.E degrees in optics and optical engineering, both at Shandong University, China. After he completed his PhD in physics with Dr. Robert K.Y. Chan at Hong Kong Baptist University in 2010, he stayed in the Advanced Optical Instrument Lab of Physics Department working as research assistant, then lecturer and finally research assistant professor for six years. Since October 2016, he moved to Shenzhen Institutes of Advanced Technology of Chinese Academy of Sciences, where he is working in the Center for Optoelectronics Engineering and Technology as an associate professor. Dr. Jianping Li is one of the inventors of light-sheet fluorescence imaging flow cytometer, which is a new technology for high-throughput phytoplankton analysis. His research interests include optical spectral imaging and flow imaging technologies and their applications in biology, chemistry, material and marine sciences. His recent work has focused on developing field-applicable imaging systems for plankton studies.



Jianping Li delivered a keynote talk entitled “How can imaging flow cytometry serve ocean colour science?”. Since launch of the first ocean colour satellites after 1970s, the understanding of global phytoplankton biomass, distribution, community composition, bloom mechanism and estimation of total primary production has been greatly promoted, thanks to the rapid development of ocean colour science. With more observations from the unique top-view macroscopic perspective, demand on having more accurate *in situ* microscopic observations of phytoplankton is also growing. To correct and validate modeling and retrieval algorithms, and to complement underwater depths beneath the photic layer, *in situ* observation methods are expected to achieve accurate measurement on an ever larger tempo-spatial scale with high sampling frequency. This stimulated the advent and development of imaging flow cytometry (IFC), an automated flow-through optical microscopy method in equivalent, for highthroughput *in situ* quantitation and characterization of phytoplankton in natural seawater. IFC can automatically extract multi-parameter statistical information of phytoplankton water samples by computer analyzing numerous digital micrographs captured while they flow through an optical interrogation area. This means it is much faster than traditional microscopy. However, taking fast yet accurate measurement of diverse natural phytoplankton with extreme heterogeneity remains challenging for current IFC instruments. Without new solutions to resolve technical issues such as deficiency in sensitivity and resolution, compromise between imaging throughput and image quality, and trade-off between analyzable water volume and statistical accuracy, the advantages and potential of this technology in taxonomy and automation will remain underscored, as its resultant analyzing throughput is much smaller than other underway methods such as spectrophotometry that can be used for inline observation on R/Vs cruise. This talk introduces the basics and reviews typical instruments of IFC technology for *in situ* phytoplankton observations, followed by a progress report on FluoSieve, a new fluorescence IFC developed by

their team towards resolving the aforementioned issues. Finally, the challenges and trends of IFC technology development for future *in situ* phytoplankton observation were discussed.

4.4 Keynote 6: - Atsushi Matsuoka (Université Laval, Canada)

Atsushi Matsuoka is the lead of the remote sensing group at Takuvik Joint International Laboratory (CNRS-ULaval), Québec city, Canada. He received a doctorate in the fields of satellite oceanography and marine bio-optics from Hokkaido University (Japan), and conducted post-doctoral research at Laboratoire d'Océanographie de Villefranche/Université de Paris 6 (France), plus at Takuvik Joint International Laboratory (Canada). Since July 2015, He has been leading Takuvik's remote sensing group. His research activities extend from examining intricate in situ relationships between optical properties and microbes/phytoplankton to monitoring much broader scale global climate change from space. His most significant research contributions include establishing fundamental relationships among optical properties and constituents observed in the ocean based on in situ observations, introducing these relationships into a



radiative transfer model and developing appropriate algorithms for satellite data, and applying them to satellite remote sensing for retrieving and monitoring geophysical variables with known uncertainties. In recent years, his research has further expanded to monitor carbon fluxes from permafrost thaw. When combined with a numerical model, this knowledge will be particularly useful to assess the global impact of this phenomenon on the atmospheric CO₂ budget. Due to his increasing expertise in a variety of remote sensing applications, he has had the opportunity to be involved in a number of national and international projects including an European project, NUNATARYUK in the framework of Horizon 2020 where he is a Co-PI of a workpackage. He is also actively involved in ocean colour satellite missions such as the PI of the Japan Aerospace Exploration Agency (JAXA)'s GCOM-C/SGLI project.

Atsushi Matsuoka gave a keynote address entitled “Ocean colour remote sensing in Polar seas”. Global climate change is affecting a broad spectrum of terrestrial, marine, cryospheric, and atmospheric environments. This is particularly evident at high northern latitudes. Compared to Antarctic sea ice, whose trend is not clear, Arctic sea ice area and thickness has been continuously decreasing over the last four decades due to global warming and ice-albedo feedback. The newly-opened area is now responsible for dissolution of atmospheric CO₂. Depending on nutrient availability and physical conditions (e.g., mixing), primary production of the Arctic Ocean is likely to increase, mainly because of increased light availability associated with the increase in open water area, another sink of CO₂. On land, river discharge has increased in both North American and Siberian sides of the Arctic region since the late 20th century. This increase is likely linked to the recent dramatic decrease in sea ice area and thickness and concomitant atmospheric moisture transport. It is anticipated that a significant amount of organic carbon originating from permafrost thaw will be delivered by river discharge into the Arctic Ocean. The amount of organic carbon sequestered in the permafrost is enormous (1700 Pg C), accounting for over 50% of global soil carbon stocks, almost double that contained in the atmosphere (800 Pg C). It is also anticipated that a significant amount of organic carbon originating from permafrost thaw will be delivered by river discharge into the Arctic Ocean. A portion of this organic carbon that was previously sequestered in the permafrost

may be actively utilized by heterotrophic bacteria, which may accelerate CO₂ release back to the atmosphere. How organic matter from permafrost-origin impacts the global climate system is not clear.

Satellite remote sensing estimates of organic carbon in Arctic coastal waters, where a significant amount of terrestrial organic matter is transported, have been used to answer part of this important question. In more recent collaborative work, estimates of concentrations of dissolved (DOC) and particulate organic carbon (POC) have been compared with numerical modeling results. Research includes investigation of a recent trends in these fluxes observed in major Arctic river mouths by developing a semi-analytical algorithm with known uncertainty. To examine the influence of river input on coastal marine ecosystems, an objective algorithm has been developed for discriminating different surface water sources using remote sensing data alone. Broader application of this algorithm may lead to the discrimination of water sources in the surface layer in a variety of environments, which may be useful to improving our understanding of physical and biogeochemical processes related to each water source. While Arctic research is central to this study, a similar approach can be applied to other environments at lower latitudes for better understanding of biogeochemical processes. The presentation is thus relevant to studies investigating organic matter processes in various environments.

4.5 Keynote 7: - Griet Neukermans (Laboratoire d'Océanographie de Villefranche-sur-Mer, France)

Griet Neukermans is an optical oceanographer with fundamental and applied expertise in remote and in situ optical sensing of marine particles. Throughout her career she embraced a wide range of research topics in marine optics, biogeochemistry, phytoplankton biogeography and climate change. Her scientific contributions include pioneering work on remote sensing of water quality from geostationary optical satellites, investigating relationships between (hyperspectral) optical properties and characteristics of marine particles in natural waters, theoretical modeling of optical properties of phytoplankton, bio-optical measurement protocols and uncertainties, and investigations on the poleward expansion of temperate phytoplankton into the Arctic. In recent years, she developed a particular interest in calcifying phytoplankton (coccolithophores) and their climate relevance. Griet received her MSc. in Applied Mathematics and her MSc. in Marine Ecology from Brussels University in Belgium and obtained her Ph.D.



in Physics from Lille University in France in 2012. She was a postdoctoral fellow at Scripps Institution of Oceanography/University of California San Diego, held a Banting postdoctoral fellowship from the government of Canada at Laval University in Québec, and currently holds a Marie Skłodowska-Curie postdoctoral fellowship at the Oceanography Laboratory of Sorbonne University in Villefranche-sur-Mer. Griet has led multidisciplinary field campaigns, her scientific contributions have been internationally recognized through various awards, and she serves as Associate Editor for Frontiers in Marine Science. See <https://grietneukermans.weebly.com/> for further information.

Griet Neukermans gave a keynote address entitled “Optical properties and remote sensing of coccolithophores: recent advances and selected applications”. Coccolithophores are a group of

phytoplankton that form an exoskeleton of calcium carbonate scales called coccoliths. Found throughout the world ocean, coccolithophores are major contributors to pelagic calcification and play a crucial role in the ocean carbon cycle. In the temperate and subpolar oceans, coccolithophores form intense and vast blooms, covering hundreds of thousands square kilometers, which are easily observed from optical satellite sensors. A brief overview was given of the optical properties of coccolithophores and ocean colour remote sensing algorithms used to quantify their calcite mass concentration. Next, some selected applications were presented of marine optics and remote sensing in coccolithophore ecology, biogeochemistry, and climate science. For example, using long-term satellite observations of coccolithophore blooms and the physical environment, she showed that coccolithophore blooms are expanding poleward at a remarkably fast pace due to climate change. She also demonstrated that coccolithophore blooms promote deep carbon export using a combination of ocean colour remote sensing and optical measurements on autonomous profiling floats of the Biogeochemical-Argo network.

4.6 Keynote 8: - Curtis Mobley (Sequoia Scientific, Inc., USA)

*Curtis Mobley has had a 40-year career in optical oceanography. The widely-used HydroLight software, the textbook *Light and Water: Radiative Transfer in Natural Waters*, and the *Ocean Optics Web Book* (www.oceanopticsbook.info) are the best-known products of his efforts. His papers have been cited over 10,000 times. Early in his career, he was a Fulbright Fellow to Germany, and he has held both regular (at the NOAA Pacific Marine Environmental Lab) and senior (at the Jet Propulsion Lab) National Research Council Resident Research Associateships. He has worked at a number of universities and companies, and he was the second Program Manager of the Ocean Optics program at the Office of Naval Research. Since 1997 he has been the Vice President for Science at Sequoia Scientific, Inc. He was the 2012 Distinguished Alumnus for the School of Atmospheric and Oceanic Sciences at the University of Maryland, and he received the 2016 Jerlov Award, in part for “applications of radiative transfer theory to problems in optical oceanography.” When not doing radiative transfer theory, he can usually be found in a sea kayak—most recently on a 30 day expedition along the west coast of the Antarctic Peninsula.*



Curtis Mobley delivered a keynote address entitled “The Evolution of Radiative Transfer Theory”. The sine qua non of Radiative Transfer Theory (RTT) is an equation that governs the propagation of light through an absorbing and scattering medium, including perhaps internal sources as well. RTT as we know it today began to take shape in the 18th century but was not conceptually fully formulated until the 21st century. This talk traces the development of RTT from its empirical foundations, through its early mathematical formulations, ending with an overview of recent re-examinations of its foundations. A fast survey will be taken of the contributions by Lommel, Chwolson, Schuster, Planck, Schwarzschild, King, Milne, Gans, Gershun, Ambartsumian, and Preisendorfer, with particular emphasis on Lommel and Ambartsumian. The talk finished with an outline of a “proper” derivation of the radiative transfer equation as developed in recent years by Mishchenko.

5. Breakout Workshop Reports

A total of 9 breakout workshops (3 parallel sessions at one time) covering a wide range of topics took place at the IOCS-2019 meeting as follows:

- **Tuesday 9 April 2019 (Breakout Workshops 1 – 3)**
 - **Breakout 1:** Open source scientific computing tools and resources
 - **Breakout 2:** Requirements for assessing phytoplankton composition
 - **Breakout 3:** High temporal/spatial resolution applications
- **Wednesday 10 April 2019 (Breakout Sessions 4 – 6)**
 - **Breakout 4:** Remote sensing of optically-complex and shallow waters
 - **Breakout 5:** Vicarious calibration and validation protocols
 - **Breakout 6:** Research to operations (R2O) applications
- **Thursday 11 April 2019 (Breakout Sessions 7 – 9)**
 - **Breakout 7:** Emerging new technologies for ocean colour research
 - **Breakout 8:** Ocean colour satellite sensor calibration
 - **Breakout 9:** Atmospheric correction under complex/extreme environments

The agenda, workshop description and a full report from each of these breakout workshops is available on the IOS website at: <https://iocs.ioccg.org/iocs-2019-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. This type of feedback will help to improve communication between the scientific research community and the space agencies by focusing on the value and impact of new research avenues, including cutting-edge issues.

5.1 Breakout 1: Scientific computing and the open source software revolution: how ocean colour science can benefit

Chair: Joaquín E. Chaves (NASA GSFC/SSAI)

Co-chairs: Erdem M. Karaköylü (NASA GSFC/SAIC), and Joel P. Scott (NASA GSFC/SAIC)

5.1.1 Introduction

Until recently, ocean colour practitioners have principally relied on commercial off-the-shelf software (COTS) for data analysis (e.g., IDL, Matlab, etc). Use, support, and maintenance of COTS requires paid licenses, and often come with proprietary, black-box features. This framework hinders task-oriented modification and is an obstacle to transparency, code sharing, and scientific reproducibility. While COTS were instrumental in past progress toward better understanding the ocean and its processes, the restrictions associated with the use of COTS have become an obstacle to innovation and collaboration, hindering ocean colour science from truly realizing its full potential as a diverse global discipline of scientists, data users, and data producers.

During the past few years, there has been an explosive growth of information technology advances in computational power, data availability, and the open source software movement. These factors have resulted in the democratization of advanced computational tools and platforms for diverse commercial and scientific applications. There is now a rich ecosystem of accessible, open source software (OSS), that is freely available and modifiable, including programming languages, such as R, Python, Julia, and Octave. These tools are now easily accessible via the internet and their use is reinforced with online software and knowledge repositories such as GitHub, StackOverflow, Bitbucket, and others. OSS, combined with transparent scientific project management platforms like Slack and the Open Science Framework, have lowered the threshold for entry to ocean colour science, while expanding the user pool, increasing opportunity for collaboration, and promoting scientific innovation, transparency, and reproducibility. The rise of OSS enables new approaches for answering ocean colour research questions, conducting instrument calibration and algorithm validation, and streamlining data access, use, and availability.

5.1.2 Session Summary

Ocean colour science is a data-intensive discipline that requires advanced computational and analytical tools to fully realize its societal benefits. It is important to the ocean colour scientific community that the technologies being leveraged facilitate transparent, reproducible scientific results, while being accessible and understandable to allow for the training and mentoring of young scientists and new practitioners. As ocean colour science continues to expand globally, reliance on COTS has become a limiting factor. However, the growing adoption of OSS is encouraging collaboration that would otherwise have been a logistical impossibility. OSS and 'open science' principles are promoting diversity, inclusion, and accessibility to ocean colour science, driving international collaboration, and encouraging the key scientific principles of transparency and reproducibility. Examples of open source technologies and of how

they are being leveraged to advance ocean colour research were highlighted in presentations and discussions centered around the following themes:

- Python is an emerging language with widespread adoption across all experience and skill-levels of the scientific community. Python offers a vast ecosystem of libraries that allow it to be a versatile choice for scientific computing with libraries for machine learning, modeling, data analysis/plotting, and web development.
- Jupyter notebook is a popular integrated development environment (IDE) that accommodates Python, Julia, and R open source languages and enables intuitive code testing and debugging features, as well as versatile tools for export and publication of code to encourage open, reproducible science.
- Open source Python modules are ideally suited for collaborative, scientific work, since they are 1) free from costly licensing, 2) easily installable in a ready-to-use state, and 3) well-supported with online resources, documentation, and tutorials. Some examples of Python modules used by the discussion leaders in this session, include:
 - NumPy for array computation
 - pandas for 2-D labelled data organization and manipulation
 - xarray for N-D labelled data manipulation with chunking and parallel processing
 - Matplotlib, Seaborn, and Cartopy for general, statistical, and geo-referenced graphing, respectively
 - PyMC3 for statistical modeling with explicitly debatable assumptions
- Anaconda is a popular Python package manager, used to handle module distribution and dependency resolution. Anaconda enables the creation of portable project-based environments, to track and export only the packages required for the project at hand (e.g., https://github.com/jpscot/IOCS_2019_Busan_OpenScience).

5.1.3 Recommendations

1. Develop and publish a community 'open science' statement to encourage making data and software open and discoverable. Responsible party: IOCCG
2. Encourage international adoption of 'open science' policies and open source technologies through existing training and education instances (e.g. - University of Maine Summer Ocean Optics class, EUMETSAT trainings, NASA SeaDAS trainings, Cornell Ocean Satellite class, etc). Responsible party: Agencies and the Community
3. Establish a code repository as a live IOCCG report, titled: Open Science Principles & Open Source Methods for Ocean Colour Science, to contain open source code and common ocean colour science workflows as a place-to-start for learning open source technologies. Responsible party: IOCCG to approve and host on GitHub/GitLab; Community/Agency members to contribute content and code examples.

5.2 Breakout 2: Going beyond HPLC: Coming to rapid consensus on science requirements for assessing phytoplankton composition from satellite imagery

Chair: Astrid Bracher (AWI, Germany)

Co-chairs: Ryan Vandermeulen (NASA, USA), Stewart Bernard (CSIR, South Africa)

This breakout group is a follow-up on previous activities of the international ocean colour phytoplankton composition group's discussion (IOCCG working group 2007-2014; PFT Satellite Group Meetings 2011, 2012 and 2015; breakout groups at IOCS 2013 and IOCS 2015; PFT validation IOCCG WS 2014, ESA CLEO workshop 2016; Ocean Optics Town Halls in 2016 and 2018). These activities resulted in specific reports and peer-reviewed publications summarizing the (to the time of publishing) multiple Phytoplankton Functional Type (PFT) and Particle Size Class (PSC) algorithms (user guide), their validation and intercomparison, and recommendation (roadmap) for moving further to obtain practical use satellite PFT/PSC products with well-characterized uncertainties (see references provided in Bracher et al. 2017). To advance the objectives of the community, and following the recommendation of the latest satellite PFT roadmap (Bracher et al. 2017), the discussions in the BO were focused on moving beyond the limited uncertainty assessment of PFT algorithms via High Precision Liquid Chromatography (HPLC).

A summary was given outlining the requirements for *in situ* data validation as well as the pressing need for data integration, which were identified as priorities in past activities. Following a brief discussion of validation program requirements, there were a series of presentations on current regional and global satellite PFT/PSC algorithms, including an assessment of their performance and detection capabilities. This was followed by a discussion of the limitations in properly assessing model uncertainties, and challenges to meet the diverse needs of users. Then a few examples of using synthetic data sets, derived either by simple reflectance forward modelling (e.g. using GIOP) or using in water or coupled ocean-atmosphere radiative transfer, for algorithm development and sensitivity analysis were presented, and the benefit and current limitations of their modelling were discussed. In the last subsection a thorough overview was presented on U.S., Chinese, Australian, Korean, European and international activities or programs in terms of satellite PFT/PSC validation data sets and their integration beyond HPLC.

From the subsections and final discussions, the BO group formulated key gaps and recommendations, as well as short to medium term action items to close these gaps which requires support from space agencies and the IOCCG in terms of providing the funding for enabling the networking and collaboration of *in situ* experts with algorithm developers as well as data providers and end users. The related workshops and round-robin experiments, will help to facilitate regional and international cooperation to enable the determination of optimal user benefits of satellite PFT/PSC products.

5.2.1 Current gaps for satellite PFTs

Several key gaps identified in the BO session have remained persistent topics to the community, such as the need for higher spatial and spectral resolution data from satellites for nearshore bloom detection,

proper characterization of the temporal/spatial/vertical resolution of PFT/PSCs, and to standardization and thorough uncertainty assessment of *in situ* methodologies. As one of the highest priority gaps revolves around the logistical challenges of properly validating phytoplankton groups, as the optimal ranges of any single *in situ* instrument does not cover the full continuum of PFTs/PSCs. The discussions identified that using multiple instruments to characterize community composition is best, however, the feasibility of obtaining a globally representative database is daunting, as the collection of an ideal data set can be expensive, time-intensive, and the merging of disparate data sets is not trivial or well understood. Unilaterally translating phytoplankton community composition into a unique optical signal can also be challenging without the use of thorough biogeographical/temporal parameterization to prevent false positives/negatives of groups that may have very similar spectral signatures. Each of the methods for assessing PFT/PSCs (see key observables below) all have distinct advantages and limitations, and face the challenge that each requires different assumptions to link observations of composition to carbon or biomass. Even so, there is no existing frame work for integrating multiple PFT data types into a common data repository with standard formats, nomenclature, and quality control, which is requirement for robust algorithm development (note, efforts are underway to incorporate imaging data into data repositories). Discussions highlighted critical gaps in the realm of radiative transfer modeling, including the challenges faced in discriminating PFTs in waters with low algal contribution, or dominated by NAP, and that current scattering models are not accurate enough to produce real world phytoplankton-specific b_{bp} .

5.2.2 Key (in situ) observables to characterize phytoplankton communities

The following *in situ* observables comprise the recommended set of observations required to assess the full breadth of phytoplankton community composition and aid in algorithm development:

- Phytoplankton pigments from HPLC, phycobilins from spectrofluorometry
- Phytoplankton cell counts and ID, volume/carbon estimation and imaging (e.g. from flow cytometry, FlowCam, FlowCytobot type technologies)

Inherent optical properties, hyperspectral radiometry:

- Particle size distribution, size-fractionated measurements of pigments and absorption
- Genetic/-omics data for evaluation when needed

5.2.3 Recommendations to scientific community and space agencies

- 1) Support a comprehensive and systematic analysis to fully understand PFT/PSC signal across wide ranges of water types (biomass, IOP ranges) using unambiguous *in situ* measurements of phytoplankton composition and optimal AOP/IOPs, including uncertainties, complemented by an analogous RT study on the water leaving signal.
- 2) Promote both the standardization and integrated merging of afore mentioned key-observables to enable routine and comparable phytoplankton taxonomy resolving observations and thus the production of viable phytoplankton community metric products. Support in the form of

international round-robin experiments, validation exercises, and targeted workshops will be essential.

- 3) Enhance the capabilities of phytoplankton composition IOP measurements, especially improving the characterization of backscattering properties with increased spectral resolution, re-visiting chi factors, further characterizing phytoplankton-specific phase functions, and incorporating non-spherical shape/structure model assumptions.
- 4) While more abstract, there is a broader need for all members of the community and space agencies to be diligent in continuing to promote and quantify the novel impacts of phytoplankton composition to local/regional/global economies and ecosystems, as well as further assess the specific needs of end-users. This is necessary for the sustained funding of critical research needs.

5.2.4 Short to Midterm Actions

- 1) Specialized group activities (require IOCCG support)
 - Novel concept IOCCG working group in a more open way: running blog, open white paper
 - IOCCG Phytoplankton taxonomy protocol
 - Hyperspectral task force
- 2) Broader community discussion forums (in person) for moving towards consolidation: e.g., specific workshops, or breakout groups /Town Halls at larger meetings
- 3) Agency supported actions:
 - International round-robins for *in situ* PFT data integration, representative satellite PFT validation exercise, modelling translation (systematic analysis) of *in situ* PFT to IOP into numerical model;
 - Workshop for User information on PFT products and fostering their contribution to *in situ* PFT validation by their integrated PFT data sets from regular monitoring activities.

All references provided in:

Bracher, A. H. Bouman, R. Brewin, A. Bricaud, V. Brotas, A. M. Ciotti, L. Clementson, E. Devred, A. DiCicco, S. Dutkiewicz, N. Hardman-Mountford, M. Hieronymi, T. Hirata, S. N. Losa, C. B. Mouw, E. Organelli, D. Raitso, J. Uitz, M. Vogt, A. Wolanin (2017) Obtaining Phytoplankton Diversity from Ocean Color: A Scientific Roadmap for Future Development. *Frontiers in Marine Science*, 4:55, doi: 10.3389/fmars.2017.00055.

5.3 Breakout 3: High temporal/spatial resolution applications

Chair: Joe Salisbury (U. New Hampshire, USA)

Co-Chairs: Kevin Turpie (UMBC, USA), Wonkook Kim (Pusan National University, South Korea), Antonio Mannino (NASA GSFC), Maria Tzortziou (U. Columbia, USA) and Arnold Dekker (CSIRO, Australia)

5.3.1 Objective

This breakout workshop provided a forum to address key observational gaps and technological challenges for high quality and high spatial-, temporal-, spectral- resolution remote sensing of short-term and spatially complex processes in open ocean and coastal, estuarine, ice edge and inland aquatic environments. Among the main objectives of the workshop was to discuss how existing, or planned, high resolution remote sensing technologies can be utilized in the study of open ocean and aquatic margin systems, identify how these observations can support applications/science end-users and stakeholders, and determine what still must be developed.

5.3.2 Key Recommendations

- Science and end-user communities are seeking high temporal, high spatial resolution, hyperspectral satellite observations (H4D, CEOS report, etc.). How is trade space resolved under current paradigm of ESA, NASA, and NOAA, that are focused on global missions?
- Given formal interactions with end-user groups, revisit time is the most critical aspect in the trade space, and that temporal resolution must be adequate to resolve processes that change on a sub-daily time step.
- A constellation of ~ 15 m (baseline) to 30 m (threshold) resolution sensors with as high as possible radiometric performance and 8 to 15 nm contiguous spectral bands (VIS-NIR-SWIR) would serve a wide range of applications in inland and nearshore coastal waters as well as shallow coastal and coral reef environments.
- Inter-consistency in observations and products is challenging and requires dedicated effort. Yet, satellite ocean colour products that combine high quality, high spatial, high temporal, and high spectral characteristics may only be attainable through multi-source remote sensing data fusion methods. We recommend that space agencies coordinate mission development, from formulation to operations, and pre-launch calibration to facilitate multi-source data fusion and minimize potential differences in products.

5.3.3 Requirements and priorities

- For aquatic ecosystems (with the exclusion of optically deep oceans and very large inland water bodies) temporal, spectral and spatial resolution were all identified at the workshop as the core sensor priorities; radiometric resolution and range and temporal resolution needs to be as high as is technologically and financially possible.

- SBG VSWIR data volume is estimated to be ~18TB/day, the magnitude of which concerned some workshop attendees. However, many current and near-future technology approaches can help cope: on-board processing, per ecosystem or large scene area spectral band settings, on board programming and processing, cloud and HPC should be able to cope with automated routines though.
- Emphasis was placed on currently existing inconsistencies within the ocean colour community regarding the terminology and definition of "low", "medium" and "high" spatial-, spectral-, temporal-, radiometric- resolution for aquatic environments. Workshop participants recommended that these terms are defined and used consistently across environments, application concepts, and areas of expertise.
- The inland/estuarine aquatic ecosystems community has been extremely productive at opportunistically using satellite sensors not originally designed for addressing aquatic/ocean science and application questions. Although this increases the cost effectiveness of satellite missions, workshop participants recommended that as a community we adequately report on the limitations of this approach and we make explicit what we would gain with increased spectral, spatial, temporal resolution and particularly radiometric quality.

5.3.4 Spatial and Temporal Resolution Requirements and Recommendations

- One hour repeat coverage e.g. (GOCI; GOCI-2) is adequate to resolve most (but not all) relevant coastal processes. Such resolution is needed to capture diurnal growth processes, and trajectories of coloured substances.
- ~15 to 17 m spatial resolution was discussed as the ideal compromise for global coverage and covering enough lakes, rivers, delta's, estuaries, lagoons, as well as suitable for seagrass, macro-algae and coral reefs. A spatial resolution of ~25-30 m was discussed as threshold.
- Assume 1 km sufficient for ocean, but not necessarily true —> when/where sufficient to go from low 1 km or 300 m to higher spatial resolution. Currently the switch is from 300 to 30 m (Sentinel-3 to Landsat) and then to Sentinel-2 at 10, 20 and 60 m spatial resolution.
- Should a system of EO satellites for aquatic ecosystems all have the same specifications, or should we aim for a mix (multi, hyper, fine to medium spatial resolution)?
- Scale of spatial heterogeneity for coral/seagrass/macro-algae/benthic micro-algae/macrophytes/mangroves/rocky reefs etc., vs ecosystem scale 2 m, versus ecosystem scale mapping at ~15 to 17 m and ~30 m)
- Participants emphasize that there will be many cases where the suggested resolution requirements are not adequate for the size of the water body, the complexity of the suite of constituents, or frequency of the process. We do not know how these inadequacies would accumulate to affect our knowledge of global processes (e.g. global productivity).

5.3.5 Spectral Resolution Requirements and Recommendations

- +/- 40 to 50 multispectral bands required or hyperspectral at ~ 5-to 8 nm average resolution over range of 380-1000 (for optical systems) and 1000-1400 for SWIR

- +/- 40 to 50 multispectral bands required or hyperspectral at ~ 5 to 8 nm resolution over 380-820 nm, 16 to 20 nm 820-1000 nm; 16-20 nm in SWIR.

5.3.6 End-user requirements

- In the inland waters, near coastal, coastal and seagrass/macro-algae/coral reef environments the end-user requirements are highly diverse (mainly due to the scale of the ecosystems and the management boundaries) , which has been an obstacle for getting dedicated sensors designed, built and launched. Workshop participants highlighted that many grey literature report and inventories exist (sensor studies and proposals, H2020 projects, state and national government level reports, etc.). It is recommended to unearth all these reports and to do a meta-analysis and publish this in the international peer reviewed literature. Such consolidated end user requirements across continents and use cases would be very beneficial. This could flow through to a globally accepted science and applications traceability matrix.

5.3.7 Science Community ideas

- The EO science community would greatly benefit from a simulated dataset (e.g. contain such aspects as global, high spatial, high spectral, high radiometric, high temporal (hourly- to daily) as well as optically deep and optically shallow environments with both homogeneous and heterogeneous substratum types, representative for LEO polar and equatorial and geostationary orbits.
- Study how to Include vertical resolution (e.g., Lidar or stereo-photogrammetrical approaches or inversion approaches) in water column
- Study benefit and disadvantages of spatial and spectral blending: multiple spatial and/or spectral resolution from the same sensor (e.g., Landsat) or a suite of sensors, including World View V, Sentinel-2 and Landsat. This emphasizes the need for coordinated mission developments from formulation to operations.
- Geostationary satellite ocean colour sensors could go down to 50 m spatial resolution. More studies are needed to explore whether a swarm of polar LEO or 4-6 geostationary high spatial resolution sensors, or a combination of these approaches would result in optimal observing system architecture and increased cost effectiveness.
- The adjacency effect vs. spatial resolution is an area where more research needs to be done; the physics say adjacency is not only a function of distance from the land boundary but also it depends on environmental conditions (e.g., aerosol optical thickness, aerosol height, topography, land cover). Ranging from 5 Landsat pixels to 5 MODIS pixels: this apparent contradiction requires dedicate research.

5.3.8 Relevant publications

- CEOS feasibility study 2018 (http://ceos.org/document_management/Publications/Feasibility-Study-for-an-Aquatic-Ecosystem-EOS-v.2-hi-res_05April2018.pdf)

5.4 Breakout 4: Remote sensing of optically complex and shallow waters

Chair: ZhongPing Lee (UMass Boston, USA)

Co-Chair: Dirk Aurin (NASA/GSFC)

5.4.1 Description

Optically complex waters and shallow water environments continue to present unique challenges to our evolving understanding of ocean color remote sensing, and to the operational and mission capabilities we are bringing to bear on the problem today. By definition, complex waters contain optically active constituents which fail to co-vary in concentration or optical characteristics with one another, thus belying the assumptions we tend to use in the open ocean to invert reflected sunlight for the estimation of those constituent properties such as chlorophyll concentration. Also, variations in the vertical dimension further complicate the matter. Shallow water reflectances are often anomalously high (i.e., routinely masked and problematic for atmospheric correction), and characterized by extreme spatial heterogeneity compared to most other aquatic environments, while also contributing an additional unknown parameter to the inversion of the light field beyond the capability of standard semi-analytical approaches. Most current and legacy ocean colour sensors are not optimized for observing optically complex or shallow waters – for example having too few spectral channels for accurate separation of inherent optical properties or characterization of phytoplankton pigments, saturating over shallow or turbid pixels, or underestimating constituent concentrations due to spatial/vertical sampling limitations, among other problems. These technological limitations exist despite the fact that many of these waters are situated near-shore or inshore and host fragile and important ecosystems such as coral reefs and fisheries that are important to human life, while being significantly impacted by human activity. As more sophisticated sensors are developed with higher spatial, temporal, and spectral resolutions, as well as polarization sensitivity and active sensing through LIDAR, their capabilities have the potential to vastly change and improve how we study optically complex and shallow waters remotely. This workshop is designed to explore these recent developments and consider whether our theoretical understanding is keeping pace with technological capabilities scheduled to come online in the near future.

5.4.2 Breakout workshop presentations

To provide a full picture of the challenges and status of current knowledge and technology, this breakout workshop was composed of the following presentations:

Colleen Mouw: Overview of the challenge of complex waters

Antonio Mannino: Requirement of the sensing of “new” water in high latitudes

Chuanmin Hu: Floating algae

Yingcheng Lu: Oil spill

Yongxiang Hu: Lessons from CALIPSO

Deric Gray: Ocean LIDAR

Rodrigo Garcia: Advancement of shallow water algorithm

5.4.3 Discussion/Recommendations

There were active and “intense” discussions after the presentations, ranging from data to capacity, with a summary presented below:

- 1) “Complex” water is not limited to coastal or shallow environments. Oceanic waters also consist of optically significant and varying properties including CDOM and bio-optical pigments that do not necessarily co-vary with chlorophyll-a concentration, though they do contain relatively lower amounts of nearly all biogeochemical components.
- 2) There is a strong demand for more high-quality *in situ* data, which includes (but is not limited to) measurements in high altitude lakes and in high latitude (Arctic/Antarctic) waters, reflectance data in the UV and near-IR, as well as libraries of substrate reflectances, etc. It is strongly recommended that, in addition to submitting data to designated data center (e.g., SeaBASS), members of the community publish their valuable data in data journals.
- 3) To tackle the issues/challenges related to remote sensing in complex waters, simply relying on aquatic colour is not enough. It is important to incorporate information from other sources, such as temperature, vertical profiles (Lidar), mix-layer depth, etc. Measurement and reporting of such *in situ* parameters are strongly recommended in order to fully understand and interpret the complexity of various aquatic environments.
- 4) The establishment a few “super sites” worldwide – where the community can obtain time series measurements of broad environmental parameters – is recommended in order to improve our understanding of complex waters and the remote sensing thereof.
- 5) The expansion of ocean Lidar remote sensing suggests the development and distribution of a community-accepted simulation system for active remote sensing analogous to Hydrolight for passive remote sensing.
- 6) The first-order product from passive or active remote sensing is still an optical product, such as the inherent optical properties. In addition to continuing the refinement of algorithms for IOPs, it is recommended to expand the training and the application of IOPs for biogeochemical studies.

5.5 Breakout 5: Vicarious calibration and validation protocols

Chair: Giuseppe Zibordi (EC JRC, Italy),

Co-Chairs: Kenneth Voss (U. Miami, USA) and B. Carol Johnson (NIST, USA)

5.5.1 Summary Report

The Breakout Workshop aimed at finding consensus on standardized protocols for the operational identification and application of *in situ* measurements to validation and system vicarious calibration (SVC) processes. Two short talks introduced the two sub-sessions on Validation and SVC. The first talk “*Introduction to practices for the construction of in situ – satellite matchups, their application to the validation of data products and the presentation of matchup statistics*”, was delivered by G. Zibordi. The second talk “*Introduction to practices for the construction of in situ – satellite matchups, their application to SVC and the statistical assessment of derived calibration factors*”, was delivered by K. Voss. Each talk was followed by discussions supported by tables listing key elements for the construction of matchups with the final objective to reach agreement on basic protocols (i.e., standard guides) supporting validation processes and SVC. Care was put in ranking requirements by stressing the fact that different spatial/temporal/geophysical applications may impose very different levels of requirements.

The following main elements were debated during the validation and SVC sub-sessions:

- i. The fundamental requirements for *in situ* measurements supporting single missions for regional/global applications or multiple-missions addressing climate studies (e.g., geophysical quantities, spectral characteristics, uncertainty budgets and traceability, geographical relevance, ...);
- ii. The fundamental physical methods to enforce equivalence of satellite and *in situ* data (e.g., application of identical corrections for BRDF effects, corrections for minimizing the impact of different spectral bands, ...);
- iii. The fundamental criteria to be met for the construction of matchups (e.g., local spatial/ temporal variability, observation conditions, ranges of applicability, time-lags between *in situ* and satellite data, geographical origin of the *in situ* data, ...) and additionally, the fundamental methods and criteria that should be commonly applied for the statistical analysis of matchup data and the following presentation of summary results (e.g., the statistical methods for the determination of systematic differences and dispersions affecting satellite data with respect to *in situ* measurements, the information complementing matchup analysis when presenting results, ...).

Outcomes from the workshop are summarized in the following two tables centred on Validation and SVC requirements. Future actions, benefitting of contribution from participants to the break out session and additional members of the ocean color community, envisage the consolidation of the tables with the possibility of formalizing requirements in a Report or a White Paper.

5.5.2 Validation Protocol Requirements

5.5.3 System Vicarious Protocol Requirements

5.6 Breakout 6: Research to Operations and Applications (R2O&A)

Chairs: Veronica Lance (NOAA, USA)

Co-Chair: Ewa Kwiatkowska (EUMETSAT, Germany)

5.6.1 Final Report

The value to society of satellite-based ocean colour (OC) remote sensing observations is realized when they are used to improve decision outcomes. For OC to be incorporated routinely into downstream user operations, data products must be consistent, robust, routine, and sustained, mature, fit-for-purpose, discoverable, well-described and accessible in forms conducive to their use. The new paradigm of “operational” satellite data extends beyond near-real time to also include consistent, longer term time series (full missions and across missions). Given the multiple satellite missions now routinely providing robust OC data along with additional missions anticipated in the near future and out into the coming decades, OC has reached the maturity to be incorporated into downstream operational applications, yet barriers remain.

The 2013 IOCS splinter session, Operational Ocean Colour Data in Support of Research, Applications and Services, produced 15 recommendations. In the past ~6 years, many of these recommendations have been implemented or are in progress by operational agencies. The various reports from IOCCG helped tremendously to influence agencies to accept and adopt these practices and requirements.

Data quality, stability, continuity, sustainability, accessibility and operational maturity (2013 recommendations 1-5) have largely been the rule for NOAA (VIIRS on SNPP and JPSS-1/NOAA-20) and EUMETSAT (OLCI on Sentinels 3A and 3B).

Data products (2013 recommendations 6-13), with some exceptions, are available at multiple processing levels, near real-time streams and delayed mode streams are available for full missions. The requested availability of open source processors still requires further effort.

Stakeholder engagement (2013 recommendations 14 and 15) activities have been taking place at various levels (e.g., training programs) and progress is being made across the international community, especially through efforts of the IOCCG.

In this 2019 workshop we focused on the next level of progress from the perspectives of users (clients), remote sensing scientists, and those working to bridge gaps between them in order to get OC data into more applications where they can make a positive impact on decision outcomes. The scope included both 1) broad, efforts in making OC data more accessible (intellectually and functionally) to a wider audience and 2) narrow, vertically integrated services that drive the value chain from earth observations to actionable information for targeted applications.

The Session organizers asked presenters to address the 3 Key Questions listed and ensured time for discussions involving all session participants.

5.6.2 Three “Key Questions”

- 1) What are the user requirements for operational OC products and where should the main research and technical efforts be concentrated?
- 2) What developments in approaches, techniques and/or tools are needed to address users at multiple levels of sophistication, how best to supply necessary details while not overwhelming as needed for free and open access to data through multiple outlets and serving distinct and diverse audiences?
- 3) What mechanisms are useful to bring developers and users together at early stages and how best to engage parties to achieve successful implementation?

Some of the suggested topics listed above generated more focused discussions (shown in bold) than others.

- **Need for low latency NRT - within 2-3 hours with data quality adequate for purpose (case-by-case)**
- **Cross-mission continuity and consistency of datasets (differences in products are problematic)**
- **More value-added products, e.g., Primary Productivity, PFTs, Anomalies (especially for chl and SST)**
- Better inter-parameter viewing, querying, data access - need an attractive front end
- **User support for large data volumes**, e.g. data sub-setting, cloud computing with on-the-fly processing tools and tools for online analyses
- **Merged multi-mission time series (e.g., one daily composite)**
- **Regionally relevant products, where standard products currently do not work**
- Serving model results and downstream applications (but see bullet #2)
- Metadata (describe the dataset “well” and “interoperably”, i.e. GHRSSST-like)
- Documentation of product quality (i.e., performance, uncertainties, for what purposes are the data “fit”, ATBDs)
- ***TRAINING, TRAINING, TRAINING (e.g.: weather service approach; product training for sector-specific users and for commercial users, etc.)**

5.6.3 Summary and IOCCG Recommendations

In summary, our detailed and productive discussions encompassed users/clients, products, and training. Some specific recommendations to IOCCG have been extracted from these.

Summary

- **USERS/CLIENTS:** Clients knowledge and technical capabilities (and/or resources) span a wide range forming a “matrix” of needs to be served. For example, a non-satellite subject matter expert may use a highly sophisticated model and possess advanced processing capabilities, but

may know little about how to choose an appropriate ocean color dataset or s/he may have a relatively good understanding of the meaningfulness of a downstream ocean color product and prefer it be produced “ready-made” to simplify and streamline their use of data to quickly, routinely address their application/decision.

- **PRODUCTS:** Users want single consistent and stable product time series, long-term to NRT, merged from multiple instruments which are regionally adjusted to assure the highest quality, as well as anomaly products.
- **TRAINING:** Need to actively engage with different type of users, provide on-line resources (guide for different applications e.g. fisheries, HABs, aquaculture), workshops, training, also opportunities for the OC community to engage with higher level users.

Recommendations to IOCCG

Recommendations to IOCCG arising from this R2O&A Breakout Session include:

- Support outreach materials (e.g., refreshed handbook of examples reflecting current operational satellite ocean color products) and promote training activities (e.g., non-expert training courses) directed to non-satellite-expert users focused by sector or by application.
- Support ocean color science research and development of higher level products (e.g.: endorse the development of an operational consistent, multi-mission NRT and long term time series with “guarantee” to continue forward), products especially useful for model assimilation, and regionally adapted products.
- Allocate portions of future IOCS and IOCCG events dedicated to hearing from non-ocean-color-expert clients (or potential clients) from multiple sectors (management agencies, commerce, research, etc.).

5.7 Breakout 7: Emerging technologies for ocean colour science

Chair: Mike Twardowski (Florida Atlantic University, USA)

Co-Chair: Griet Neukermans (LOV, France)

5.7.1 Session goals

Discuss breakthrough technologies for ocean colour, considerations in implementation, and associated potential for new applications in ocean colour science. The focus of the session was not gaps in technology for ocean colour, as this has been addressed in several recent papers and workshops. Emerging technology types were grouped into 3 categories: radiometry for cal/val, IOPs, and emerging imaging systems for ocean colour. Each session included at least one presentation from each technology group followed by discussion.

5.7.2 Summary of discussion for radiometry

Besides the sensor systems presented, another emerging radiometric sensor system being developed is the MOBY-NET system, with focus on OC calibration for the NASA PACE mission. Another system that was mentioned was the Floating Optics Buoy (FOBY) developed in China by Liqiao Tian (Wuhan U), Zhaohua Sun (S. China Sea Inst. of Oceanology), Qingjun Song (National Ocean Satellite Application Center), and Jun Zhao (Sun Yat-sen U) based on the approach of Lee et al. (2013) in blocking skylight glint with a cone.

The importance of consistent, rigorous, and transparent approaches to calibration and characterization of radiometric sensor systems being developed globally was emphasized. A key recommendation was for all groups to adopt the protocols for calibration and characterization detailed in the Zibordi and Voss draft NASA protocols document currently available on the IOCCG website. This document is currently undergoing a period of review by the community. Another recommendation was the necessity that detailed instrument specifications, characterization and performance results be published with peer-review for all systems. If these recommendations are met, then a centralized lab for calibration and characterization of all radiometric systems should not be necessary.

With the emergence of new radiometric cal/val assets for ocean colour globally, the need for developing a coordinated strategy for global calibration and validation requirements was recognized. Radiometric assets for cal/val may soon include stationary buoys (MOBY-NET, BOUSSOULE), profiling floats (HyperNAV, ProVal), and stationary above-water systems (AERONET, HYPERNETS, WATERHYPERNETS), as well as more conventional boat deployed systems for in-water and above-water radiometry. Optimal calibration and validation strategies must be developed that balance numbers and locations of specific assets with practical considerations such as cost, who pays, and possibly international restrictions in mobilizing assets. Furthermore, optimal strategies will vary depending on specific science questions of interest and/or management applications.

5.7.3 Summary of discussion for IOPs

Besides the scattering sensor systems presented by Slade from Sequoia, other emerging IOP sensors discussed included the multi-wavelength backscattering sensors recently commercialized by In-situ Marine Optics, Freemantle, Australia. These devices have larger dynamic range than WET Labs ECO sensors, with quantitative b_b measurements possible in extremely turbid waters. It was also noted that servicing of existing a_c devices from SeaBird/WET Labs was becoming increasingly sluggish and it is rumored these devices may be discontinued entirely in the near future, creating a potential issue with disappearing technology that is critical to our community.

A key topic of discussion was finding compatibility between the community's need for increasingly complex, expensive instrumentation with extensive capabilities (i.e., hyperspectral, multi-angle, polarization, etc.) and a viable business model for the companies willing to develop these sensors. If our market can only bear the sale of a handful of these sensors, conventional commercial sales will struggle to be profitable. One thought was to use a centralized business service model, where community-certified, high quality instrumentation with experienced technician and associated protocols are hired for field efforts from the company. This model would help ensure consistent, high quality measurements are being made within the community, and the market for providing the service may be large enough to actually be profitable.

5.7.4 Summary of discussion for remote imagers and platforms

The point was made there is no program at NASA focused on developing capabilities for Earth observing from CubeSats. While programs such as INVEST sometimes use CubeSats to test remote sensing technologies before deploying on a full mission, there is no program we are aware of where the pursuit of remote sensing from high altitude platforms (i.e., stratospheric drones and LEO CubeSats) to enhance current measurement capabilities for cost-effective, quantitative science IS the mission. As a general comment, imaging technology is progressing to a point where high quality ocean colour measurements may soon be possible on CubeSat type platforms. These platforms may address a significant current gap in high spatial (~10 m), high temporal (~hourly) frequency measurements in coastal regions with hyperspectral capabilities. Such devices could also enhance data collection at the poles. Considering the cost-effective nature of these imaging systems and platforms and the potential for broad global coverage through a constellation of such systems—as well as conflicting/tenuous political support within the US for typical NASA style ~\$1B global ocean colour missions—such an approach may be worth investment, at least in parallel to the global type missions. In the future, if we were able to couple a CubeSat constellation with the global missions, we would increase the range of spatial and temporal resolutions sampled while enabling cross-calibration of CubeSat imaging technologies with the very high quality global imagers. And if there was a gap in the future in global class ocean colour imaging, our community would still have a resource to continue ocean colour research.

The potential of imaging from CubeSats and high altitude platforms has been recognized within the European Space Agency, resulting in a new program initiated in 2018 call phi-lab, focused on “disruptive technologies” in Earth observing such as CubeSats, high altitude long endurance (HALE) platforms, Earth observing sensors for these platforms, and emerging techniques for assimilating data from these emerging technologies for science applications. The US Office of Naval Research has also started a new program for development of Earth observing sensors for CubeSats, and the technology demonstration division of the US Navy, SPAWAR, has a CubeSat testing program and a new program to test HALE drone platforms. A recommendation is NASA should consider investing in these types of programs in the US.

While imaging technology for compact platforms is progressing, it was pointed out that the capability to provide ocean colour imagery from these platforms of adequate quality to address key science applications has yet to be demonstrated. There is a chicken and egg argument here, as without support from the major space agencies such as NASA and ESA to develop and test such technology, such a demonstration is challenging. Other funding sources currently must be leveraged. As mentioned, US ONR is now supporting development of CubeSat sensors for Earth observing. Also, the Hawkeye imaging system for CubeSats (UNCW) is funded by the Moore Foundation.

CubeSat platforms come with reaction wheels for fine attitude adjustment, so multi-angle views through orbit are possible, as well as periodic platform rotation for moon calibration. It was mentioned that liability insurance is needed to deploy CubeSat platforms.

CubeSats are usually piggybacked on larger mission deployments, but this can still cost US \$250K according to UNCW. The ESA phi-lab has offered CubeSat deployment opportunities as well and there may be cheaper deployment options in the future.

5.7.5 Summary of Recommendations

Radiometry recommendations

- Individual global entities with emerging technology for radiometric systems for vicarious calibration should all use “established (draft)” protocols of Zibordi and Voss (IOCCG website).
- Need for International strategy for integration of all emerging technologies for vicarious calibration of ocean colour satellites

IOPs recommendations

- May need to consider a centralized business-service model with complex technology that is emerging

Emerging imaging systems for ocean colour

- High quality ocean colour measurements may soon be possible on CubeSat type platforms: ESA Phi-lab funding programme for Earth observation from HALE (high altitude long endurance) platforms; will there be a NASA analogue?

5.8 Breakout 8: Ocean Colour Satellite Sensor Calibration

Chair: Gerhard Meister, NASA

The meeting started with an introduction by the Chair. The main issue was planning the next meeting, which will need to occur earlier than the next planned IOCS meeting, preferably in about 2 years. Several options were proposed:

- SPIE in San Diego, USA
- Sentinel 3 Validation Team meeting in Europe
- IVOS (The Infrared and Visible Optical Sensors Subgroup of CEOS)
- Ocean Optics

A survey among the group members regarding the venue for the next meeting was initiated.

The format of this year's meeting was a series of presentations, with ensuing discussions. Interest was high and some of the discussions took much longer than anticipated. The allocated time for the breakout session was significantly exceeded.

The first presentation was by Gerhard Meister (NASA) on the calibration program for the Ocean Color Instrument (OCI) on the Phytoplankton, Aerosols, Clouds, and Ecology (PACE) mission. In addition to heritage measurements, OCI will have the capability to measure changes to the radiometric gain linearity on-orbit.

Jack Xiong (NASA) presented results from the prelaunch calibration and characterization campaign for the JPSS-2 VIIRS sensor. Overall performance is as expected and good, with fewer non-compliances than for JPSS-1 VIIRS.

Ludovic Bourg (ACRI, ESA) showed qualitative results from the first lunar image acquisition of an OLCI sensor. It is likely that this work will lead to a refinement of the OLCI straylight correction. The 1020 nm channel appears to be affected the most.

Shihyan Lee (SAIC, NASA) evaluated the impact of straylight on MODIS Aqua ocean scenes. The worst case assumption underlying the definition of the current NASA cloud flag for MODIS (and probably VIIRS as well) is too conservative. It should be investigated if the flag size can be reduced.

Kibeom Ahn (KIOST) presented the lunar calibration and MTF plan GOCI-II. Lunar measurements are possible without a spacecraft maneuver with GOCI-II because GOCI-II has a full disk imaging mode (a new feature relative to GOCI-I).

Menghua Wang (NOAA) showed that after April 27, 2018, VIIRS-NOAA-20 ocean colour data quality meets the data provisional (or even validated) requirements. He also determined that before April 27, 2018 VIIRS-NOAA-20 ocean colour data have some data quality issues due to discontinuities in the gain calibration.

Hiroshi Murakami from JAXA presented the on-orbit radiometric calibration of SGLI. A solar diffuser and lunar measurements were used for gain trending. Lunar measurements also verified the straylight correction. Additional analysis was required to improve consistency between the three telescopes.

Xianqiang He (SIO) talked about the on-orbit performance of the HY-1C/COCTS. A cross-calibration technique using MODIS Aqua was used for gain calibration and polarization characterization. The results were validated against MODIS Aqua, SNPP VIIRS and Aeronet-OC with good results.

Ewa Kwiatkowska (EUMETSAT) presented new results from the Sentinel-3 OLCI in flight diffuser characterization. On-orbit yaw maneuvers significantly improved the usability of the solar diffuser time series for relative gain trending over time, but could not reduce a constant bias in the calibration. In general, special care must be taken during prelaunch BRDF characterization of the solar diffuser to match the on-orbit view and illumination geometries as closely as possible and to obtain the most accurate BRDF at least at one of these geometries. For sensor intercomparison, the alignment accuracy specifications for the diffuser orientation relative to the instrument must be tight enough to allow matching the on-orbit angles across instruments.

Ludovic Bourg (ACRI, ESA) showed first results from the tandem flight of OLCI-A and OLCI-B. The comparison of the two data sets showed new possibilities that the ocean colour sensor calibration community has not had before. The results will be extremely useful e.g., to investigate the radiometric gain differences between OLCI-A and OLCI-B. The slightly different spectral calibrations between the two sensors are a challenging feature when comparing the two sensors. Based on the discussions following each presentation, we arrived at the following 3 main recommendations.

5.8.1 Recommendations

- 1) Every mission should evaluate if lunar observations can be acquired, at least infrequently (for gain corrections and/or straylight evaluation). ESA and JAXA presented preliminary results of a straylight analysis of the lunar measurements. Results are extremely useful for evaluating the accuracy of the current straylight correction and may lead to improved correction algorithms/coefficients.
- 2) Every mission should evaluate if, for a newly launched sensor, a tandem flight with another sensor is possible. A tandem flight is where one sensor follows the other in orbit closely, in order to achieve very similar view and illumination geometries. This provides an enormous data set for a direct comparison of the measured top-of-atmosphere radiances.
- 3) The gain calibration trends for ocean colour sensors should not contain discontinuities or seasonal patterns that are not clearly supported by calibration measurements. If erroneous discontinuities or patterns do occur, they should be replaced by continuous trends in a timely fashion.

5.9 Breakout 9: Atmospheric correction under complex/extreme environments

Chair: Constant Mazeran (SOLVO),

Co-Chairs: Amir Ibrahim (NASA) and Robert Frouin (UCSD)

5.9.1 Objectives

Building on the earlier IOCS-2013 session about atmospheric correction (“Advances in atmospheric correction of satellite Ocean-Color imagery”), the goal of the present workshop was to review the recent progress achieved by the OC community for complex conditions frequently observed by satellites: atmospheric correction over optically-complex waters and under complex atmosphere (absorbing aerosol, NO_2). Another topic relevant in complex environments was the provision of evolved level of confidence, such as per-pixel uncertainties, instead of binary flags. See the slides of Breakout workshop 9 on the IOCS website at: <https://iocs.ioccg.org/iocs-2019-meeting/iocs-2019-presentations/>

5.9.2 Recommendations

1. Better understand the performance of AC algorithm

Many algorithms have been developed over the past years, covering a large range of forward models and inverse techniques. There is now a need to better understand their performance by answering the following questions: why do algorithms work or fail? What are their fundamental assumptions which explain their performance? Are there compensations in the errors (e.g. between marine and atmospheric modeling)? International validation/comparison exercises should be encouraged (such as the IOCCG working group “Intercomparison of Atmospheric Correction Algorithms over Optically-Complex Waters” or the CEOS Atmospheric Correction Intercomparison Exercise (ACIX-Aqua) activities) to provide guidance and recommendations to the users, but they have to go beyond a simple ranking and explain the root causes of the AC performance. To address this, the ACIX-Aqua will report performances as a function of water types, surrounding landcover, imaging geometry, and aerosol conditions.

2. Use the full spectral information

For complex environments, focus should be put on AC using the full spectral information (e.g. spectral matching algorithm), instead of the heritage NIR-based approach. This is important to get the proper spectral shape in the blue-green bands over complex waters. Because coupled approaches require a representative marine reflectance model, this requires to improve physical modelling (e.g. better knowledge of IOPs) or to go to statistical approaches.

3. Pay attention to pre-corrections

In general, AC algorithms start from the Rayleigh corrected signal. In complex conditions, this actual radiometry might not be accurate enough and degrade the theoretical performance of the AC itself. The following pre-corrections, although already part of the Level-2 processors, should get more attention:

- Effect of surface reflection (sun/sky glint), in particular for pushbroom technologies (Landsat-8, Sentinel-2).
- Gaseous corrections and out-of-bands. Water vapor is particularly crucial for OLCI bands in the NIR. NO₂ is also of most concern near industrial coastal area (see below).
- White-caps
- Rayleigh correction itself

4. Provide open code and open data

Understanding the performance of the AC algorithms and improving them requires a public access to their source code. This is the case of various codes (e.g., SeaDAS, POLYMER, ACOLITE...) but still not of the OLCI Level-2 processor. This should become a principle of funding agencies. Simulated datasets should also be shared in the community (open data). In particular in complex/extreme environments, where there are little or non-optimal in-situ measurements. For instance, a new simulated dataset could represent events of absorbing aerosols.

5. Better exploit and extend validation datasets

Existing datasets (e.g. AERONET, AERONET-OC) are probably under-exploited when only used to get overall validation statistics on the retrieved marine reflectance or aerosol optical thickness. There is a need to investigate them in more details to understand the sources of failure of AC, based on physical analyses (e.g. discrepancies with respect to aerosol phase function).

It is highly recommended that the space agencies collaborate with operational water agencies/ authorities benefiting from satellite data products to extend the validation network. This capacity building requires inter-agency effort to coordinate data collection. More importantly, using this new type of data requires further attention to the protocols and representativeness of the measurement.

A general recommendation about validation datasets is to maintain them in open access at international level, with inter-agency coordination. For complex environments, there is a particular need to gather data representative of situations expected to be acquired by satellite (for instance today UV measurements are lacking).

6. Address specifically the issue of absorbing aerosols

Absorbing aerosols are present over vast oceanic regions. They cannot be neglected as their impact can be 10 times larger than acceptable errors. AC based on NIR-SWIR only cannot handle the issue. Various solutions exist and should be analyzed in more details, notably for PACE, such as:

- Estimate the relevant optical properties (e.g., using multi-angle photo-polarimetry); still, it should be checked that accuracy of these properties is sufficient for the purpose of ocean colour.
- Use all the wavelengths with deterministic/statistical schemes, in particular bands sensitive to aerosol absorption, i.e., UV. With such approach, there is a need to study what would be the radiometric requirement in the UV, depending on the AC method (physic-based, spectral matching...). Another option is to consider the current capability in field radiometry in the UV and performance of existing UV sensors.
- Using multi-angle information (allows one to avoid determining separately the relevant variables). Feasibility for PACE (SPEX, HARP) should be investigated.

- Detect the presence of absorbing aerosols and, shift to a set of absorbing models in the standard AC algorithm.

To address the issue, agencies should encourage interdisciplinary collaboration between the modelling, atmospheric and the OC communities. For instance, global assimilated aerosol transport models could constrain the inversion; this solution could be implemented to past sensors to ensure continuity and to sensors from which we could not obtain a reliable AC.

The potential of hyperspectral inversion of the oxygen band should be studied to get the vertical distribution of the aerosol. Experiments could be done with PACE and its 0.6 nm resolution programmable bands. Lastly, using Lidar for better describing the aerosol vertical column profile should be encouraged. This would help to select aerosols in a subset of models.

7. Take into account small scales variability of NO₂

Small scale variability in tropospheric NO₂ needs to be taken into consideration for coastal imagery. Effect can be as large as 50, 100 or 200% on remote sensing reflectance in the blue depending on Sun zenith angle. Diurnal variability impacts not only the amplitude of the signal but also its spectral shape.

The need for high-spatial and temporal resolution of atmospheric NO₂ instead of current climatology could be achieved:

- From shipboard platforms, to integrate these measurements to AC approaches
- From satellite observations of atmospheric NO₂ (e.g., TEMPO, TROPOMI, GEMS, Sentinel-4, Sentinel-5) in operation.

The idea of using hyperspectral bands in the blue (400-450 nm) is challenging but should be investigated with PACE.

8. Derive uncertainties as part of the algorithm development

Deriving uncertainties should be a requirement when developing algorithm, especially in complex environments. It is found to be a rigorous approach to understand performance of the AC and list the various sources of errors (calibration, absorbing gas, sea state, aerosols...).

In complex environments, the target uncertainty in ocean colour radiometry should go beyond the historical 5% requirement defined over open ocean. Because of small signal, new requirements should be defined in radiometric unit, and could distinguish the water types. For the same reason, slightly negative reflectance should be kept (up to a given level) to not bias the statistics in the uncertainty assessment. Ideally the spectral error covariance should be also specified for appropriate use in the downstream ocean colour products.

Providing uncertainties of the OC radiometry requires to characterize the input L1-B uncertainties following metrology principles, both the pre-launch and post-launch. The full uncertainty structure is required: random & systematic components, temporal evolution, correlation (spectral, spatial). Agencies should provide in the L1B products the covariance matrix of the noise as well as the uncertainty of the calibration coefficients.

6. Q & A Session: Ocean Colour Community and Space Agencies

On the final day of the meeting, a Q & A session was held for the ocean colour community to ask insightful questions and communicate their views, ideas and concerns with the space agencies. Cara Wilson noted that the IOCCG is considering restructuring the breakout sessions because the time available is not sufficient for in-depth discussions as well as formulating recommendations. Input from the community is very important to help structure IOCCG's work plan and to provide community input to the agencies. In future, the IOCCG will establish breakout workshop teams ~1 year before the meeting so that they can develop strawman recommendations to be discussed and validated during the meeting. It was also noted that two years is a relatively short timeframe for community recommendations to change and evolve, and for the IOCCG, the community and the space agencies to address and implement these recommendations, so it was suggested that the next IOCS meeting should perhaps take place in 4 years time, around May 2023, in the USA.

Cara Wilson summarised the recommendations from the current nine current breakout groups (see <https://iocs.ioccg.org/wp-content/uploads/2019/04/fri-1445-wilson-summary.pdf>), highlighting which recommendations were directed towards the IOCCG, the ocean colour community and/or the space agencies. Relationships between past IOCS breakout workshop recommendations and current/past IOCCG activities were highlighted (e.g., IOCCG reports and Task Forces), and the uptake/implementation of past IOCS recommendations by the agencies and/or the ocean colour community was also summarised.

Arnold Dekker suggested holding another meeting dedicated to the synthesis of recommendations emerging from the IOCS-2019 meeting, since many recommendations go across breakout groups. Ewa Kwiatkowska (EUMETSAT) commented on the progress of IOCS meetings over the past 6 years. When these meetings first started in 2013, breakout groups were discussing issues such as data dissemination, the need for L3 products, data formats etc., which have since been addressed. She noted that other recommendations from groups such as atmospheric correction take much longer to implement as the science needs to develop first.

In response to a question regarding encouraging interdisciplinary collaboration between different communities (e.g., modelling community and atmospheric correction, and the need for better spatial and temporal resolution), Paula Bontempi responded that the IOCCG has added modellers to the IOCCG Committee, and that the disconnect between data products and uncertainties is being addressed. A numerical modelling breakout group may also be considered at the next IOCS meeting to ensure that the agencies are providing the community with what they need. Menghua Wang pointed out that NOAA was providing global data products (e.g., Chl) that can be routinely used for models. It was also noted that an IOCCG report on modelling is nearing completion.

There is also the need to cooperate across the disciplines to improve the quality of atmospheric correction. An audience member gave an example of the AeroCom/AeroSAT projects - scientists

interested in aerosol modelling and aerosol remote sensing, respectively, which meet every year to exchange ideas and develop consensus

Astrid Bracher (AWI) noted that the PFT community needs help from the IOCCG and the agencies to support international round-robin experiments, validation exercises, and targeted workshops to identify gaps for satellite PFTs and resolve issues. It was also noted that more could be done using machine learning and artificial intelligence to extract usable data from imagery.

Kevin Ruddick drew attention to the successful ESA FRM4SOC project and noted that these types of transverse intercomparison exercises are very effective in raising the quality of *in situ* measurements. He recommended that the IOCCG should support such types of activities in the best way they can. Robert Frouin drew attention to the recurrent need for *in situ* data to understand variability of parameters, but also to develop bio-optical algorithms. Perhaps the agencies should get together to define the proper way to collect the data and identify gaps for global scale algorithms. Ewa Kwiatkowska welcomed input from the community in identifying gaps in *in situ* data, e.g., to improve algorithms in specific water types, indicating where the agencies should focus their investments. Paula Bontempi pointed out that part of the issue was not so much data limitation, but rather getting researchers to submit their data to SeaBASS, as NASA has funded many projects over the last two decades. But all agencies welcomed input on observational gaps.

Chuanmin Hu noted that it is impossible to have a one-stop data repository, but suggested that the agencies work with the IOCCG to provide more information for the IOCCG resource page, to guide users on where to look for different data products from different sensors. Having metadata on the IOCCG website would also be useful .

Capacity building and training plans were also discussed. Cara Wilson noted that IOCCG training courses are always over subscribed, but many resources are available on the IOCCG website, including video recordings of all the lectures from the IOCCG Summer Lecture Series. The IOCCG also plans to update IOCCG Report 3 on remote sensing in optically-complex waters, which is an extremely useful resource, but the science has progressed over the past 20 years. Veronica Lance noted that it is important to provide training for different audiences (research scientists as well as other users). The IOCCG will develop a training roadmap to direct users to the right resources. Hayley Evers-King suggested that the IOCCG also promote inter-agency training labs, as users often use multiple types of data from different satellites.

Arnold Dekker noted that most people still use the OC3 and OC4 algorithms which only require 4 or 5 spectral bands, and suggested that IOCCG encourage the use of full spectral data. Ewa Kwiatkowska noted that EUMETSAT is working on developing new algorithms, but they must still ensure an operational data stream. Researchers are welcome to develop new algorithms which the agencies may adopt. Perhaps more training should focus on hyperspectral methods?

Geostationary sensors were mentioned as a way forward, but the proposed NASA GEOCAPE mission did not make the priority list in 2018. Furthermore, the European Earth Explorer OCAPI instrument did not

succeed, as the call was for innovative technology. ESA and EUMETSAT are still hoping for some geostationary capability in future, perhaps on the next generation Copernicus missions, however there needs to be a strong push from the community (White Papers etc.). It was also pointed out that there were not enough users of geostationary OC data in Korea and SE Asia, so capacity building should be encouraged in these areas.

Cara Wilson concluded the meeting by saying that the IOCCG would convey the breakout workshop recommendations to the agencies, as well as focus the IOCCG and the ocean colour community on the implementation of all the initiatives emerging from IOCS-2019. She expressed IOCCG's extreme gratitude to KIOST for supporting the very successful meeting, including the many people at KIOST working behind the scenes to ensure the flawless logistics.

7. Poster Sessions

Participants were able to discuss their research with colleagues during four scientific poster sessions: two interactive poster viewing sessions and two very popular "poster lightening" sessions, where all poster presenters could share information with the audience quickly and efficiently through short (1 minute) oral presentations about their research. These poster lightening sessions took place during the main Plenary Session on Tuesday and Wednesday (9-10 April 2019), while the poster viewing sessions took place on Thursday evening (with refreshments) and Friday morning (with coffee).

A total of 130 posters were presented covering a wide range of topics. Poster abstracts can be viewed on the IOCS-2019 meeting website at: <https://iocs.ioccg.org/wp-content/uploads/2019/03/poster-abstract-iocs-2019.pdf>. These poster sessions allowed researchers and young scientists to present their current research and receive useful feedback from other scientists working in the same field.



8. Social Programme

IOCS-2019 meeting participants were fortunate to be invited to an ice breaker event, sponsored by KIOST and Airbus on the first evening. Pierre Coste (Airbus) gave an interesting talk on GOCI-II development, followed by a fascinating performance by the Yulparan ensemble playing traditional Korean instruments. A wide selection of tasty hors d'oeuvres were also served.



Following the meeting, participants were invited to a free bus tour of Busan and surrounding areas, compliments of the Busan Tourism Organisation (BTO). One of the highlights was a visit to the Haedong Yonggungsa temple, built in 1376, situated next to the sea.



Some of the IOCS-2019 participants at the seaside Yonggungsa temple.