International Ocean Colour Science Meeting 2013 | Advancing Global Ocean Colour Observations

Proceedings of the

International Ocean Colour Science Meeting

Darmstadtium Conference Centre

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6-8 May 2013

Convened by the International Ocean Colour Coordinating Group (IOCCG)
Sponsored by EUMETSAT, NASA, ESA and CNES

International Ocean Colour Coordinating Group (IOCCG) www.ioccg.org

David Antoine, IOCCG Chairman
antoine@obs-vlfr.fr

Venetia Stuart, Project Scientist
vstuart@ioccg.org

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1. Introduction

1.1 IOCS Meeting Rationale

Several space agencies have launched ocean-colour sensors in the past 15 years and will continue to do so in the future (CNSA, ESA, JAXA, KORDI/KARI, NASA, NOAA), while others plan to launch for the first time, or to operate such sensors in the coming decade (EUMETSAT, CNES, INPE/CONAE). Ocean-colour missions face a number of challenges in terms of instrument and vicarious calibration, building of long-term time series, data merging, and data distribution, to mention but a few. These challenges exist for all missions, yet each agency responds with a different approach. There is therefore a need for more communication, exchange of ideas, and collaboration among representatives from the various ocean-colour missions and the ocean-colour community. This need for better coordination is particularly important when it comes to merging data from multiple missions in view of generating long-term, consistent, global time-series for analysing climate-driven changes, which is why the overarching theme of the 2013 International Ocean Colour Science (IOCS) meeting was "*Building of global, multi-mission, long-term (multi decadal) ocean-colour time series for climate research*".

Ocean-colour scientific communities are organized differently around the World. In the U.S., for example, the NASA Ocean Color Research Team is the forum for scientific exchange. In France, a new research consortium called "GIS COOC" (http://gis-cooc.org) aims at progressively reinforcing the interaction among scientists involved in ocean-colour science. In South America, the Antares network has been active for several years (http://home.antares.ws) and in Canada a Canadian Ocean Colour Network is currently being discussed. These initiatives show efforts at the national level. The overall goal of setting up the IOCS meeting is to direct efforts at the international level, and to start building more international linkages among these different communities. The IOCS meeting was therefore conceived to:

- Allow space agencies to deliver information about their current and future missions to the scientific community;
- Set up the "big picture" of current ocean-colour science through keynote presentations;
- Provide a forum (breakout splinter sessions) for discussions on various topics;
- Help the IOCCG in its oversight role;
- Build and reinforce our community at the global scale;
- Allow more people from the ocean-colour community to be involved in IOCCG activities than is feasible through IOCCG Committee meetings and working groups alone;
- Produce synthesis documents of interest for the community in question (e.g., this meeting report); and

- Reinforce the ocean-colour community's voice when it comes to high-level discussions with space agencies.

As such, the IOCS is not another scientific conference. It is a community consultation meeting built on the same logic and model as meetings organised for many years by other scientific communities, such as the annual science team meetings of the GHRSST (Global High Resolution Sea Surface Temperature project) or the OST-ST (Ocean Surface Topography Science Team) meeting. These are working meetings where participants are engaged in a great deal more discussion than is possible during a traditional science conference.

1.2 Organisation and Structure of the First IOCS Meeting

The first International Ocean Colour Science meeting was convened by the International Ocean Colour Coordinating Group (IOCCG) and took place in the City of Darmstadt, Germany from 6-8 May 2013. EUMETSAT and NASA were the main sponsors of the meeting, with additional sponsorship being obtained from ESA and CNES. An Organizing Committee (10 members, with representatives from IOCCG, EUMETSAT, NASA and ESA) helped to arrange all aspects of the meeting via regular telephone conferences, while the Scientific Planning Committee (24 members) provided advice on developing the scientific program and the selection of the keynote speakers as well as the splinter groups.

In total, 244 scientists from 36 different countries participated in the three-day meeting, including representatives from all the major space agencies with an interest in ocean-colour radiometry. The IOCS meeting thus helped to bring together both the users and the providers of ocean-colour data for in depth discussions of detailed requirements for ocean-colour products and services.

The primary focus of the IOCS meeting was to build and strengthen the international ocean-colour community by providing a structure and mechanisms to collectively address common issues and goals, thus allowing the ocean-colour community to achieve the best quality ocean-colour data that meet scientific, environmental, climate and operational needs through international collaboration and scientific and technological innovation.

The format of the IOCS meeting included 8 space agency presentations, 5 invited keynote talks, 12 breakout splinter sessions (4 parallel sessions at any one time), 2 poster sessions as well as open floor discussions. The full meeting agenda plus all of the presentations from the plenary and splinter sessions, as well as the poster abstracts, can be accessed via the IOCS website at http://iocs.ioccg.org/.

An Icebreaker Event was held on Monday evening, sponsored by the City of Darmstadt, which was very well received. In addition, EUMETSAT offered a tour of the facilities at EUMETSAT HQ on Tuesday evening, followed by a conference dinner, which was a most enjoyable event.

The overall feedback from the meeting has been extremely positive. The IOCCG expresses their sincere gratitude to all the meeting sponsors as well as to the organising and scientific committees, for helping to make the meeting such a success.

1.3 IOCS Meeting Outcomes and Impact

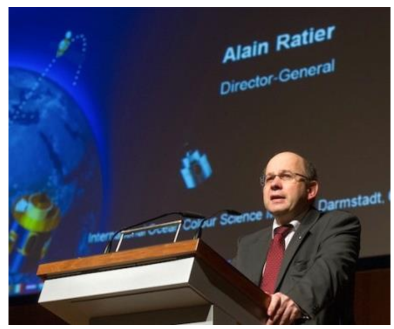
One of the concrete outcomes of the first IOCS meeting is this report, which includes summaries of agency talks and keynote presentations, as well as the reports and recommendations from the 12 splinter sessions. This document therefore represents a synthesis of current issues and questions related to ocean-colour remote science and, as such, can be used by space agencies and interested scientists to better understand the current state of the art, and to propose future actions and directions. By nature, the report is non-exhaustive and specifically covers the topics addressed in the 12 breakout splinter sessions. Numerous other issues could be the topic of discussion at future IOCS meetings.

To maintain momentum after the meeting, the splinter session chairs were asked if they were willing to continue working on the topic of their splinter session and if they would benefit from a dedicated follow-up workshop (sponsored by the IOCCG) to pursue the goals and outcomes of their respective sessions. This process is still on-going at the time of writing, and many groups have responded positively.

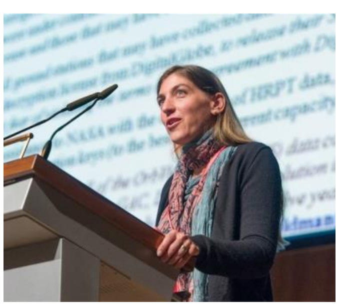
A less visible, yet tangible, output of the IOCS meeting is the progressive networking and establishment of relationships among ocean-colour scientists from around the world. Before the IOCS came into existence, this community had very few occasions to meet globally. Some members of the global ocean-colour remote sensing community attend meetings such as the bi-yearly Ocean Optics conference, or Ocean Science conferences organised by associations such as the ASLO and AGU. As mentioned previously, these conferences are not the ideal venues for community building. The overall feedback from the IOCS meeting has been extremely positive in this respect and many participants expressed the fact that this type of international meeting was long overdue in our community.

The IOCCG expresses their sincere gratitude to all the meeting sponsors as well as to the organising and scientific committees for helping to make the meeting such a success. The first IOCS meeting is an important milestone and we hope that it continues as a forum for future ocean-colour collaboration and planning discussions**.**

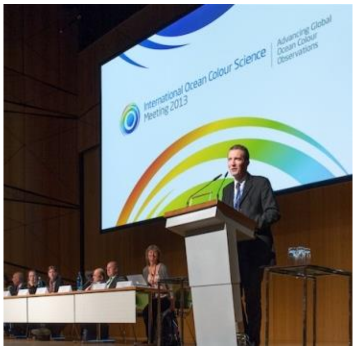
2. Opening Plenary Report



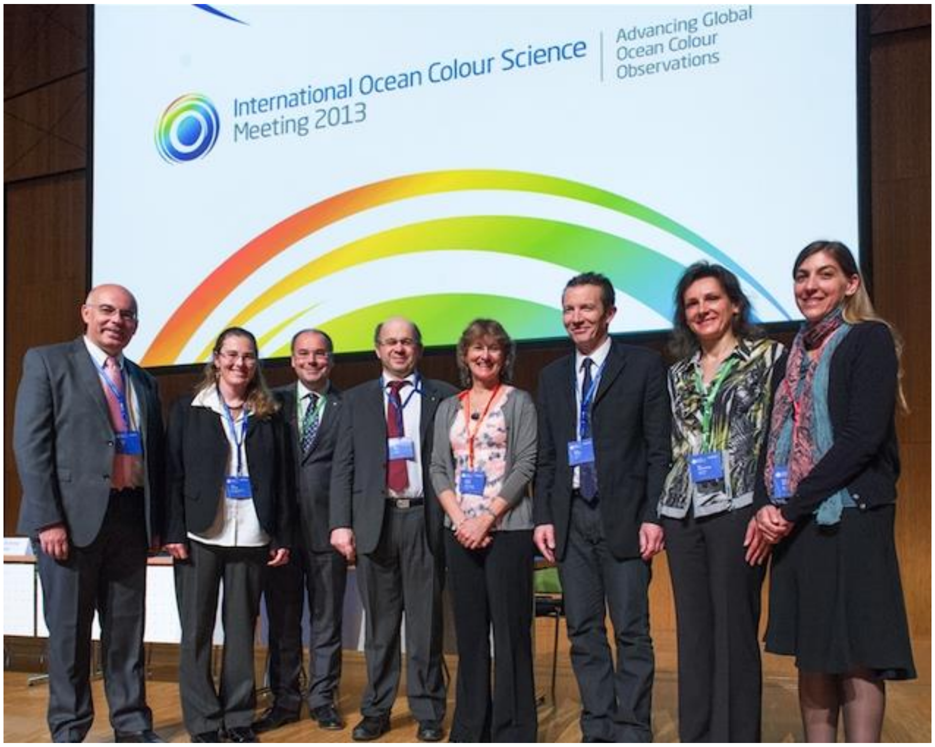
Paul Counet, Head of EUMETSAT's Strategy and International Relations division, opened the first International Ocean Colour Science meeting and welcomed participants to Darmstadt, Germany. He introduced Alain Ratier, the EUMETSAT Director General, who gave an overview of EUMETSAT satellites and their involvement with ocean colour. EUMETSAT's mission is to establish, maintain, and exploit European systems of operational meteorological satellites (monitoring weather, atmospheric composition, ocean, global land and climate) taking into account WMO recommendations. EUMETSAT delivers data services to the ocean community and will continue in the long run with two generations of Meteosat, Metop and Jason satellites. EUMETSAT's role will expand in the operational phase of Copernicus (formerly GMES – a joint EU/ESA initiative) from 2014-2020, in cooperation with ESA and the EC EUMETSAT contributions will include continued delivery of marine data, products and services from Metop, Meteosat and Jason missions, as well as the operation of the Sentinel-3 mission and delivery of S-3 data and product services (altimetry, SST and ocean colour) together with ESA. EUMETCast is EUMETSAT's primary dissemination mechanism for the near real-time delivery of the integrated meteorological/ocean data stream and is available to users of three continents.



Paula Bontempi (Program Manager for NASA's Ocean Biology and Biogeochemistry research program) thanked EUMETSAT and their staff for the incredible job they did in helping to organise the meeting. She also thanked the IOCS Organising and Scientific Committees for helping to plan the scientific program and the 12 focussed slinter sessions. Her key point was that the meeting is only as good as the discussions so participants were encouraged to take part in the discussions to get the agencies attention.



The IOCCG Chairman, David Antoine thanked all the participants for attending the meeting and provided a brief overview and update of IOCCG activities. Currently 13 IOCCG Reports have been published, with 6 other working groups in various stages of deliberation. The Ocean Colour Radiometry-Virtual Constellation (OCR-VC) has been established by IOCCG through CEOS to provide a long time series of calibrated ocean-colour radiances from measurements obtained from multiple satellites, and includes activities such as the INSITU-OCR initiative and the new Task force on Essential Climate Variable Assessment. An important goal of IOCCG is training and capacity building, encompassing introductory training courses in developing countries as well as advanced training courses targeting the scientific research community (specifically the IOCCG Summer Lecture Series). Dr. Antoine also outlined the IOCS meeting rationale which is to increase communication and collaboration among ocean-colour missions and communities to allow for the building of global, multi-mission, long-term ocean-colour time series for climate research. Venetia Stuart, IOCCG Project Coordinator, then reviewed the structure of the agenda for the IOCS meeting and the expected outcomes from the various splinter sessions, including the splinter session reports.



3. Agency Reports

Program managers from various space agencies with an interest in ocean-colour remote sensing were invited to update the community on the status of ocean-colour programs at their respective agencies.

3.1 Future Directions for NASA Ocean Colour Remote Sensing (Paula Bontempi)

Paula Bontempi provided a brief update of historical, present and future NASA missions. NASA will be requesting copies of all HRPT data from the SeaWiFS mission (1997-2010) collected by remote ground stations (foreign and domestic) for incorporation into the NASA archive, following a recent agreement with DigitalGlobe. All data collected during the mission will be placed into the public domain. The MODIS-Terra and Aqua missions are still in operation and are undergoing a mission extension review. A partial reprocessing of MODIS-Aqua data (2011-2013) was recently completed to maintain instrument calibration. MODIS-Terra reprocessing will follow using MODIS-Aqua as a calibration source. Suomi-NPP VIIRS (2011-present) is performing well. Significant degradation of radiometric sensitivity in the NIR/SWIR bands has been observed, but is stabilizing. NASA is supporting the evaluation of the operational products from NOAA (Level-2: EDRs), while also evaluating the potential of the instrument to support continuity of ocean-colour science. NASA has just received concurrence from the Navy for the release of all HICO data collected since 1 January 2013 to the NASA OceanColor web. HICO is a hyperspectral imager on the International Space Station designed to sample the coastal ocean at a resolution of 90 m. The PACE mission is an ocean colour, aerosol, and cloud mission to be launched in the 2019/20 timeframe. The primary science objectives are to understand (and quantify) global biogeochemical cycling and ecosystem function in response to anthropogenic and natural environmental variability and change, and to quantify the role of aerosols and clouds in physical climate. The PACE mission is technologically advanced and will support many different applications especially those in the coastal zone (e.g. detection and forecasting of HABs). NASA's planned ACE mission is an ocean ecosystem imager with an aerosol-cloud component. Lastly, GEO-CAPE is a planned geostationary mission focussed on U.S. and South American coastal waters planned for launch no earlier than 2022. Collaboration between the Korean KOSC GOCI team and NASA GSFC is moving forward.

3.2 Update on EUMETSAT Ocean Colour Services (Ewa Kwiatkowska)

Ewa Kwiatkowska (Remote Sensing Scientist, EUMETSAT) reported on EUMETSAT ocean-colour services. EUMETSAT is an operational satellite data provider for services and end users including weather, climate, oceanography, and atmospheric composition. EUMETSAT is the future operator of Sentinel-3 satellites under the EC/ESA Copernicus programme. EUMETSAT is currently supporting ESA in the development of Sentinel-3 Space and Ground Segments and, during operations, it will monitor and control the Sentinel-3 platform and payloads as well as acquire, process, maintain and distribute instrument data and marine products. Sentinel-3 Marine Centre is presently under integration at EUMETSAT Headquarters. EUMETSAT will provide operational ocean-colour data services for diverse and evolving applications including climate and science. EUMETSAT is developing a consolidated approach to meeting the needs of ocean-colour data users as it actively collaborates with the users and supports community initiatives that include this IOCS meeting, the IOCCG inter-agency Calibration Task Force, and the IOCCG ECV Task Force. ESA and EUMETSAT have developed a joint Sentinel-3 Cal/Val plan and have issued a joint call for a Sentinel-3 Validation Team (S3VT), where the call is continuously open for submissions. EUMETSAT will disseminate Sentinel-3 data in near-real time (3h) via EUMETCast broadcast, and the data will also be available from a long-term archive as well as on-line from a rolling archive (OLCI data volumes will be quite substantial). In response to a question about the production of Level-3 data products, it was noted that this idea should be pushed forward and that it was up to this community to influence the future.

3.3 From MERIS to OLCI - Ocean Colour at ESA (Henri Laur)

Henri Laur (Earth Observation Missions Management Office, ESA) reported on ocean-colour activities at ESA. Envisat MERIS had excellent performance with observations lasting 10 years, until 2012, helping to expand the OC community in Europe and fostering a high demand for long-term OC data for marine and coastal monitoring. Quality of MERIS products was improved under the leadership of the MERIS Quality Working Group with several reprocessings. A number of programmes exploit MERIS data including ESA Climate Change Initiative, CoastColour, GlobColour and MyOcean. GMES (now known as Copernicus) is an initiative led by the European Union, which aims at establishing a European capability for the provision and use of operational monitoring information for a wide range of environment and security applications. It has a service component, an *in situ* component and a space component (coordinated by ESA). Sentinel-3 OLCI is part of GMES and will provide continuity of MERIS class observations into the future. Full performance will be achieved with two satellites in orbit (A and B units). The launch of the first Sentinel-3 (A unit) is planned for November 2014. EUMETSAT will be the operator of the marine part of Sentinel-3 while ESA will be the operator of the land part of Sentinel-3. The size of Sentinel-3 data products will be substantial (3 times MERIS) so data access and delivery to users will be appropriately sized. Joint Principles for a GMES Sentinel data policy shall allow anyone to access the data, and licenses will be free of charge. Those principles remain however to be confirmed by the European Commission. In addition there will be open collaboration with international partners to enhance Sentinel-3 data exploitation.

3.4 Update on NOAA Ocean Colour Activities: VIIRS et al. (Cara Wilson)

Cara Wilson (NOAA/NMFS/SWFSC Environmental Research Division) reported on NOAA ocean-colour activities, on behalf of Menghua Wang. The Suomi National Polar-Orbiting Partnership (NPP) mission was launched in October 2011, and is a bridge to the Joint Polar Satellite System (JPSS), a collaborative effort between NOAA and NASA. The VIIRS sensor on NPP provides ocean colour and SST at a resolution of 750 m. Official NPP Mission data is archived and distributed by the NOAA National Data Centers. NOAA's Comprehensive Large Array-data Stewardship System (CLASS) serves as the official repository of NPP mission data, including VIIRS. VIIRS ocean Colour EDR (Level 2) data was declared "Beta" status in Jan 2013, and is available via CLASS. It is anticipated that the data will be moved up to "Provisional" status in fall 2013, and will include vicarious calibration gains. Daily global merged VIIRS ocean colour (1- and 4-km) data will be available on a rolling basis from NOAA CoastWatch by summer 2013, and reprocessing of VIIRS ocean-colour data is expected to occur by early 2014. MOBY operations, funded by the JPSS Program, have been functioning extremely well with no issues since the launch of Suomi-NPP. However, MOBY is 20 year old technology and funding support to replace MOBY optics and control system with current technology was not provided for FY13, so the current instrument operation will become increasingly risky without refresh due to system age and reliability issues. In conclusion, VIIRS can potentially provide high-quality global ocean-colour products in support of research and operational applications.

3.5 KIOST: GOCI status and GOCI-II plan (Joo-Hyung Ryu)

Joo-Hyung Ryu (KIOST, Korea) reported on GOCI, the first geostationary ocean-colour sensor successfully launched in 2010. The Korea Institute of Ocean Science and Technology (KIOST) provides global leadership in advanced marine sciences and technology while the Korea Ocean Satellite Center (KOSC) is in charge of GCOI operations including mission development, Cal/Val , applications, and research. The COMS satellite carries three payloads including GOCI, the main objective of which is ocean environment monitoring. Version 1.2 of the GOCI Data Processing System (GDPS) has just been released. GOCI data supports numerous applications including red tide detection, yellow dust distribution, aerosol optical depth, and water current vectors. Over 1,000 scientific users receive GOCI data either via ftp or via a public user portal site (8 times per day). A redistribution (mirror) site for faster download by international scientific users has been approved by the GOCI operation committee. The GOCI detector shows stable radiometric calibration and geometric accuracy. A standard atmospheric correction algorithm for GOCI has been developed by KOSC and comparisons of GOCI and *in situ* data show a good relationship except at 412 nm. An R_{rs} matchup database is being constructed for validation of Chl, TSS, CDOM. *In situ* measurements are being collected using a variety of means (research vessels, buoys, ocean research stations etc.). Initial validation results indicate that the bio-optical algorithms need to be improved, and semi-analytical algorithms should be considered. There is strong international collaboration for GOCI Cal/Val and foreign scientists are encouraged to participate in the annual GOCI validation cruise and the GOCI PI workshops – the 3rd GOCI PI workshop will take place in ~2014. Eight GOCI scenes are received per day allowing for cloud-free imagery and examination of short-term variability (e.g. tidal movement of suspended sediments, sea ice and sea fog).

The GeoKompsat-2 satellite is under development to carry the GOCI-II instrument which will have better spatial resolution (300 m × 300 m) and spectral performance (13 spectral bands). GOCI-II is scheduled to be launched in 2018. GOCI-II will also have a new capability, supporting user defined observation requests e.g. clear sky areas and special-event areas. Unlike GOCI, GOCI-II has the capability for daily global observations. GOCI-II is a twin satellite (GK-2A and GK-2B) each carrying three payloads allowing for multi-sensor fusion algorithms.

3.6 JAXA: Update on GCOM-C1/SGLI (Hiroshi Murakami)

Hiroshi Murakami (JAXA/EORC) reported on the development of GCOM-C1/SGLI, a global change observation mission scheduled for launch in 2015/16. The instrument has 250m spatial resolution with a 1150 to 1400-km swath for the land and coast, and polarization observation for the land aerosols. The instrument will also have multiple calibration functions (solar diffuser, LED, Moon, and vicarious calibration). The first draft algorithm was provided to JAXA by PIs in autumn 2011 and the evaluation results are reflected in the development of the operational processing system. The second research period for GCOM-C1 algorithm development is underway (April 2013 – March 2016) with many scientists participating. The ocean group is starting characterization of coastal IOPS, focussing on Japanese coastal waters and improvement of the candidate aerosol models (with aerosol network groups). Relationships with organisations outside of JAXA have been established for collection of *in situ* data for product development. GOCI products will be released to the public one year after launch and will be free of charge for internet acquisition.

3.7 CNES: Ocean Program Status: Perspectives for Ocean Colour (Bertrand Fougnie)

Bertrand Fougnie (CNES, France) reported on CNES involvement in ocean observations, on behalf of Juliette Lambin. Ocean sciences are one of the major interests of CNES Earth observation programs and they support a strong scientific community through dedicated research funding as well as several larger scope projects and initiatives such as Bio-Argo and Boussole. In terms of satellite missions the focus is on physical ocean observations but in terms of ocean colour CNES supports the Parasol mission and is involved in joint activities around Sentinel-3 and GEO-OCAPI. The main objective of Parasol is to monitor clouds and aerosols but it has an ocean-colour observing capability (and polarimetry). It has been moved to a lower orbit (collision risks avoidance) and the mission has been extended up to the end of 2013. A reprocessing of the archive is planned for 2014 which includes significant radiometric improvements. Some ocean-colour level-2 products are generated by CNES - distribution is upon request, but could be more widely opened if requested by users.

There is strong French involvement in GMES (Copernicus) ocean component: cooperation with ESA on Sentinel-3 development, support to Mercator-Ocean and upstream R&D support, funding for a Marine Collaborative Ground Segment and science support (S3VT). For the Ocean Colour Advanced Permanent Imager (OCAPI), the phase 0 study has been completed at CNES. A Mission Definition Review is planned to prepare transition to Phase A, which is not yet funded but GEO-OCAPI is first on the waiting list. GEO-OCAPI mission requirements were reviewed: the two main challenges are image quality, and radiometric and geometric quality. The main trade-offs are resolution (100 m, 250 m or 500 m) versus revisit (every ½ h to 1 h). Feasibility and cost studies favour the GEO-OCAPI 250 m design. This program strongly depends on the development of critical technologies (e.g. specific detectors) but also on international cooperation.

3.8 China: Ocean Colour Remote Sensing and Application in China (Delu Pan)

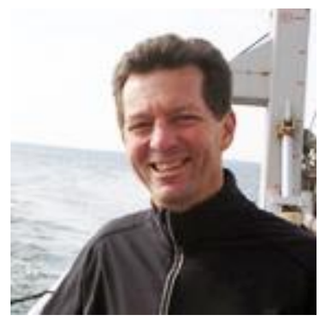
Prof. Delu Pan (Second Institute of Oceanography, China) reported on ocean-colour remote sensing and application in China, giving a review of present and future Chinese satellite missions. There are four series of satellites for ocean-colour remote sensing in China: the HY series is for ocean observation, the FY series for meteorology, the HJ series for environment and disaster monitoring, while the SZ series is the spacecraft program. China launched the first ocean satellite HY-1A in May 2002 which operated successfully for two years, and was followed by HY-1B in April 2007, which is still in operation. These missions carry two ocean-colour sensors: the Chinese Ocean Color and Temperature Scanner (COCTS) with 10 bands, and the Coastal Zone Imager (CZI) with 4 bands and a CCD Camera. There are four HY-1B satellite ground stations in China which receive the raw data in real time and process, archive, manage and distribute the data. The ground station in Hangzhou is primarily concerned with developing algorithms and software for the HY-1 mission. Products such as Chl, SST and TSM are produced routinely. Data from HY-1/2 can be requested from the National Satellite Ocean Application Service of China. Regarding future missions, the HY-1C and HY-1D satellites are planned for launch before 2016 for ocean colour and SST observation. These satellites will carry the COCTS and CZI sensors, as well as a new UV imager for CDOM retrieval and atmospheric correction in highly turbid waters. Ocean-colour sensors will be included on HY-3 Sea-watch and HY-4 Sea-Geo (geostationary) ocean satellite series until to 2025.

Ocean-colour data has many applications, including measuring the sea surface partial pressure of carbon dioxide (pCO_2) and global air-sea CO_2 flux. A number of empirical algorithms have been developed to estimate aquatic pCO_2 using proxies such as SST, Chl-a and salinity although it is difficult to find a straightforward, significant relationship. Mechanistic-based, semi-analytic satellite algorithms can be used to develop more accurate, quantitative expressions using satellite products of Chl-a, SST, salinity, as well as DIC and alkalinity values. Results using satellite data provide more frequent estimates of pCO_2 with less uncertainty, and can also provide air-sea CO_2 fluxes.

4. Keynote Addresses

A total of five keynote speakers were invited to give presentations throughout the three-day IOCS meeting. Full abstracts of their talks are available on the IOCS meeting website.

4.1 Keynote 1 - Steve Ackleson (SA Ocean Services, USA)



Dr. Steven G. Ackleson received a Ph.D. from the University of Delaware in 1985 and is currently the Associate Director for Education and Observation at the Consortium for Ocean Leadership, Washington, D.C., where he also served as Senior Project Scientist for the Ocean Observatories Initiative. Prior to joining the consortium, Dr. Ackleson managed the Ocean Optics Program at the Office of Naval Research, where he established major interdisciplinary projects directed at observing and modeling processes associated with the ocean surface boundary layer, interior, and shallow ocean floor. These investments produced new in situ optical sensors, coastal ocean-colour algorithms for hyperspectral imagery, and instrumented autonomous systems for ocean observatories. He served as Co-Vice Chair of the Interagency Working Group for Ocean Observations and Chairman of the Ocean Optics Conference. His research experience spans diverse oceanographic problems related to optical processes and ocean-colour remote sensing, including the use of flow cytometry in bio-optical studies, bio-physical coupling within the upper ocean, and particle dynamics in coastal ecosystems.

Steve Ackleson gave a keynote address entitled "*In Situ Observation Strategies Supporting Future Ocean Colour Science*" where he outlined what our observational capabilities should be a decade from now. Science is increasingly driven by societal concerns such as climate change (oceanic uptake of atmospheric CO_2 and impact of ocean acidification) and an increasing human population depleting resources. We need to develop the capability to monitor ocean biogeochemical processes in greater detail and fidelity to address future ocean science questions. To meet these challenges, future ocean-colour satellite systems, such NASA's PACE and GEO-CAPE missions will include sensors capable of imaging the ocean with greater spatial and spectral resolution and radiometric sensitivity. These enhanced capabilities are expected to result in better understanding of the oceanic ecosystem.

Satellite data must be climate quality i.e. time series observations of sufficient length, consistency, continuity, and accuracy to reveal meaningful climate variability and change. In addition, a well-coordinated and executed program of accurate *in situ* observations is required to aid in the calibration of satellite sensors and validation of operational and emerging product algorithms. The Marine Optical Buoy Program (MOBY) has been used successfully for 15 years for calibration of satellite data, and is now in need of a technology refresh. The BOUSSOLE buoy is successfully co-sited with the DYFAMED site - perhaps a better location for MOBY would be ocean station Aloha, which collects essential ocean variables?

The Ocean Observatories Initiative (OOI) is also collecting many core optical, biogeochemical, physical and meteorological parameters using autonomous profiling systems with optical and biogeochemical sensors, on moored and mobile platforms, that yield continuous streams of data. Another exciting advance is the development of profiling drifters such as Argo floats equipped with various optical and biogeochemical sensors to measure pH, optics, particles, dissolved oxygen and nutrients. It is now possible to have hundreds of match-ups with profiling floats.

Quality control of the *in situ* data is a major challenge and protocols and standards for these sustained, *in situ* optical and biogeochemical observations need to be developed before the data can be used for Cal/Val activities or employed in ocean biogeochemical process studies. The IOCCG well poised to take on the responsibility to formalize protocols for QA/QC procedures applied to *in situ* optical and biogeochemical data.

4.2 Keynote 2 – Frédéric Mélin (EC Joint Research Centre, Italy)

Dr. Frédéric Mélin received a degree in Engineering from the Ecole Nationale Supérieure de l'Aéronautique et de l'Espace, Toulouse (France) in 1995, and a Ph.D. from the Université Paul Sabatier, Toulouse (France) in 2003. From 1995 to 1997 he carried out research at the NASA Jet Propulsion Laboratory / California Institute of Technology (US), studying the seasonal to inter-annual variability of the equatorial Pacific and Indian oceans using ocean surface circulation models and satellite data. In 1998 he joined the Joint Research Centre of the European Commission (Italy). His research interests include the development, validation and analysis of optical remote sensing products, the creation of ocean-colour climate data records, and the modelling of primary productivity for the study of marine ecosystems.

Frédéric Mélin gave a keynote address entitled "*In Search of Long-Term Trends in the Ocean Colour Record*". He outlined some of the challenges behind creating ocean-colour Climate Data Records (CDRs) possessing "a sufficient length, consistency, and continuity to determine climate variability and change". A major concern is the existence of significant differences between mission-specific data sets that must be properly accounted for before these data sets can be combined for time series analyses. The presentation focused on two ocean-colour variables considered as "Essential Climate Variables" (ECVs) by GCOS: the spectrum of water-leaving radiance (or remote sensing reflectance, R_{RS}), and the concentration of chlorophyll-a. In both cases, the emphasis was on inter-comparison results and the implications in terms of data set consistency and trend detection.

A complete inter-mission comparison was conducted on the SeaWiFS, MODIS-Aqua and MERIS R_{RS} data sets. A spatially-resolved estimate of the random error of the R_{RS} uncertainty budget for SeaWiFS, MODIS and MERIS was computed through an analysis of variance and covariance terms over the comparison ensemble. Inter-mission biases were assessed and corrected for to prevent artificial trends in the combined data set. Inter-mission biases vary with wavelength, time and space, but they show well defined spatial patterns that were discussed using two different approaches: a class- based optical classification approach and a province-based approach. Preliminary conclusions for the R_{RS} data sets studied indicated good agreement of their uncertainty level, fair consistency between products and still some work to be done to fully bring these records in line with each other. Apart from inter-mission differences, spurious trends can be found for a single mission, resulting from: residual variations in the calibration equation, artifacts in the processing ancillary data (ozone, wind, SST etc.) and actual trends in variables that can impact the atmospheric correction (cloud coverage and type, aerosol, etc.)

For the chlorophyll-a concentration time-series analysis, existing differences between the monthly time series of Chl-a derived from SeaWiFS, MERIS, MODIS-Aqua and MODIS-Terra were analyzed through various statistical indicators e.g. average differences, correlation, or their inherent variances. The trends displayed by each mission were illustrated, and showed significant differences when computed on different periods (e.g., SeaWiFS and MODIS-Aqua). Trends were then computed on data sets combining Chl-a series from different missions, and compared with mission-specific trends. The part of these trends resulting from biases between missions was analyzed using artificial climatologies and actual time series. The level of inter-mission biases that can be tolerated for trend detection was also discussed.

In conclusion, it was recommended that efforts be maintained for sensor calibration, characterization and temporal stability and that full inter-mission consistency be ensured through the entire processing chain. Furthermore, inter-mission differences need to be thoroughly characterized and integrated into analyses, and research on the relationships between OC-derived variables and other ecosystem variables (particularly in the context of climate oscillations) should be developed.

4.3 Keynote 3 – Shailesh Nayak (ESSO, India)

Dr. Shailesh Nayak is the Chairman of the Earth System Science Organization and Secretary of the Ministry of Earth Sciences, Government of India since August 2008, where he provides leadership for programs related to Earth system sciences. He obtained his PhD degree in Geology from the M.S. University of Baroda in 1980. In 2007, he was responsible for setting up a state-of-the-art tsunami warning system for the Indian Ocean in the space of just two years, providing tsunami advisories to the Indian Ocean rim countries. Dr. Nayak has also pioneered the development of algorithms and methodologies for application of remote sensing to coastal and marine environments. He helped generate a baseline database of the Indian coast, and developed services for fishery and ocean state forecast. Dr. Nayak was awarded an Honorary Doctor of Science degree by the Andhra University in 2011, and was conferred the prestigious ISC Vikram Sarabhai Memorial Award in 2012 as well as the Bhaskara Award for 2009, Fellowship of the International Society of Photogrammetry & Remote Sensing (ISPRS) for his outstanding contributions in remote sensing and GIS. He has published over 80 papers in peer-reviewed journals.

Shailesh Nayak from the Earth System Science Organization (ESSO), India, gave a keynote address entitled "*Challenges and Opportunities for the Operational Use of Ocean Colour for Fisheries*". Remote sensing of ocean colour affords the capability of monitoring large spatial areas at very high temporal scales and has been used for many different applications including long-term forecasting of potential fishing zones. The availability of food, feeding habits and environmental conditions play a key role in the distribution of fishery resources: the abundance, type and distribution of fish species is controlled by the supply of suitable food. Chlorophyll images from ocean-colour data provide information on primary productivity as well as oceanographic features such as colour boundaries, fronts, eddies, rings, gyres, meanders and upwelling regions, and can facilitate interpretation of fundamental relationships between certain fish species and their oceanic environment. Knowledge of physiologically-suitable environments of target fish species is of utmost importance. Satellite-derived sea surface temperature (SST), in conjunction with other satellite data, can also be used to detect habitat preferences of certain fish species

The SST images, when used together with ocean-colour images, allows identification of the oceanographic features used for generating the daily potential fishing zone (PFZ) advisories, provided by INCOIS and used by ~90% of the artisanal fishermen. The coincidence of chlorophyll and SST features indicate close coupling of the physical and biological processes. Sea surface winds also provide information on the movement of oceanographic features and thus on circulation. The synergistic analysis of time series measurements of chlorophyll, SST and surface wind vectors provides an understanding of the formation of productive fishery grounds as well as the dynamics. In the SW Arabian Sea, the fishery is controlled by upwelling whereas in the Bay of Bengal it is controlled more by eddies. Attempts are being made to assess fishery potential using ocean-colour data, since overall productivity is linked to physical processes.

Satellite ocean-colour data has also been used to monitor and predict the outbreak of harmful algal blooms such as *Trichodesmium* and *Noctiluca* as well as the impact of climate change on their distribution. Ocean-colour maps have also been used to examine the biological response to the monsoons, which generally leads to an increase in chlorophyll concentration as a result of coastal upwelling driven by monsoon winds causing nutrient enrichment in the surface layer. Long-term trends in the sardine fishery show a 30 year cycle corresponding to the wet and dry epochs in summer monsoon rainfall. The delayed monsoon of 2012 led to fewer fish eggs and larvae. Ecosystem models have been used to help understand the biogeochemical processes and to predict the primary production using numerical simulations, thus helping with the assessment of fishery resources.

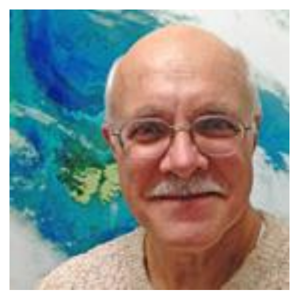
4.4 Keynote 4 – Stewart Bernard (CSIR, South Africa)

Dr. Stewart Bernard grew up in Zimbabwe, Malawi and England before completing M.Sc and PhD at the University of Cape Town. He currently works for the Council for Scientific and Industrial Research in Cape Town as a principal researcher. His main research interests are in the field of bio-optics in eutrophic waters: phytoplankton optical and radiative transfer modelling, algorithm development particularly for harmful algal bloom applications, ocean-colour validation, and application of these algorithms for ecosystem characterisation in upwelling and freshwater systems. He also has interests in technological development, such a low-cost buoys and optical sensors, and developing operational Earth observation systems. Teaching and building capacity, particularly in Africa, is important and he has taught several bio-optical courses and has supervised or is supervising fifteen PhD and M.Sc students. He also wishes he could play the mandolin better than he does.

Stewart Bernard from the Council for Scientific and Industrial Research, South Africa, gave a keynote presentation entitled "*Issues Related to Ocean Colour in Coastal Zones and Inland Waters*". He reviewed the principal challenges facing the application of ocean-colour radiometry in eutrophic and turbid waters, focusing on the ecological, bio-optical and algorithmic aspects. Several example ecosystems encompassing a range of ecological and optical complexity were used as illustration, including the highly productive Benguela upwelling system, the tidally-dominated North Sea with variable sediment influence, the highly-stratified Baltic Sea with gelbstoff-rich waters and periodic cyanobacterial blooms, the large meso- to hyper-trophic Lake Erie, and the very small hypertrophic Hartbeespoort Dam in South Africa. In each case a preliminary ecological review is conducted to determine temporal scales of variability and the range in optical complexity. More detailed analyses are then used to spectrally characterise the range of water types making use of techniques such as spectral clustering and principal component analyses. At high biomass, the main signal-carrying wavelengths shift towards the green-NIR range and the resultant importance of the fluorescence and 709 nm bands. Almost all the variability is explained by backscattering in these waters. Coupled inherent optical property/radiative transfer models are used to obtain a better understanding of causality of the signal. Key spectral shifts in reflectance can be identified, the effects of IOP variability can be isolated, and the diversity in optical properties of coastal and inland waters can be assessed.

The challenges of collecting radiometric and other bio-optical data in turbid and hypertrophic waters were also discussed (e.g. sub-pixel variability, and instrument/data processing issues in highly attenuating waters) and the need for new bio-optical protocols for such water types was highlighted. Lastly, algorithm options for coastal and inland waters were considered, including several algorithms that bypass the need for aerosol correction in hypertrophic waters. Examples of other algorithm types were also discussed e.g. empirical, semi-analytical and coupled neural network approaches. A number of spectral classification algorithms were presented to show the opportunities for system-transferable algorithms, with examples from both the global ocean and coastal/inland waters to demonstrate the scalable nature of this approach. The benefits of class versus regionally-based approaches to algorithm selection and application were also briefly discussed.

4.5 Keynote 5 – Charles R. McClain (NASA Goddard Space Flight Center, USA)



Dr. Chuck McClain received a Bachelor of Arts (BA) degree from William Jewell College (physics) in 1970 and Doctor of Philosophy (PhD) from North Carolina State University (marine science) in 1976. From 1976 to 1978, he was a post-doctoral fellow at the Naval Research Laboratory in Washington, DC and worked on validation of GEOS-3 altimeter estimates of significant wave heights. Since 1978, he has worked at NASA Goddard Space Flight Center in Greenbelt, Maryland. During his career at NASA, he has conducted research on the couplings between ocean physics and biology and the marine carbon cycle using satellite ocean-colour data. He was a member of the CZCS reprocessing team in the late 1980s and has assumed a number of project management roles including the SeaWiFS calibration and validation manager, project scientist, and project manager, SIMBIOS project manager, and ocean team leader for MODIS, NPP/VIIRS, and the ACE mission formulation activity. He recently served as a member of the PACE mission science definition team and was co-editor of IOCCG Report 13 of the IOCCG monograph series. He was the original principle investigator for the PC-SEAPAK and SeaDAS software packages distributed to the ocean-colour research community.

Charles McClain gave a keynote address entitled "*Past Observations and Future Challenges for Ocean Colour Remote Sensing*". The ten most important projects, events, and developments that played a major role in advancing the field of satellite ocean-colour remote sensing were reviewed. The list emphasizes activities initiated and led by members of the research community that reflect outstanding team work, initiative, and vision. These include the demonstration Nimbus-7/CZCS mission, which proved much more successful than anticipated in providing quantitative estimates of pigment concentrations and diffuse attenuation coefficients; the reprocessing of global CZCS data which helped to redistribute the data to the global community and generate publicity for a follow-on mission; the establishment of the SeaWiFS Project Office which initiated Cal/Val schemes, protocols etc.; the development of SeaDAS to allow the community to work with the data; the development of MOBY and vicarious calibration methodology; the Atlantic Meridional Transect (AMT) using ships of opportunity to our advantage; the establishment of the IOCCG for coordination between users and space agencies; the SIMBIOS Project (1997-2003) to coordinate data quality across all ocean-colour missions; the development of bio-optical algorithms (empirical to semi-analytic) starting with the pioneering paper of Clarke et al. (1970); and lastly, the Chlorophyll-a multi-sensor Climate Data Record (CDR) to merge ocean-colour data from different instruments.

Dr. McClain also gave his perspective on the political, financial, and technical challenges that lie ahead for the ocean-colour community. The community must work together to collect more field data with consistent well-defined measurement protocols for current and future derived products. International cooperation is also required to obtain data from various satellite missions since resources are tight. Joint missions and partnerships should be pursued and joint international field campaigns for calibration/validation and algorithm development should be coordinated. Lastly the IOCCG International Network for Sensor InTercomparison & Uncertainty assessment for Ocean-colour Radiometry (INSITU-OCR) should be implemented.

Clarke, G. L., G. C. Ewing, and C. J. Lorenzen (1970). Spectra of backscattered light from the sea obtained from aircraft as a measure of chlorophyll concentration. *Science*, 167(3921): 1119-1121.

5. Summary Recommendations from Splinter Session

5.1 Outline of Splinter Sessions

A total of 12 separate splinter sessions were conducted at the IOCS meeting (four parallel breakout splinters in each of three sessions) as follows:

- ***Monday 6 May 2013, Afternoon Splinter Sessions***
  - Splinter 1: NASA Ocean Color Research Team (OCRT)
  - Splinter 2: Advances in Atmospheric Correction of Satellite Ocean Colour Imagery
  - Splinter 3: Geostationary Ocean Colour Radiometry
  - Splinter 4: Multi-Agency Data Sharing (Satellite and In Situ Data)

- ***Tuesday 7 May 2013, Morning Splinter Sessions***
  - Splinter 5: Operational Ocean-colour Data in Support of Research, Applications and Services
  - Splinter 6: In Situ Measurement Protocol Revision for Cal/Val
  - Splinter 7: International training and outreach
  - Splinter 8: System Vicarious Calibration

- ***Tuesday 7 May 2013, Afternoon Splinter Sessions***
  - Splinter 9: Climate Variables and Long Term Trends
  - Splinter 10: Phytoplankton Community Structure from Ocean Colour: Methods, Validation, Intercomparisons and Applications
  - Splinter 11: Satellite Data File Formats and Tools for Easy Science Exploitation
  - Splinter 12: Satellite Instrument Pre- and Post-Launch Calibration

5.2 Recommendations: Advances in Atmospheric Correction of Satellite Ocean Colour Imagery

1. Cloud screening (small clouds, shadows) should be linked to atmospheric correction.
2. Absorption by hydrosols in the NIR needs to be determined for very turbid waters. Better bio-optical models are needed in the NIR.
3. Planned sensors should complement spectral measurements from UV to SWIR with multi-angular and multi-polarized instruments.
4. Efforts should be made by space agencies to make the new techniques more visible and accessible, e.g., via inter-comparison activities, implementation in SeaDAS etc.
5. Parallel processing lines with standard and improved schemes may help users understand advantages and limitations of individual techniques, define the quality of final products, and allow for continuity.
6. Synergy between instruments/missions should be considered, in particular OLCI (visible NIR) and SLSTR (SWIR) (1b or 1c co-registered).
7. New techniques suggest sensors should not saturate over Sun glint and clouds, and that it may not be necessary to tilt them, but strategy should keep continuity while allowing improvements based on gained knowledge.
8. Aerosol altitude is an essential variable to compute atmospheric effects at ocean colour wavelengths, especially in the presence of absorbing aerosols, and efforts should be

made to determine this variable in future ocean colour missions. Measuring NO_2 is definitely needed to perform accurate atmospheric correction in the coastal zone.

9. Aerosol model determination (size distribution, index of refraction) is useful to at least constrain the ill-posed inverse ocean-colour problem, but errors may be too large to compute the perturbing signal with sufficient accuracy, i.e., it is desirable to estimate the perturbing signal more directly. Yet aerosol information is required for studies of aerosol/ocean interactions (e.g., iron fertilization).

5.3 Recommendations: Geostationary Ocean Colour Radiometry

1. Broader distribution and application of GOCI data is recommended to demonstrate the utility of geostationary ocean colour radiometry data.
2. Additional activities on geostationary ocean colour radiometry are needed to inform the IOCS community, other scientists, managers and public on the utility of such observations through:
   - sessions at future meetings (IOCS, Ocean Optics, AGU, EGU, etc.);
   - articles in various publications (IOCCG newsletter, EOS, peer-review articles, etc.)
3. More extensive discussions on geostationary ocean colour radiometry are required to:
   - address and consider solutions to issues of atmospheric correction and BRDF;
   - consider novel products and applications;
   - discuss how to engage users both on research and applications and;
   - discuss how the community can advocate for such missions.

5.4 Recommendations: Multi-Agency Data Sharing (Satellite and In Situ Data)

1. When using data from MERMAID (MERIS Matchup In-situ Database) in publications, the Principal Investigators of *in situ* data should always be contacted for approval, be offered co-authorship and acknowledged.
2. Collaboratively identify and resolve bottlenecks to free and open exchanges of source data and software (satellite and *in situ*).
3. Space agencies should continue the pursuit and support of international multi-agency collaborations.
4. Researchers should archiving satellite data sets used in publications. The agencies are not responsible for keeping older versions once the data has been reprocessed.
5. The user community should get together to discuss standardisation of metadata.
6. Space agencies/data providers should commit to providing global Level-3 composites of ocean colour climate variables to facilitate sensor intercomparison and global biogeochemical modeling and research.

5.5 Recommendations: Operational OC Data in Support of Research, Applications and Services

1. The quality of operational ocean colour data is of critical importance. Operational agencies should develop and maintain infrastructure and scientific and technical activities to ensure that the accuracy and long-term stability requirements are met globally and across regions.
2. Assure data continuity and sustainability of product delivery. Distribute NRT data as well as consistent long-term time series of ocean colour observations.
3. Produce and distribute Level-3 data.
4. Ensure that operational capabilities are achieved soon after launch and enable early data access to marine service and cal/val users, even if the data are not yet well calibrated.
5. Provide open source modular software that matches the operational processor and that can be run in batch mode on local user computers; preferably multi-mission software.
6. Provide all data online for downloading (instead of a limited rolling archive).
7. Expand the core product suite; keep algorithms state-of-the-art.
8. Consolidate ocean colour requirements for services, ecosystem and management applications.
9. Create a framework within which the wider international community can collaborate through permanent working groups on specific topics identified by the IOCCG/IOCS meeting and the stakeholder community.

5.6 Recommendations: In Situ Measurement Protocol Revision for Cal/Val

1. *In situ* measurement protocols should not be revised by a single investigator but through an international community effort spanning multiple universities and space agencies e.g. under the IOCCG umbrella.
2. Some support for protocol development should be secured from various agencies (NASA, ESA, EUMESAT, etc.).
3. Participants agreed on the following workshops to revise the protocols (ranked highest to lowest) and possible workshop leads:
    - Inherent Optical Properties (IOPs): E. Boss, D. Röttgers (lab particle abs), N. Nelson (lab CDOM abs), M. Twardowski, E. Rehm (code) and other TBD;
    - Apparent Optical Properties (AOPs): G. Zibordi (not confirmed), K. Voss, E. Rehm (code) and others TBD;

- Particle sizes: M. Twardowski and others;
- Carbon stocks and rates: A. Mannino, H. Sosik, G. Mitchell (bacteria), B. Balch (PIC) and others;
- Bio-fouling and deployment modes: no identified leads.

5.7 Recommendations: International Training and Outreach

1. More online / distance resources are required.
2. Training on software and tools to support use of VIIRS and OLCI data, as well as other new missions, is strongly recommended.
3. EUMETSAT's role in training may be best focused on the operational users and potentially those involved in the management / decision making processes.
4. Wikipedia can be used for outreach and information provision, to provide more information on ocean colour and ocean-colour training.
5. Outreach activities aimed at the policy/decision making level are also recommended.
6. In the future to explore the value, and practicalities of competencies and certification.

5.8 Recommendations: System Vicarious Calibration

1. The current VIS and NIR method for system vicarious calibration of satellite ocean color sensors, which rely on the vicarious calibration of VIS bands with respect to NIR bands with the application of highly accurate *in situ* VIS data, is considered a robust approach over clear waters and should be considered for the forthcoming missions.

2. The importance of involving National Reference Laboratories in the characterization of field radiometers and SI traceability of measurements is essential. Still, the evaluation of new *in situ* platforms (i.e., gliders, AWS, …), in addition to existing bio-optical buoys, is recommended.

3. The analysis of legacy constraints for *in situ* measurements and sites supporting system vicarious calibration suggests that spatial homogeneity of the measurement site(s) is an essential requirement. The constraint on the aerosol optical thickness lower than 0.1 in the visible could be likely "relaxed" as long as the atmospheric conditions are well characterized. It is additionally recommended that the availability of supplementary atmospheric measurements at the vicarious measurement site(s) (e.g., vertical characterizations of the atmospheric components) are of potential aid to system vicarious calibration.

4. The use of commercial systems to support system vicarious calibration imposes the generation of *in situ* traceable measurements through fully characterized hyperspectral systems. This requires comprehensive characterizations of commercial hyperspectral systems whose performances often need thorough verification.

5. The standardization of system vicarious calibration is a necessary strategy for the generation of CDRs from multiple satellite instruments. Current system vicarious calibration exercises involving NASA and ESA sensors appear to indicate that the lack of standardization between institutions (not only for the system vicarious calibration process) may lead to significant differences in derived satellite data products not compatible with the creation of CDRs from independent missions. However, standardization using current technologies should consider that forthcoming advanced systems like PACE may benefit from additional measurement capabilities (e.g., polarization) with respect to current space sensors.

6. The short time available for the Splinter Session on System Vicarious Calibration has not provided the capability to comprehensively address all specific elements of relevance for the forthcoming satellite ocean color missions. It is then expected that results from the Splinter Session are the start for additional international actions aiming at detailing specific requirements and methods for System Vicarious Calibration of new missions like PACE and Sentinel-3.

5.9 Recommendations: Climate Variables and Long Term Trends

1. Calculation of uncertainties, including bias, in the time series of ocean-colour products is vitally important. Space agencies should ensure resources are made available to support these developments.
2. Interactions between climate modellers and ocean-colour scientists are essential to ensure that the ocean-colour time-series and models are appropriately used in describing and understanding the optical properties and signatures within the oceans.

5.10 Recommendations: Phytoplankton Community Structure from Ocean Colour

1. Agencies should support PFT algorithm development, validation and intercomparisons as well as activities to merge different techniques and multi-mission data sets, in order to develop a new "standard product" of ocean colour.

2. The development of PFT methods (including radiative transfer modelling to hyperspectral data sets) should be supported with relevant *in situ* measurements from ships, gliders and buoys.
3. Simultaneous collection of *in situ* HPLC pigments, other PFT parameters which identify size, groups and functions (e.g. size-fractionated Chla, particle size distribution etc.) and optical data are essential for validating PFTs from current and upcoming satellite missions.
4. The validation of HPLC-PFT data sets should be supported by all agencies: a single method may not be globally applicable.
5. Optical and pigment methods used to discriminate PFTs should be linked for a better understanding of actual community structure using imaging flow cytometry and genetics. Better methods to allocate cellular carbon across the PFT categories should be defined.

5.11 Recommendations: Satellite Data File Formats and Tools for Easy Science Exploitation

1. All space agencies should adopt the netCDF4/CF format for their ocean-colour data.
2. Space agencies should continue to support the existing line of data processing, analysis and exploitation tools (i.e. SeaDAS, BEAM and ODESA), and continue them for future sensors. This should include further development as well as training of users.
3. Space agencies should support large volume, batch data access and download (e.g., through established means such as ftp/http), as well as more targeted access through protocols such as THREDDS/OpenDAP.
4. Regarding data distribution, the ocean-colour community is requested to provide concrete and justified requirements to EUMETSAT so that the distribution of Sentinel 3 data through EUMETCAST can be properly dimensioned.

5.12 Recommendations: Satellite Instrument Pre- and Post-Launch Calibration

1. Calibration teams from each of the current and future ocean-colour sensor are encouraged to join the international collaborative effort GSICS (Global Space-based Intercalibration System) to help intercalibrate TOA radiances for different low Earth orbit sensors.
2. It is strongly recommended that a permanent calibration task force be established to share expertise and information on instrument calibration and characterization. It

should be supported by space agencies and should have close interaction with the extended ocean-colour community. It could be established either under the CEOS-IVOS framework, or the IOCCG/INSITU-OCR.

6. Detailed Splinter Session Reports

Splinter Session 1: NASA Ocean Color Research Team (OCRT)

Chair: Paula Bontempi (NASA HQ)

Paula Bontempi (NASA HQ) provided an update on NASA's programmatic planning for the Ocean Biology and Biogeochemistry programme as well as an overview of US federal government financial issues, including the budget sequestration issue. This was followed by brief reports of ongoing projects in NASA:

- NASA Satellite Ocean Color Time series (Bryan Franz, NASA GSFC), including an overview of reprocessing updates (MODIS reprocessing currently underway).
- NASA Science Team Assessment of Suomi-NPP VIIRS Ocean Colour Products (Kevin Turpie, Univ. of Maryland) – there are some issues with the VIIRS data stream and sensor, but the mission has the potential to serve some aspects of the ocean-colour community. The NASA-NPP science team has made suggestions to make the data climate quality.
- Pre-Aerosol, Cloud, ocean Ecosystem (PACE) Science (Carlos Del Castillo, Johns Hopkins University) - – a review of the work done by the Science Definition Team for PACE, who have done a very thorough job – all the reports are available on line.
- Controls on Open Ocean Productivity and Export eXperiment (COOPEX) (Dave Siegel, University of California - Santa Barbara) – a science plan has been developed for this project, to be funded through NASA ROSES.

At the end of the team meeting, the group was joined by participants from the multi-agency data sharing splinter session (Splinter Session 4) for group discussions. Broad questions about standardising satellite data formats were addressed as well as sharing *in situ* data.

Splinter Session 2: Advances in Atmospheric Correction of Satellite Ocean Colour Imagery

Co-Chairs: Sean Bailey (NASA/GSFC), Robert Frouin (SIO/UCSD) and Cédric Jamet (LOG/ULCO)

During the past decade major improvements to atmospheric correction of satellite ocean-colour imagery have been made. They allow one to deal effectively with absorbing aerosols, sun glint, thin clouds, adjacency effects, and highly turbid waters, and to attach uncertainties to the retrieved marine reflectance. The proposed techniques do not rely solely on observations in the red and near infrared, the approach currently used for processing data from ocean-colour missions, but include information from other spectral regions. Some techniques also exploit the bidirectional and polarization properties of sunlight reflected by the ocean-atmosphere system. The inversion is semi-empirical, physical, or statistical, and tools of various complexities are used, such as principal component analysis and neural networks. The session was organized to discuss the new techniques, including advantages and limitations, and their potential for operational processing of ocean-colour imagery from next-generation sensors.

<u>Objectives</u>

- To review advances in atmospheric correction.
- To identify areas/issues that still need improvements.
- To examine whether planned sensors have the capabilities to exploit the advances and improvements.
- To discuss mechanisms to value/assess the new algorithms, in the context of operational processing and continuity versus innovation.

The session included three talks followed by a general discussion:

(1) Atmospheric correction over turbid waters (C. Jamet);
(2) Aerosol determination with emphasis on aerosol absorption (S. Bailey); and
(3) Atmospheric correction in the presence of Sun glint, thin clouds, and adjacency effects (R. Frouin).

<u>Recent Advances</u>

Many approaches have been investigated to account for non-negligible marine reflectance in the near infrared. They consider spatial homogeneity for the spectral ratio of the aerosol and water reflectance in the red and near infrared or for the aerosol type, defined in a nearby non-turbid area. They also use iteratively a bio-optical model, exploit differences in the spectral shape of the aerosol and marine reflectance, or make use of observations in the short-wave infrared, where the ocean is black, even in the most turbid situations.
Regarding aerosol determination, new aerosol models, based on observation of optical properties measured at island and coastal sites have been used. To deal with absorbing

aerosols, spectral matching or spectral optimization methods have been proposed, that include information in spectral bands sensitive to aerosol absorption. In other methods, absorbing aerosols are detected by using a constraint on expected values of marine reflectance, and the set of aerosol models to choose from is selected accordingly. The coupling between aerosol absorption and scattering, which depends on viewing geometry, is also exploited to correct, using multi-angle observations, the spectral extrapolation to the visible of scattering properties observed in the near infrared.

New algorithms, in which the perturbing signal, smooth spectrally, is approximated by a low-order polynomial or a few eigenvectors, as well as powerful nonlinear regression techniques (e.g., neural networks), have shown great potential to deal with imagery contaminated by Sun glint, thin clouds, and adjacency effects. The inverse ocean colour problem has also been investigated in a Bayesian context, with the solution expressed in the form of a probability distribution from which expected value and covariance can be computed. This provides not only an estimate of the marine reflectance, but also a measure of uncertainty.

Question/Issues and Recommendations

1. How significant are the advances? What aspects still require improvements: Aerosol model determination, bio-optical modeling in the near infrared, dealing with imagery gaps? What Strategy to adopt?

- The new techniques proposed are robust in situations of absorbing aerosols, Sun glint, thin clouds, and adjacency effects, generally ignored in the standard processing of ocean-colour imagery, are robust, and their performance against in situ measurements is comparable to the performance of standard techniques. Retrieved marine reflectance under Sun glint and thin clouds exhibits continuity with adjacent estimates in clear conditions. Application of these techniques is expected to increase significantly the spatial coverage of ocean-colour products. But further evaluation is necessary.
- Cloud screening (small clouds, shadows), often an issue in coastal waters, should be linked to atmospheric correction.
- Even with recent advances, large gaps still exist in ocean-colour products. More attention/ effort should be placed by agencies on this problem – generating long-time series is not just lining up ocean-colour missions (e.g., combining observations and modeling).
- Aerosol model determination is useful to at least constrain the ill-posed inverse ocean-colour problem, but errors may be too large to compute the perturbing signal with sufficient accuracy, i.e., it is desirable to estimate the perturbing signal more directly. Yet aerosol information is required for studies of aerosol/ocean interactions (e.g., iron fertilization).
- Aerosol altitude is an essential variable to compute atmospheric effects at ocean-colour wavelengths, especially in the presence of absorbing aerosols (but even if they are not absorbing).

- Absorption by hydrosols becomes important in the near infrared in the case of very turbid waters, and needs to be determined. Better bio-optical models in the near infrared are needed.

2. Do planned sensors have the capabilities to exploit the advances? What are the implications for future ocean-colour sensor/mission design?

- Planned sensors generally have the required spectral capability (measurements from ultraviolet to shortwave infrared), but it is recommended to complement spectral measurements by multi-angular and multi-polarized instruments, at least to constrain the range of possible solutions. Also high spectral resolution is recommended in specific spectral regions, such as the oxygen A-band. Measuring NO_2 is definitely needed to perform accurate atmospheric correction in coastal zone.
- Synergy between instruments/missions should be considered, in particular OLCI (visible NIR) and SLSTR (SWIR) (1b or 1c co-registered).

- New techniques suggest sensors should not saturate over Sun glint and clouds, and that it may not be necessary to tilt them, but strategy should keep continuity while allowing improvements based on gained knowledge.

3. How to value the new techniques? Are they mature enough for operational processing? How to integrate advances and new capabilities for climate change detection?

- Efforts should be made by space agencies to make the new techniques more visible and accessible, e.g., via inter-comparison activities, implementation in SeaDAS for evaluation/feedback, etc. (requires resources and dedicated programs).
- Parallel processing lines with standard and improved schemes, that may be targeted to specific products in view of accuracy, may help to understand advantages and limitations of individual techniques and define the quality of final products and allow for continuity. This approach should be considered by space agencies to maximize the investment made in the development of new techniques and to yield more accurate ocean-colour products. Yet, several processing lines may be confusing to users.

Splinter Session 3: Geostationary Ocean Colour Radiometry

Co-Chairs: Joo-Hyung Ryu (KIOST, Korea), Kevin Ruddick (RBINS/MUMM, Belgium) and Antonio Mannino (NASA GSFC)

The splinter session on Geostationary Ocean Colour Radiometry was organized into three themes, each with a series of short presentations followed by brief discussions, as indicated below:

1. Geostationary Products and Applications:
   - Overview of GOCI mission (J.-K. Choi)
   - Dynamics of suspended particulate matter in river plumes using GOCI (D. Doxaran)
   - Estimating PAR from GOCI (R. Frouin)
2. Geostationary Data Processing Techniques:
   - GOCI atmospheric correction applications (S. Son for M. Wang)
   - Specificities in geostationary ocean colour radiometry processing (C. Mazeran)
3. New Geostationary Missions and Synergy:
   - Korean geostationary new mission synergy (J.-H. Ryu)
   - NASA GEO-CAPE Status (A. Mannino)
   - European GEO – OCAPI (D. Antoine)
   - MODIS-SEVIRI Synergy Product (Q. Vanhellemont)

At the conclusion of all the presentations, a series of provocative questions were posed to elicit a more in depth discussion on each of the session themes. There were approximately 40-50 attendees at our session.

Discussion questions and overview:

- What new products can be derived from geostationary ocean colour data?
  - Surface currents; sediment transport; particle tracking
  - Event tracking such as oil spills, ship waste disposal activity, harmful algal blooms, sea fog, storms, forest fires, volcanic eruptions, etc.
  - Daily PAR derived from multiple GOCI's 8 hourly measurements yield a much improved PAR product compared to a single daily value.
- What new processes can we describe?
  - Tidal dynamics, eddies, fronts
  - Diel evolution of traditional ocean colour products
  - Direct net primary production and net community production
  - Phytoplankton bloom dynamics
  - Exchange of materials at the land-sea interface
  - Exchange at the air-sea interface
  - Rapidly evolving phenomena such as river and aerosol plumes
  - New users would include modellers
- What are the new challenges for geostationary data processing?

- Sun glint appears to be a minor issue
- Side and forward scattered light to the TOA must be taken into account
- Backscattering geometry for GEO, for more extreme angles, will limit the capability for aerosol model selection and aerosol optical thickness estimations and thus application of atmospheric corrections.
- Geostationary will improve coverage due to optimization for clouds, i.e., cloud clearing from multiple scanning opportunities throughout each day.
- High air mass fractions (AMF) and extreme viewing angles will pose challenges for ocean radiometry retrievals.
    - Atmospheric corrections for AMF>4 exceed current processing specifications.
    - Retrievals within a 60-degree viewing angle will be
    - The measured radiances from geostationary (GEO) sensors will contain a larger volume of aerosols and trace gases compared to low earth orbit (LEO) sensors such as SeaWiFS, MERIS and MODIS.
- Approaches for atmospheric corrections at high AMF need to be evaluated.
    - Uncertainty in corrections for the air-sea interface at high sun/viewing zenith angles (>75-degrees) due to wave-induced shadows.
    - Corrections for earth curvature at edges of scan may not be possible
    - Spherical shell model for atmospheric correction is being studied.
- Bidirectional reflectance distribution function (BRDF) increases rapidly with viewing angle and poses additional challenges for geostationary ocean colour radiometry.
- Limitations in the modulation transfer function (MTF), scale of details observable by a sensor, will limit the spatial resolution that can be obtained from geostationary orbit.

• How should GEO and LEO be designed to optimize synergy?
• Do we need a global GEO constellation?
• Potential for synergy in combining measurements from multiple platforms such as (1) merging SEVIRI and MODIS example presented by Vanhellemont and (2) Korean GOCI-II ocean colour, GEMS atmospheric trace gas profiler and MI-II meteorological sensors.
• Should we attempt to harmonize multi-agency requirements such as spectral bands, signal-to-noise ratio (SNR), etc.?
• GEO poses stringent trade-offs in requirements among spatial resolution, temporal resolution, SNR, spatial coverage, spectral resolution, etc.
• Current technology limits sensor designs to three categorical solutions
    - 2D frame capture multispectral sensors (GOCI, SEVIRI, ABI, etc.)
    - 1D - single slit multi- or hyperspectral sensors with very wide field of view
    - 1D - multiple slit multi- or hyperspectral sensors

The presentations were quite informative and relevant to the session themes. The community is just beginning to see the potential value in geostationary ocean colour radiometry observations with GOCI data, as well as other sources of geo data (e.g. combining SEVIRI with MODIS). The release of IOCCG Report #12 on geostationary ocean-colour radiometry will promote a greater understanding and facilitate future splinter session discussions on this topic. The following recommendations are suggested for future splinter sessions on this topic:

Recommendations:

1. Broader distribution and application of GOCI data is recommended to demonstrate the utility of geostationary ocean colour radiometry data.
2. Additional activities on geostationary ocean colour radiometry are needed to inform the IOCS community, other scientists, managers and public on the utility of such observations through:
   - sessions at future meetings (IOCS, Ocean Optics, AGU, EGU, etc.);
   - articles in various publications (IOCCG newsletter, EOS, peer-review articles, etc.)
3. More extensive discussions on geostationary ocean colour radiometry are required to:
   - address and consider solutions to issues of atmospheric correction and BRDF;
   - consider novel products and applications;
   - discuss how to engage users both on research and applications and;
   - discuss how the community can advocate for such missions.

Splinter Session 4: Multi-Agency Data Sharing (Satellite and In Situ Data)

Co-Chairs: Lothar Wolf (EUMETSAT) and Henri Laur (ESA)

The purpose of the session was to address the issues related to ocean-colour data distribution and sharing amongst the various operators of ocean-colour instruments. During the session, each agency/operator (i.e. ESA, EUMETSAT, NASA, NOAA and JAXA) provided a description of their respective ocean-colour data distribution policies as well as restrictions and timeliness of satellite data provision. In addition, the operators provided a description of their related *in situ* data distribution policies.

The descriptions of the ocean colour (and related *in-situ*) data distribution provided by the agencies was of high value and is summarized in the table below.

Operator	Ocean Colour data policy	Ocean Colour data access	In-situ data access
ESA / Eumetsat	**MERIS** (Envisat): *open & free of charge*	**MERIS** (Envisat): - *Reduced Resolution (1200 m) archive fully on Internet* - *Full Resolution (300 m) archive not (yet) fully on Internet* - *L1b to L2 source code available to users (Odesa)*	**MERMAID**: *Policy set by in-situ data providers*
	OLCI (Sentinel-3): *open & free of charge* (TBC by European Commission)	**OLCI** (Sentinel-3): *data distributed through Internet and through Telecom Satellite.* → *Collaborative Ground Segment agreements are foreseen (e.g. redistribution through mirror sites).*	
NASA	**MODIS/SeaWiFS**: *open & free of charge*	**Multi-mission ocean colour data access**: - *All archive on Internet;* - *Fast reprocessing capabilities* - *L0 to L3 source code available to users*	**SeaBASS**: *Same as NASA EO data policy*

JAXA	**SGLI (and GLI)** *open & free of charge for non-commercial purpose (Special agreement for NRT)*	**SGLI (and GLI)** *All L1 and L2 to be made available on Internet*	**JAXA on-line system**: *Policy set by in-situ data providers*
NOAA	**VIIRS**	**CLASS** *All archived data available, including L0* *NRT within NOAA Coastwatch*	

Recommendations:

1. When using data from MERMAID (MERIS Matchup In-situ Database) in publications, the Principal Investigators of in situ data should always be contacted for approval, be offered co-authorship and acknowledged.

2. Collaboratively identify and resolve bottlenecks to free and open exchanges of source data and software (satellite and in situ).

3. Space agencies should continue the pursuit and support of international multi-agency collaborations.

4. Researchers should archive satellite data sets used in publications. The agencies are not responsible for keeping older versions once the data has been reprocessed.

5. The user community should get together to discuss standardisation of metadata.

6. Space agencies/data providers should commit to providing global Level-3 composites of ocean colour climate variables to facilitate sensor intercomparison and global biogeochemical modeling and research.

Splinter Session 5: Operational OC Data in Support of Research, Applications and Services

Co-Chairs: Ewa Kwiatkowska (EUMETSAT) and Stewart Bernard (CSIR)

1. Redefining "operational"

We are experiencing the rise of operational ocean colour as countries and continents invest in sustained long-term and routine ocean-colour observations. However, the general perception of operational data services has to be updated because the core requirements for ocean colour include the need for 24/7 data delivery but also extend far beyond it. The reason is that users and applications of ocean-colour data are very diverse. NOAA, the European MyOcean programme, and global partners from Brazil, China, Korea, South Africa and India have applications as varied as marine ecosystem monitoring (also, for oil and gas exploration); services like fisheries, aquaculture, water quality, harmful algal blooms, marine disaster monitoring, turbidity and eutrophication; as well as climate, science, and marine and costal management. The timescales for most of these applications are much longer than the standard near-real time operational paradigm. User needs and applications vary regionally and across the globe. An operational service therefore has to deliver NRT data as well as routine consistent long-term time series of ocean-colour observations.

Most importantly, the principal requirement is data quality. The experience from NOAA Fisheries, HAB forecasting and from MyOcean is that data accuracy and long term stability are crucial. These goals are particularly challenging in the operational scenario. Their realization hinges on a continuous calibration effort, monitoring of data quality in NRT and over time series, and on the immediate resolution of instrument and processing issues. Calibration, validation and monitoring in turn rely on on-orbit activities, such as lunar looks for NPP VIIRS, on ground cal/val resources and infrastructure, and on capabilities for frequent mission data reprocessings.

The process of transitioning ocean colour from research to operations is therefore challenging. Operations require a parallel research programme as maintaining the data quality is far from routine.

Recommendation 1: The quality of operational ocean-colour data is of critical importance. Operational agencies should develop and maintain infrastructure and scientific and technical activities to ensure that the accuracy and long-term stability requirements are met across regions.

Recommendation 2: Define long-term data stability goals for operational ocean-colour applications.

Recommendation 3: Assure data continuity and sustainability of product delivery via operational missions. Operational services require satellite data from two operational data streams and one experimental stream as a backup, or three streams in the optimal case, to provide robust services.

Recommendation 4: Distribute regional and global data to marine service and cal/val users early in the mission, even if the data are not well calibrated.

Recommendation 5: Ensure that operational capabilities are achieved soon after launch.

2. Scientific and technological innovation in support of evolving applications and user needs

Ocean-colour applications and services have significant potential to meet a range of societal needs and challenges. The experience from the UK MetOffice is that operational assimilation of ocean-colour data in ecosystem and carbon cycle models can reduce model errors by 50% in the chlorophyll field and by 20% in unobserved model variables, such as pCO2. Hence, the integration of ocean colour in biogeochemical models has the potential to advance the global operational observation network as well as to be a powerful tool for monitoring the marine environment. However these capabilities are still underused. Modellers require products that include chlorophyll, SPM, Kd490, IOPs, PFTs and carbon which are not all core ocean-colour products from the providers such as European Sentinel-3 OLCI and NOAA's NPP VIIRS. Routine exploitation of the data by end-users is lagging. Results from an ICES WGOOFE survey revealed that fisheries managers require primary production, chlorophyll, phytoplankton phenology (timing of algal blooms) and SPM products, half of which are not core products, and they need time series of monthly averages in simple data formats, where corresponding Level-3 data are, once more, not core for Sentinel-3 OLCI.

A compilation of user surveys conducted by the Sentinel-3 Mission Advisory Group and by ESA's Ocean Colour Climate Change Initiative emphasized that open and easy access to data at all levels, open source software, and user tools are prerequisites to broad data usage. Feedback from MyOcean, Brazil and South Africa confirms the need to empower the users by distributing open source modular software for all data levels (with the highest priority for L1 to L2 code) so that the operational algorithms can be adapted to regional conditions, new ad hoc algorithms and processing chains can be developed, and data can be processed locally. Software that works with multiple ocean-colour sensors is recommended. The availability of L3 data products was deemed critical by many users during this splinter and the plenary sessions. Access to L1A uncalibrated radiances (and calibration tables) is also recommended so that the users can create their local data archives and reprocess the time series locally each time the calibration changes. The CCI survey indicated that Earth Observation users choose L1/L2 data whereas modellers prefer L3 data. Harmonization of data formats among ocean-colour missions was emphasized.

Ocean-colour data download using ftp (wget) is the most favoured method in the science and modelling communities for both NRT and historical data, followed by data access via web-browser and OPeNDAP (for the modelling community). Users from South America and Africa additionally benefit from NRT access via EUMETCast, particularly where internet access is poor. A typical NRT timeliness of less than 12 hours from the time of satellite data acquisition is requested.

The provision of ocean-colour data analysis tools is considered critical. The non-specialist users want easy on-line tools such as NASA's GIOVANNI. Other examples include tools based on Open Geospatial Consortium web services that enable flexible web visualization and processing, data subsetting in time and space, and data aggregation.

Recommendation 6: Produce and distribute Level-3 data.

Recommendation 7: Provide open source modular software that matches the operational processor and that can be run in batch mode on local user computers; preferably multi-mission software.

Recommendation 8: Disseminate data in NRT via dedicated interfaces, internet and broadcast (by means such as EUMETCast), where the acceptable NRT timeliness is less than 12 hours. Distribute reprocessed consolidated data within a few days, where a maximum of 4 days is adequate.

Recommendation 9: Provide all data online for downloading (instead of a limited rolling archive).

Recommendation 10: Distribute Level-1A uncalibrated radiances with calibration tables.

Recommendation 11: Expand the core product suite to satisfy the modellers and end-users.

Recommendation 12: Provide NRT information on the status of service provision, data stream continuity and quality.

Recommendation 13: Support outreach to, and empowerment of, all stake holders, including commercial users.

3. Community organization to support the implementation of its goals and recommendations

At present, the international ocean-colour community is organized around IOCCG, CEOS Ocean Colour Radiometry Virtual Constellation, GEO Blue Planet, ChloroGIN, GOOS / GODAE, as well as a variety of programmes linked to specific applications or agencies. The IOCCG's IOCS meeting is the first to bring together the international community at large –agencies, scientists and data users– to formulate common goals and to jointly address the practical implementation of solutions from a wide scientific, technical, and programmatic perspective. These objectives match the OCR-VC purpose, which aims to produce long time series of calibrated ocean-colour products from multi-mission measurements in an operational and non-operational manner by focusing on calibration, validation, algorithms and standardized products/formats, applications and services, and on training and outreach.

The wider ocean-colour community, from data producers, scientists, to end-users, can be organized by following the GHRSST model as it brings together international expertise around specific topics common to all. However, the organization also has to address the diversity of ocean-colour applications and regional specificities. Clear vision and goals are needed. These currently exist for global ocean science and climate, but are not as well specified for services, marine ecosystems, and marine and coastal management.

Recommendation 14: Define ocean-colour requirements for services, ecosystem and management applications. Involve international data users, other stakeholders and the scientific community and draw on existing information on user requirements gathered by various projects and agencies.

Recommendation 15: Create a framework within which the wider international community can collaborate through permanent working groups on specific topics identified by the IOCCG/IOCS meeting and the stakeholder community. Support harmonization where appropriate, accounting for the regional diversity in the methodological/algorithmic requirements, user needs and societal challenges.

Splinter Session 6: In Situ Measurement Protocol Revision for Cal/Val

Co-Chairs: Giulietta Fargion (San Diego State University) and Jean-Paul Huot (ESA)

The session was well attended with around 66 participants. The presenters reviewed the status of the assigned protocols (i.e., AOP, IOP, carbon stock rates and particle sizes). In addition, presenters addressed the present protocol status and, if available, the community protocol consensus, highlighted the possible areas of protocol improvement, and concluded with recommendations. Presentations have been posted on the meeting web site (http://iocs.ioccg.org/presentations/). We encourage the community to download them and contact the presenters if they have questions.

The present ocean-colour community agreed on the strong need to revise protocols for calibration and validation (Cal/Val) activities. The last revisions to NASA Protocols were in 2003 (Mueller, Fargion, et al.) under the SIMBIOS Program. These protocols are now over ten years old. Within that time, several new instruments have been developed and are now in use, and in some areas there has been an important evolution of methods. As such, revised protocols are needed in consideration of several new ocean-colour missions presently flying, as well as for upcoming missions.

The 2003 NASA protocols and other documents such as the ACE/GEO---CAPE review of bio---geochemical protocols for accuracy assessment and the report from the ACE Workshop on Ocean Productivity and Carbon Cycle (http://people.eri.ucsb.edu/~davey/OPCC/) can act as a starting point for the revised protocols.

The SIMBIOS program's revision of SeaWiFS protocols may provide a template for revising protocols for calibration and validation. Although not discussed, it should be noted that the SIMBIOS Program's starting point in revising the old SeaWiFS protocols was to define the "essential and required" parameters to be sampled during the field campaigns, in reference to the wanted ocean-colour products' required accuracy (see "Ocean Optics Protocols For Satellite Ocean Colour Sensor Validation, Revision 4, Volume I: Introduction, Background and Conventions", page 38). Further, SIMBIOS identified the importance of doing coincident measurements for atmospheric and marine bio---optical properties in a variety of bio---optical regions. These regions include under sampled regions and/or those that might be "problematic" due to the presence of dust, rich in CDOM, etc. Particular attention was given to support regions, where historically, we had long time series (i.e., CalCOFI, CARIACO etc.).

Recommendations:

1. Protocols should not be revised by a single investigator but through an international community effort spanning multiple universities and space agencies.

2. The IOCCG is the ideal entity for this international effort.
3. The effort should be done if possible through a working group or workshop type meeting to facilitate discussion among participants in a manageable group size. This group could be led by one or two topic leaders. The need for a technical editor/organizer was recognized as well. The participants also thought that this goal would only be achievable if a minimum level of funding was secured for the workshop (to cover travel) and if a technical editor were present to compile all documents produced, coordinate the effort, and handle logistics.
4. It was further recommended that for the IOCS community to move forward, some support for protocol development should be secured from various agencies (NASA, ESA, EUMESAT, etc.).
5. All workshops currently planned and those in the future should be under the IOCCG umbrella.

The workshop location should be located in the US, Europe, or in a similarly convenient location to facilitate participation. The proposed workshops should coordinate with upcoming events such as Sentinel 3 activities for possible inclusion. Further, NASA GSFC is planning a CDOM workshop (soon to be scheduled), in addition to a NASA GSFC particle absorption workshop to be scheduled afterwards.

The format of new protocols (paper, PDF, web forum) was left to be discussed and decided in the future. Some discussion was devoted to defining the concept of the "*revised protocols.*" Generally, the participants felt that written documentation (to be defined) and open source, computer code should be made available to the community. The document produced should be a "living document," in other words, a readily accessible, Internet document that can be modified with relative ease (e.g., Wiki). The community computer code for *in situ* data could be implemented in gradual steps, such as open access libraries, but no code ownership was identified. It was not discussed whether or not the community should request manufacturers to adopt common data formats that would facilitate the use of open source software.

The splinter session did not address or discuss the essential field measurements that are required for calibration and validation efforts, or the accuracy/precision required for each parameter, or the uncertainty of the measurement budget. Other topics not discussed but to be addressed in future workshops are the use of different instruments among investigators, different national calibration standards (such as traceability to NIST in the USA), and quality assurance criteria (such as those implemented in SeaBASS). Effects of the above differences may lead to unpredictable uncertainties seriously affecting Cal/Val activities. The community recognized the need for convergence towards a minimum level of uncertainty. The importance of round-robins (RR) and the SIMBIOS radiometric RR activities were briefly discussed.

Participants voted and agreed on the following workshop rankings (highest to lowest) and possible workshop leads:

1. Inherent Optical Properties (IOPs): E. Boss, D. Röttgers (lab particle abs), N. Nelson (lab CDOM abs), M. Twardowski, E. Rehm (code) and other TBD;
2. Apparent Optical Properties (AOPs): G. Zibordi (not confirmed), K. Voss, E. Rehm (code) and other TBD;
3. Particle sizes: M. Twardowski and others;
4. Carbon stocks and rates: A. Mannino, H. Sosik, G. Mitchell (bacteria), B. Balch (PIC) and others;
5. Bio-fouling and deployment modes: no identified leads

We encourage the community to contact Giulietta Fargion to participate in the upcoming workshops (gfargion@ldeo.columbia.edu). All necessary word documents will be provided to the workshop leads identified above. Workshop leads will also state if documentation is still current.

Finally, having a standard set of measurement protocols is indispensable in developing consistency across the variety of international satellite ocean-colour missions either recently launched or scheduled to launch in the next few years. While each mission has its own validation effort, the mission validation teams should not need to define separate validation measurement requirements (protocols).

Splinter Session 7: International Training and Outreach

Chair: Mark Higgins (EUMETSAT)

This session was attended by 16 people and focused on training for the ocean-colour research community, with particular emphasis on scientists at the early stages of their career. In some sense this was the first meeting of a ''training coordination group''. The group was aware of a bias towards developed countries in our representation and discussion - the specific needs of other countries was less well represented.

A small survey was conducted prior to the conference to gauge [qualitative] interest in various training areas. 56 people responded to the survey.

From that survey some themes emerge:

- The survey confirmed a priority for training in data access, manipulation and visualisation, with BEAM and SEADAS being commonly used software.
- There is inconsistent awareness of the training available to the community
- There is an awareness of the importance of training for policy makers and managers

State of play today

There are a number of ocean-colour training activities already in place:

University of Maine **Ocean Optics course**: http://misclab.umeoce.maine.edu/~optics/. This course has been funded in the past by NASA*. This is an intensive three-week, cross-disciplinary, graduate-level course in optical oceanography and ocean-colour remote sensing. The major theme of this year's [2012] course is vicarious calibration of satellite-based ocean-colour radiometers using Earth-based measurements and the use of in-situ optical sensors for validation of products derived from ocean-colour remote sensing. [from the Ocean optics site]*. There are more international applicants than this course is able to support. This course has supported the initiation of an online Ocean Optics book – accessible to all: http://www.oceanopticsbook.info/ . Contribution to this resource and wide use is very welcome

The Summer Lecture Series, run by IOCCG, in 2012, *was a 2-week intensive course that took place from July 2nd – 14th at the Laboratoire d'Océanographie de Villefranche (LOV), Villefranche-sur-mer, France. A total of 13 renowned lecturers were invited to teach at the course and 17 students from 13 different countries took part in the course. More than 100 students had applied to participate in the course and the 17 remaining applicants were primarily chosen with respect to their motivation and on the basis of their academic background.*

[http://www.ioccg.org/training/SLS_2012.html]. The Summer Lecture Series will take place every two years (next course in Summer 2014). IOCCG can sponsor [to a limited extent] students to attend other training courses endorsed by IOCCG for example JRC training courses, or those conducted by NOWPAP CEARAC (http://cearac.nowpap.org/monitoring/4thRST/1st_Announcement.html). IOCCG also provides information on past training courses though the site: http://www.ioccg.org/training_ioccg.html The Partnership for Observation of the Global Oceans (POGO) [http://www.ocean-partners.org/] offers a range of training interventions including fellowships and research cruise support. POGO has also developed a network of alumni (NANO Network) to foster information and experience sharing, supported by the Nippon Foundation. POGO also contributes to the GEO Blue Planet initiative. POGO stressed the importance of having a strategic direction (not just training for the sake of it). They noticed a strong regional imbalance in applications and wanted to make a wider group of people aware of what is available. POGO looks at various ways of evaluating how successful the programme is, including looking for pull though – what difference are the alumni making?

Within the Nordic-Baltic states there are some outreach activities.
http://www.nordbaltrems.org/background.html

EUMETSAT introduced its training approach. EUMETSAT finds it important to work through networks such as VLab [http://www.wmo-sat.info/vlab/] and EUMeTrain [http://eumetrain.org] to increase accessibility to different groups. There is also a high utilisation of online resources such as Moodle [http://training.eumetsat.int] and online tools for synchronous events such as WebEx and SabaCentra. EUMETSAT is also a partner with COMET in providing online resources [http://meted.ucar.edu]. These online resources are currently used by 250,000 meteorologists around the world in their training.

Common themes

- Resourcing courses was a common theme: for any course there are the costs associated with participation for instructors and participants, and more recently, investment in sustainable training resources that can be used more widely (e.g. websites, online modules, videos of lectures). There are limited funds available for training, and funding partners often have particular restrictions of the levels, activities or geographical areas they are able to support. The group noted the importance (and current low level) of funding for coordination activities, such as those currently undertaken by IOCCG. Coordination and awareness raising of capacity development – IOCCG requests input from organizers of training initiatives to improve coordination and awareness-raising of capacity development.

- Accessibility: there is a desire across the group to make training more accessible to a wider group. This is seen in two ways: making the classrooms available to a wider community and making more of online opportunities. The limits on classrooms can come about due to partial sponsorship where students are expected to find a portion of the required support from a rage of different sponsors. This can lead to non-participation. It is preferable that multiple sponsors support the event so that students can be fully supported. Increasing the use of online technologies can also greatly increase access. This can include online lectures that take place at a moment in time and are recorded for later use, and with online courses or modules that are more asynchronous in nature.
- Students want more practical work: the group noted that learning objectives might be about what someone needs to "*know*" or *"do"*. The request for more practical work may be a request to meet the "do" type of learning objective.
- Need for training on both graphical user interface and satellite data processing software
- Copernicus: the group expressed a desire to know more about the user preparation that will be undertaken as part of the ocean component of Sentinel-3. There is an assumption that Sentinel-3 data will fit into people existing worlds (for example software).
- There is interest in using Wikipedia for outreach and information provision, to provide more information on ocean colour and ocean-colour training.
- Not discussed in detail but considered important was outreach activities aimed at the policy / decision making level. There may be some effort at this as part of the African Union – European Union supported MESA project in Africa, but the requirement is global. How are administrators educated – this may be a good question for the GEO forum to consider. The group also noted that ocean colour is sometimes used with school groups, for example using the Giovanni tools/site.

For the future

- We will have an online follow up meeting toward the end of the year.
- There is space for more online / distance resources. The ocean optics book is a great start. Additions might include more material with interactions and quizzes and the use of online lectures.
- Training will be required on software and tools to support use of VIIRS and OLCI data (and other new missions)
- In the operational environment, competencies and certification of courses is an interesting theme. This talks to value of science in real world. Potential areas of interest are: fisheries management, coastal (shore to 200nm) resource management, aquaculture.
- EUMETSAT's role in training may be best focused on the operational users and potentially those involved in the management / decision making processes.

Splinter Session 8: System Vicarious Calibration

Co-Chairs: Giuseppe Zibordi (JRC, EU) and Jeremy Werdell (NASA GSFC)

The Splinter Session aimed at:

i. *Summarizing the state-of-art on satellite ocean-colour vicarious calibration, and*
ii. *Discussing the need for advances in support of future missions*.

The state-of-art was summarized through a general introduction by the co-chairs, and targeted talks on current system vicarious calibration schemes applied to global missions and requirements for *in situ* data to support the system vicarious calibration of forthcoming ocean-colour missions. Three talks were presented:

1. *A general overview of the methods currently applied by the NASA Ocean Biology Processing Group to SeaWiFS and MODIS with focus on constraints for* in situ *reference data* delivered by Jeremy Werdell (NASA-GSFC);
2. *A general overview of the method currently applied by ESA for MERIS with focus on the dual source of* in situ *reference data* delivered by Constant Mazeran (ACRI-ST); and,
3. *An introduction to requirements for system vicarious calibration of future ocean-colour sensors with reference to sources of* in situ *data* delivered by Carlos Del Castillo (Johns Hopkins University).

Introduction

The general introduction to the Splinter Session summarized the rationale for the vicarious calibration of satellite ocean-colour sensors and reminded the audience of the legacy constraints for *in situ* measurements and sites supporting the process. In particular, it was recalled that the indirect calibration of satellite ocean-colour sensors, so called *System Vicarious Calibration*, relies on the use of highly accurate *in situ* measurements of $L_w(\lambda)$ and the application of the radiative transfer code and models embedded in the atmospheric correction scheme. This solution leads to the calibration of the entire system, i.e., the sensor plus the atmospheric correction algorithm, and forces the satellite-derived $L_w(\lambda)$ to match on average that from the *in situ* source. The temporal calibration of the satellite instrument is considered independently before the system vicarious calibration.

Accuracy specifications for the calibration of the space sensor are imposed by the target uncertainties for the satellite-derived $L_w(\lambda)$ (see (National Research Council, 2011). That is, if one assumes a maximum acceptable uncertainty of 5% in $L_w(\lambda)$ and that $L_w(\lambda)$ is 10% of $L_T(\lambda)$, the uncertainty in top-of-atmosphere $L_T(\lambda)$ must be lower than 0.6%. The allowed uncertainty in $L_T(\lambda)$ decreases to approximately 0.3% when $L_w(\lambda)$ is 5% of $L_T(\lambda)$. These uncertainty values can only be achieved through system vicarious calibration, largely to account for uncertainties in the atmospheric correction process. The uncertainties achieved through system vicarious calibration are expected to be strictly valid for the specific "observation" conditions that characterized the indirect calibration process.

It was noted that when system vicarious calibration coefficients determined from different *in situ* data sets exhibit (spectral) biases as low as 0.3-0.6%, their interchangeability in the generation of derived data products should be considered with caution. In fact, radiometric products resulting from the application of the different system vicarious calibration coefficients may exhibit (spectral) differences (i.e., biases) of the order of the uncertainties considered acceptable. This suggests that *in situ* measurements and sites supporting system vicarious calibration of satellite ocean-colour sensors need to be carefully evaluated accounting for the actual application of satellite data products, recognizing that the downstream creation of CDRs imposes the most stringent conditions.

Finally, legacy constrains for vicarious calibration measurements and sites were listed. Early indications included (Gordon 1998):

1. Cloud free, very clear, maritime atmosphere (τ_a<0.1 in the visible) to maximize the capability of correctly determining the aerosol type;
2. Horizontally uniform $L_w(\lambda)$ over spatial scales of a few kilometers to minimize effects of non-homogeneity in the field of view;
3. Oligotrophic-mesotrophic waters to minimize uncertainties *in situ* measurement of $L_w(\lambda)$ in the blue spectral region; and,
4. Coincident aerosol measurements as an aid to the validation of aerosols retrieval in the system vicarious calibration process.

Additional more recent indications included (Clark et al. 2003):

5. Hyper-spectral measurements to comply with any ocean-colour spectral band spectral response;
6. Fully characterized *in situ* radiometers to minimize measurement uncertainties; and,
7. SI traceability to ensure production of absolute radiometric quantities with defined uncertainties.

Contributions from invited talks

Two of the invited talks illustrated state-of-art system vicarious calibration method(s) relying on the vicarious calibration of visible (VIS) bands with respect to near infrared (NIR) bands using highly accurate *in situ* VIS data and assuming space sensor sensitivity decay with time is independently addressed. The talks were specifically focused on NASA and ESA system vicarious calibration schemes relying on *in situ* measurements from MOBY (Clark et al. 2003) and BOUSSOLE (Antoine et al. 2008), and confirmed the robustness of the approaches currently applied by both agencies (which largely overlap). The talk on requirements for system vicarious calibration focused on PACE and indicated the need for *in situ* measurements satisfying the following requirements:

1. Spectral range from 340-900 nm at ≤ 3 nm resolution;
2. Radiometric uncertainties ≤ 5% including contributions from instrument calibrations and data processing steps (with SI traceability);
3. Temporal radiometric stability ≤ 1% per deployment (with SI traceability);

4. Continuous deployment beginning one-year pre-launch and extending throughout the life of the mission; and,
5. Sufficient data acquisition rates to reduce vicarious gain standard errors to ≤ 0.2% within one year of launch.

Discussion

The discussion following the talks was supported by a series of seed questions that led to the following recommendations and conclusions.

1. The current VIS and NIR method for system vicarious calibration of satellite ocean colour sensors, which relies on the vicarious calibration of VIS bands with respect to NIR bands with the application of highly accurate in situ VIS data, is considered a robust approach over clear waters (and no alternative was formulated).
2. The specifications proposed for in situ measurements in support of PACE system vicarious calibration, are considered fully appropriate and complying with the state-of-art. The importance of involving National Reference Laboratories in the characterization of field radiometers and SI traceability of measurements is essential. Still, the evaluation of new in situ platforms (i.e., gliders, AWS, …), in addition to existing bio-optical buoys, is recommended.
3. The analysis of legacy constraints for in situ measurements and sites supporting system vicarious calibration suggests that spatial homogeneity of the measurement site(s) is an essential requirement. It is also affirmed that the constraint on the aerosol optical thickness lower than 0.1 in the visible could be likely "relaxed" as long as the atmospheric conditions are well characterized. It is additionally recommended that the availability of supplementary atmospheric measurements at the vicarious measurement site(s) (e.g., vertical characterizations of the atmospheric components) are of potential aid to system vicarious calibration. Finally, different sites could help cover a more representative range of water-leaving signal and correct for non-linearity issues in the system vicarious calibration (assuming the performance of the atmospheric correction process is the same at the various sites).
4. The use of commercial systems to support system vicarious calibration imposes the generation of in situ traceable measurements through fully characterized hyperspectral systems. This requires comprehensive characterizations of commercial hyperspectral systems whose performances often need thorough verification.
5. The standardization of system vicarious calibration is a necessary strategy for the generation of CDRs from multiple satellite instruments. Current system vicarious calibration exercises involving NASA and ESA sensors appear to indicate that the lack of standardization between institutions (not only for the system vicarious calibration

process) may lead to significant differences in derived satellite data products not compatible with the creation of CDRs from independent missions. However, standardization using current technologies should consider that forthcoming advanced systems like PACE may benefit from additional measurement capabilities (e.g., polarization) with respect to current space sensors.

6. The short time available to System Vicarious Calibration may have not provided the capability to comprehensively address all specific elements of relevance for the forthcoming advanced satellite ocean colour missions. It is then expected that results from the Splinter Session could be the start for additional international actions aiming at detailing requirements and methods for System Vicarious Calibration of new missions like PACE and Sentinel-3.

References

Antoine, D., F. D'Ortenzio, S.B. Hooker, G. Becu, B. Gentili, D. Tailliez, and A.J. Scott, "Assessment of uncertainty in the ocean reflectance determined by three satellite ocean color sensors (MERIS, SeaWiFS, and MODIS-A at an offshore site in the Mediterranean Sea (BOUSSOLE Project)," J. Geophys. Res. 113, C07013, doi:10.1029/2007JC004472 (2008).

Bailey, S.W., S.B. Hooker, D. Antoine, B.A. Franz, and P.J. Werdell, "Sources and assumptions for the vicarious calibration of ocean color satellite observations," Appl. Opt. 47, 2035-2045 (2008).

Clark, D.K. and 9 co-authors, "MOBY, a radiometric buoy for performance monitoring and vicarious calibration of satellite ocean color sensors: measurement and data analysis protocols," NASA T/M 2004-211621, NASA Goddard Space Flight Center (2003).

Gordon, H.R., "In-orbit strategy for ocean color sensors," Rem. Sens. Environ. 63, 265-278 (1998).

National Research Council, "Assessing Requirements for Sustained Ocean Color Research and Operations". National Academies Press, ISBN 978-0-309-21044-7, pp. 126 (2011).

Splinter Session 9: Climate Variables and Long Term Trends

Co-Chairs: James Yoder (WHOI, USA), Mark Dowell (JRC, EU) and Stephanie Dutkiewicz (MIT, USA)

Splinter Session 9 referenced the keynote address given by Frederic Melin entitled, "*In search of long-term trends in the ocean-colour record*" and also included 3 short talks:

- Mark Dowell (JRC) that discussed the complex relations involving international bodies like CEOS/SIT/GEO/GCOS, space agencies, and scientists related to climate variables.
- James Yoder (WHOI) discussed the goals and activities of the IOCCG Essential Climate Variable (ECV) Task Team.
- Stephanie Dutkiewicz (MIT) discussed interactions between the ocean colour and biogeochemical modeling communities, including what each community can learn from the other.

A key message in Mark Dowell's presentation was how important it is for the ocean-colour community to be aware of the expectations of the national and international agencies as to how ocean-colour measurements can support better understanding of climate change and its impacts. Senior managers in the space agencies are generally present at international meetings of groups like the Committee on Earth Observing Satellites (CEOS). Having ocean-colour science well represented in these forums can demonstrate how our research contributes to understanding climate change and its impacts as well as to other societal benefit areas of interest to international agencies. For example, IOCCG promoted the formation of the Ocean Colour Radiometry Virtual Constellation (OCR-VC) within CEOS to promote cooperation among national programs for sustained global ocean-colour coverage, improved data access, joint calibration and validation programs, training programs and other activities. Reports of the OCR-VC are included with those of other VCs (including VCs for SST, sea surface height and ocean vector winds) at every important CEOS meeting.

Jim Yoder reported on the recently formed IOCCG ECV Task Team. Co-Chairs are J. Yoder and N. Hoepffner, and the members include S. Henson, H. Murakami, S. Maritorena, B. Franz, M. Wang, E. Kwiatkowska, F. Melin, A. Mangin and H. Loisel. The charge to the task team is to determine how to produce basin to global scale ECV time series of ocean-colour products (specifically nLw or Rrs and derived products) for climate-related studies. In particular the task team is considering the results from 4 projects:

- NASA-GSFC project to produce nLw and Chl time series involving multiple sensors (SeaWiFS, Aqua, Terra and MERIS);
- NASA-funded MEaSUREs project which uses the GSM model to time series of inherent optical properties (IOPs) and other variables from SeaWiFS, Aqua and MERIS data;

- GLOBColour project which is also using GSM model to produce a time series of ocean-colour products from merged data from SeaWiFS, Aqua and MERIS data at 4.6km resolution; and
- ESA's CCI program which is producing a time series based on SeaWiFS, Aqua and MERIS data.

A characteristic of all of the projects is the emphasis on understanding bias and other uncertainties, and how to determine quantitative measures of both. The task team plans to establish a common data base of the products from these 4 projects to allow all groups to try various approaches for comparison and calculation of uncertainties.

Stephanie Dutkiewicz first discussed the products most commonly used by numerical modellers. She reported that global modellers tend to use only Level 3 products and prefer chlorophyll to other products. Modellers choose chlorophyll, and then primary production, because they are more familiar with these variables and know how to convert them into the units required by their respective models. Modellers are less familiar with other products such as particulate carbon.

Modellers use ocean-colour products in 3 different ways:

- sea-truth with which to compare model output;
- assimilate or merge ocean colour and models to "fill in" space and time for missing data; and
- provide feedback to the ocean-colour scientists to inform requirements and limitation for ocean-colour time series.

For example, recent modeling studies suggest that we will need a 30-year time series of satellite ocean-colour data to determine the existence of long-term trends. Other modeling studies illustrate how data gaps will require even longer time series to observe long-term trends.

There was a lively discussion following the presentations. A lot of the discussion focused on how to calculate uncertainties and what they mean, as well as how models can inform studies of long-term data records.

Take-home messages include:

- importance of collecting satellite ocean-colour data and sustaining the observations is well established within the international bodies that are involved in setting and meeting requirements for observing the global ocean;

- there is considerable interest in long ocean-colour time series and what the results are showing and/or will show;
- there is general recognition of the importance of calculating uncertainties, including bias, in the time series of ocean-colour products, space agencies should ensure resources are made available to support these developments;
- interactions between global biogeochemical modellers and those producing long time series of ocean-colour products benefit both communities, and;
- interactions between climate modellers and ocean-colour scientists help ensure that the ocean-colour time-series and models are appropriately used in describing the optical feedbacks on the numerical physical and biogeochemical/ecosystem models.

Splinter Session 10: Phytoplankton Community Structure from Ocean Colour

Co-Chairs: Astrid Bracher (Alfred-Wegener-Institute Helmholtz Centre for Polar and Marine Research and University Bremen, Germany) and Takafumi Hirata (Hokkaido University, Japan)

The remote identification of phytoplankton functional types (PFTs) is of interest to Earth system modeling due to the specific impacts of these groups on marine biogeochemistry and food web dynamics. Increasing efforts have been invested internationally to develop ocean-colour algorithms to retrieve PFTs using satellite data, providing an opportunity to yield new operational satellite products. The aim of the PFT splinter session was to bring relevant sciences and scientists together to develop and foster a larger community effort in PFT research, in order for the PFT community to contribute to interdisciplinary science using ocean colour. The session was well attended with lively discussions after each of the five overview talks, and also a final discussion at the end.

The session commenced with Shubha Sathyendranath (PML) reporting on the activities of the IOCCG working group (WG) on "Phytoplankton Functional Types" (see http://www.ioccg.org/groups/PFT.html) which was established in 2006 with Cyril Moulin as Chair. Since he had other obligations the chair passed on to Shubha Sathyendranath in 2008. The publication of the WG's report has been delayed because of this and also because the WG wanted to incorporate more recent satellite PFT algorithms. The report will consider the relevance, definition and current understanding of PFTs and will review existing techniques, compare algorithms and show applications including primary production and biogeochemical modelling. It will conclude with a series of recommendations.

Astrid Bracher (AWI/UB) and Nick Hardman-Mountford (CSIRO) gave an overview of currently available satellite algorithms to retrieve multiple phytoplankton types, based on responses of a call to the satellite PFT algorithm developers to contribute to this talk. Products either show dominance, chl-a concentration or fraction of total chl-a concentration of several PFTs or size classes (PSC). The variety of algorithms ranged from an abundance-based (using satellite chl-a only or empirical relationships via marker pigments) to spectral approaches. The latter are exploiting either reflectance anomalies to determine dominant PFTs, or use size-class specific phytoplankton absorption characteristics (based on their magnitude and slope) or particle backscattering to infer PSC or the particle size classes distribution, respectively. An analytical approach was shown which retrieves the imprints of PFT's characteristic phytoplankton absorption among all other atmospheric and oceanic absorbers from top of atmosphere data of the hyperspectral satellite sensor SCIAMACHY. All other PFT algorithms have been applied to SeaWiFS (sometimes also to MERIS and MODIS).

The lively discussion after this talk clarified that further development of PFT algorithm is currently undertaken and that the techniques vary from fast and simple versus more complex algorithms that provide a direct physiological interpretation of spectral variations, and from purely empirical to (semi-)analytical (by accounting for imprints of PSC or PFTs on radiative transfer, RT). Most techniques shown are global or have the potential for global processing. Several issues were raised during the discussion regarding the basics of satellite PFT methods, in particular in respect to spectral deconvolution and HPLC pigments: Since statistical methods like CHEMTAX apply their decomposition to PFT fractions based on an attributed matrix, the outcome will vary tremendously depending on that matrix. Also, since each species will have a wide range of phenotypic plasticity depending on acclimation status as regulated by light, temperature and nutrients, there simply is not a monolithic matrix that can be fully robust at global scale. In parallel, spectral absorption deconvolution can be fraught with challenges since the spectral shape also depends considerably on light, temperature and nutrient acclimation, due both to changes in relative proportions of pigments to each other and also due to pigment packaging effects. Finally, pigment or spectral based methods are a few steps removed from cellular carbon, which is the key basic state variable we would like to know with respect to its distribution across the PFT classes. Not much has been done to allocate relative biomass of PFT into carbon. Another separate but very important issue is the wisdom of applying a single method globally. For example, *Prochlorococcus* or *Synechococcus* do not occur in the Southern Ocean south of the Polar Front so applying methods that will allocate part of the community to those classes would not make sense.

The discussion showed that still satellite PFT products, since these are inferred properties, need justifying in order to be considered as an independent observation. The latter comment probably only holds for the part of the approaches, which have other limitations (assume fixed phytoplankton absorption spectra, large footprints of hyperspectral data, application to case-2 waters). Sensitivity tests with RT modeling should clarify the spectral resolution for the top-of-atmosphere radiance or water-leaving radiance data that is needed and how retrievals could be improved by accounting for other variables (e.g. photoacclimation) to detect different PFTs in case-1 and case-2 waters (so far satellite PFTs have been shown to cover case-2 only marginally). Sensitivity tests with RT code has recently been extended to coupled atmospheric and oceanic processes (e.g. COART, SCIATRAN), which should help to quantify errors and validate the algorithms. Several of the algorithms' PFT products have been used in wider applications; mostly for evaluation of biogeochemical/ ecosystem models, but also beyond (e.g. inferring oceanic emissions, harmful algal blooms). In order to become operational, these algorithms have to be validated, intercompared and adapted to new sensors in a consistent way. An intercomparison of the first PFT algorithms has been performed (Brewin et al. 2011). Now, a new effort has been started to intercompare and validate most of the more recent algorithms in a consistent way. The next two talks showed the first steps and discussion points for this new initiative.

Lesley Clementson (CSIRO) gave a talk on the task of "In situ/laboratory classification of phytoplankton types – data base: efforts/goals". Within this task group an *in situ* database for the development and validation of robust regional and global PFT algorithms is being built up in order to enhance standard global algorithms in the future. Global HPLC data, gathered by an international effort, will be the main base for PFT validation because HPLC is the most commonly used data source in the parameterisation of algorithms and a relatively large number of data points are available in all ocean environments. One of the major challenges is the uncertainties associated with the PFT-HPLC data (e.g. different photoacclimation, ambiguous marker pigments), so the HPLC PFT data set needs verification by other *in situ* data. The goal is to produce a database similar to the one currently established by the Australian PFT data base (IOCS Poster by Clementson et al.). This is an interrogative database of bio-optical parameters for Australian waters established by the AEsOP project, funded by the EOI-TCP. The current establishment of the PFT data base is funded, but the long-term maintenance is open and it was suggested may be provided by space agency support/hosting.

Taka Hirata (HU) showed intermediate results of the 2nd satellite PFT intercomparisons (other new satellite PFT algorithms are welcome) and a road map for the PFT satellite validation. So far, the intercomparison has been done for micro- and picoplankton (PSCs rather than PFTs), which were the only common products among the nine algorithms. The intercomparison is still open to new global algorithms. Generally, optics-based and abundance-based algorithms showed some differences in spatial distribution of PSCs, but our (= satellite algorithm developers) understanding is that the spatial distribution is generally consistent except for higher latitudes (as expected since retrieval of chl-a does not meet minimum standards at these latitudes). Discrepancies between SeaWiFS-based PFTs and SCIAMACHY-based algorithms in mission means were larger than within the SeaWiFS based ones, but generally SCIAMACHY products show similar behavior to other spectral based PFT algorithms. Different representations of phytoplankton groups within algorithms (e.g. "Micro" defined by physical size but represented by HPLC (DPA, CHEMTAX), a_{ph}, etc.) may largely explain differences/consistencies within the results. The PFT validation exercise is being planned against *in situ* PFT from HPLC (as soon as the data base is ready), globally and for time series stations' data.

Cecile Rousseaux (NASA) introduced the MARine Ecosystem Model Intercomparison Project (MAREMIP) which is very interested in satellite-derived PFT products for evaluating model performances. Many activities are currently on-going. She showed results of an exercise of the comparison of satellite (Hirata et al. 2011) and NOBM model phytoplankton groups which will help NOBM model parameterizations (Rousseaux et al. 2013 BGD). The future plan is to assimilate the satellite PFT data as is already done now in NOBM for total chl-a from SeaWiFS.

Finally, the discussion raised the following **important issues** which resulted in recommendations of actions that require funding on a broad international level:

Efforts need to be made to establish the robustness and limitations of these algorithms. In order to do so the limits on detection of PFTs and the errors in the products have to be determined. Areas for future activity include checking how many PFTs can be separated with optical methods using improved RT models and what spectral resolution for atmospheric corrected or not corrected spectra is necessary for the satellite input data. In that respect, the signal-to-noise ratio at which remotely-sensed radiative properties can be retrieved which will be a crucial issue if we aim at detected subtle changes in their spectral signature to identify PFTs. There should at least be some consideration of IOP budgets e.g. better understanding of the relative contribution of phytoplankton to the absorption and backscattering budgets across water types, biomass ranges, dominant assemblages etc.; this being a critical first step in understanding reflectance causality with respect to assemblage variability. It is important to also take into account the sensitivity studies of other aspects influencing the optical characteristics of PFTs, e.g. a change of signal due to physiology (photoacclimation). Further effort is required to intercompare the products and validate them in a consistent way (requiring more *in situ* data acquisition). The 2nd international intercomparison task group has been formed but with no direct funding and so is progressing slowly.

Efforts have to be made to have PFT/PSC products ready for applications. For global large-scale biogeochemical and ecological research many current algorithms have shown potential to be used to study changes, variability and trends of phytoplankton types, but for coastal applications (coastal management, fisheries,…) algorithms still require development. This is very challenging as, in addition to much more complex optics in those waters, the time scale of changing PFTs composition is much shorter than in the open ocean. So far the PFT satellite data sets start in 1997 (with SeaWiFS) providing a 10-15 year data set that needs extending to investigate longer-term changes, i.e., through the incorporation of upcoming missions. New missions may also be able to extend the range of PFT products due to improved spectral, temporal and spatial resolutions. The above mentioned sensitivity studies will further clarify the requirements for new sensors in respect to the retrieval of PFTs. It was also discussed that the Earth system modelers prefer other units than chl-a (e.g. carbon concentration, productivity, nitrogen), but it was also proposed that modelers would rather make their own conversions.

Recommendations to the Agencies:

1. Agencies should support PFT algorithm development, validation and intercomparisons as well as activities to merge different techniques and multi-mission data sets, in order to develop a new "standard product" of ocean colour.
2. The development of PFT methods (including radiative transfer modelling to hyperspectral data sets) should be supported with relevant *in situ* measurements from ships, gliders and buoys.
3. Simultaneous collection of *in situ* HPLC pigments, other PFT parameters which identify size, groups and functions (e.g. size-fractionated Chla, particle size distribution etc.) and optical data are essential for validating PFTs from current and upcoming satellite missions.
4. The validation of HPLC-PFT data sets should be supported by all agencies: a single method may not be globally applicable.
5. Optical and pigment methods used to discriminate PFTs should be linked for a better understanding of actual community structure using imaging flow cytometry and genetics. Better methods to allocate cellular carbon across the PFT categories should be defined.

References:

Brewin, R.J.W., Hardman-Mountford, N.J., Lavender, S.J., Raitsos, D.E., Hirata, T., Uitz, J., Devred, E., Bricaud, A., Ciotti, A. & Gentili, B. (2011). An intercomparison of bio-optical techniques for detecting phytoplankton size class from satellite remote sensing. Remote Sensing of Environment, 115(2), 325-339. doi: 10.1016/j.rse.2010.09.004

Hirata, T., Hardman-Mountford, N.J., Brewin, R.J.W., Aiken, J., Barlow, R., Suzuki, K., Isada, T., Howell, E., Hashioka, T., Noguchi-Aita, M. & Yamanaka, Y. (2011) Synoptic relationships between surface Chlorophyll-a and diagnostic pigments specific to phytoplankton functional types, Biogeosciences, 8, 311-327, doi: 10.5194/bg-8-311-2011M

Rousseaux, C. S., Hirata, T., Gregg, W. W. (2013) Satellite views of global phytoplankton community distributions using an empirical algorithm and a numerical model. Biogeosciences Discussion 10: 1083-1109.

Splinter Session 11: Satellite Data File Formats and Tools for Easy Science Exploitation

Co-Chairs: Carsten Brockman (Brockman Consult, Germany), Bryan Franz (NASA GSFC) and Simon Elliott (EUMETSAT)

The objective of this splinter session is to deliver consensus recommendations on data file content and format, meta-data, processing and analysis tools. These consensus recommendations shall be agreed by a larger community, as represented at the IOCS conference. Hence, progress compared to the current status shall be tangible progress and concrete statements. The splinter session was organised around three themes. This report presents a summary of the discussions and recommendations formulated for each of the three themes.

1. **Data file content and formats**

NASA OBPG (Ocean Biology Progressing Group) as well as ESA/Eumetsat with Sentinel 3 are currently moving towards a file format wherein data are stored in NetCDF4 format and utilize the Climate and Forecast metadata convention (NetCDF/CF). A primary reason for this transition is to improve interoperability between missions, reduce software maintenance requirements on existing data visualization tools, and improve compatibility with a host of third party tools and protocols (e.g., THREDDS/OpenDAP). Specifically, NASA OBPG is gradually migrating its Level 2 data from HDF4 into NetCDF/CF. The ESA Sentinel 3 format is a package where the image as well as ancillary data are stored in NetCDF4 files, with one file per variable, and an XML header file with all meta data. This follows the XDFU standard. KARI (Korea) is using HDF5 for GOCI data. NetCDF4 is a wrapper around HDF5, so transition from HDF5 to NetCDF4 may be feasible. Time series are also support by NetCDF4. Questions still need to be resolved as to how Level 3 data can be stored in an optimal way in NetCDF/CF and how the spatial and temporal binning needs to be adapted. Further, the CF convention does not fully cover the requirements for ocean colour and extension of the convention is required. This should be coordinated among the space agencies, an activity which could be led by IOCCG. Although there was an overall large agreement with NetCDF4/CF as common format, it was mentioned that some operational users requiring real time or near real time data require a format where satellite, in-situ and model data can be integrated.

Recommendation: The splinter session proposes to recommend to all Space Agencies to adopt netCDF4/CF for their ocean-colour data.

2. Data processing, analysis and exploitation tools

Flexible and user–friendly data processing, analysis and exploitation tools have become critical to ocean color research with the increased availability of disparate ocean-colour data; e.g, SeaWiFS, MODIS, MERIS, GOCI, and VIIRS. The splinter session has clearly expressed that the scope of required tools has to support visualization and validation, processing to higher-level products, modification and development of new processing algorithms, and visualization must include all data product levels as well as analysis of single products up to long time series and full mission data sets. Most agencies operating ocean-colour satellites today provide tools to its users which partly fulfil these requirements. The new releases of SeaDAS7 / BEAM 4.11 are a first step toward a common tool that is made available to users across agencies and works with (most) ocean-colour products.

A key to success for the acceptance of ocean-colour products is the full transparency of the processing algorithms through an open source release of the processing software. This was always the case for the SeaDAS software of NASA, and the exploitation of MERIS has been significantly improved with the availability of at least the Level 2 code in the ESA ODESA tool. The splinter group agreed that a multi-sensor approach as it is realised in SeaDAS is a significant plus and should be further pursued beyond the currently supported sensors. The demand for suitable, fast and robust data visualisation and analysis tools are very important for all users in order to quickly assess data quality and analyse single products as well as large data sets. The future development of the tools shall strive to support as many different sensors as possible and allow easy multi-sensor analysis with proper mapping and cross calibration functions. The IT technology of the tools shall be up-to-date in order to minimize processing times and thus allow for fast processing on very large datasets.

The splinter group emphasised that continuity of tools is important in order to insure user's developments and investments which build on current tools.

Finally it was discussed that the currently available tools provide a rich set of functionalities which are often not known by users. Data exploitation is thus not optimally done although proper tools are available. This has been discovered during training courses and forum discussions.

Recommendation: The splinter session recommends to the Space Agencies to further support the existing line of tools, namely SeaDAS, BEAM and ODESA, and to continue them for future sensors. This shall include further development as well as training of users.

3. Data distribution

Ocean-colour research is often focused on global applications or long-term regional time-series analyses leading to large data volume requirements. Data users require the ability to access and download data through scriptable (batch download) mechanisms (e.g., through established ftp and http protocols). Data access methods should also support regional extraction to minimize the amount of data that must be transferred to satisfy research requirements. More targeted, direct access methods of data access such as THREDDS/OpenDAP should be exploited. The splinter session considers an efficient data distribution as critical for the success of any ocean-colour mission.

EUMETSAT presented its plans for dissemination of Sentinel 3 data via the EUMETCast system. EUMETCast is a relay system where data are broadcasted via commercial telecommunication satellites. The system is in use since many years and provides high availability, maturity/stability, reliability, reproducible results, monitoring and control functionality, and maintainability. EUMETSAT currently distributes MODIS/Terra through EUMETCast and planning to include VIIRS, MERSI and OCM (both currently under negotiation), OLCI and potentially SGLI. The splinter sessions acknowledges the distribution via this medium and sees a great potential for efficient NRT distribution in it, but also stresses the point that continuation of traditional access means such as ftp is important. EUMETSAT is currently detailing the Sentinel 3 data dissemination through EUMETCast. Issues such as bandwidth need to be dimensioned properly. Concrete and justified requirements formulated by the international ocean-colour community are required and shall be forwarded to EUMETSAT.

Recommendation: The space agencies should support large volume, batch data access and download (e.g., through established means such as ftp/http), as well as more targeted access through protocols such as THREDDS/OpenDAP.

Recommendation: Sentinel 3 data will be available through EUMETCAST. The ocean-colour community shall provide concrete and justified requirements to EUMETSAT so that the distribution means can be properly dimensioned.

Splinter Session 12: Satellite Instrument Pre- and Post-Launch Calibration

Co-Chairs: Gerhard Meister (NASA GSFC) and Bertrand Fougnie (CNES, France)

The session was attended by about 25 participants. The introduction was given by Bertrand Fougnie from CNES. In addition to providing the background for this session, the point was made that it is important not to restrict our efforts to pure instrument calibration, but to include instrument characterization as well. In the first part of the session, representatives from several space agencies (ISRO, ESA, KIOST, NASA, JAXA) presented short descriptions of their instruments, the main calibration methods used, and the lessons learned from either pre-launch or on-orbit characterization and calibration efforts. Each talk was followed by a few questions from the audience.

Samir Pal from ISRO described an extensive prelaunch calibration effort for OCM-2. OCM-2 is a multispectral radiometer with 8 different bands with wavelengths mostly similar to those of SeaWiFS. The spatial resolution of 250m is achieved by using CCD detectors. One difficulty encountered during pre-flight characterization was the non-uniformity of the integrating sphere (about 4%) for the calibration of the full field-of-view of the instrument. The sensitivity of the CCD detectors is trended on-orbit with an LED source. However, the LED light does not use the full optical path, therefore another calibration mechanism is needed. Since 2010, OCM-2 has acquired 3 lunar images. A comparison of the lunar irradiances measured with these images to those predicted by the ROLO model (calculated by USGS, provided to ISRO via NASA) allows a full calibration of the instrument. So far, three maneuvers were performed. The low frequency of maneuvers is dictated by requirements of the other sensor on the Oceansat-2 mission (a scatterometer).

Steven Delwart and Ludovic Bourg presented for ESA. The sensors MERIS (on ENVISAT, operational from 2002 to 2012) and OLCI (on Sentinel-3, to be launched in 2014 or later) and the calibration approaches for them are so similar that they will be described here together. The instrument calibration relies mainly on in-flight calibration, more than pre-flight calibration. Consequently, no transfer to orbit was done and the main calibration approach was based on in-orbit evaluation using two solar diffusers. Both are well protected from solar radiation, except during the calibration measurements. One crucial aspect is the pre-flight characterization of the BRDF of both diffusers, especially for the viewing geometries that will be operated in orbit. One of the solar diffusers on MERIS was used so infrequently that its reflectance degraded by about 0.2% or less. The radiation is detected by a two-dimensional CCD, where one dimension is the spatial (across track) direction, the other the spectral dimension. Accuracies for the measurement of the top-of-atmosphere (TOA) radiances on the order of a few tenths of a percent require a careful characterization of CCD characteristics (like e.g. straylight and smearing). These characterization measurements are challenging, and often a combination of instrument model and prelaunch characterization measurements are used to produce operational corrections. The wavelength dispersion on the CCD is monitored via several mechanisms: an erbium doped solar diffuser, Fraunhofer lines, and the O2A line. The angular sampling for the prelaunch characterization measurements of the solar diffuser was enhanced for OLCI relative to MERIS in order to get a more representative sampling of the incidence angles for the on-orbit solar diffuser measurements. A schematic view of what is called the “system vicarious calibration” was presented in order to highlight the risk of an insufficient characterization (pre- or in-flight) on the ocean-colour level-2 products.

Seongick Cho (KIOST) presented a summary of GOCI. GOCI acquires its images by a CCD. The FOV is directed sequentially to 16 different slots via a pointing mechanism, the 8 (412nm to 860nm) different wavelengths are selected using a filter wheel. The on-orbit temporal trending for GOCI is achieved using a transmissive solar diffuser (note that all other solar diffusers discussed in today’s session are reflective). Overall, very little gain degradation has been detected so far by the GOCI calibration team, the sensors radiometric gains are remarkably stable. However, there are seasonal oscillations in the gains (correlated to the solar angles) that are not fully understood yet. One possible explanation could be a problem with the knowledge or aging of the diffuser’s BRDF. For GOCI-II, the calibration approach will be enhanced by a second solar diffuser and lunar calibrations.

Gerhard Meister presented details of the MODIS sensors (on the Aqua and Terra platforms) and VIIRS (Suomi-NPP mission). In the MODIS prelaunch characterization, the official documentation of the setup did not document the configuration during the polarization characterization sufficiently well, which led to significant errors in the on-orbit polarization correction in the early phase of the mission. In the MODIS design, the primary optical element (the scan mirror) is relatively exposed. In both MODIS instruments, there has been significant scan-angle dependent degradation at 412nm (more than 10%), which is an issue for the calibration because the calibration sources (lunar measurements and a solar diffuser) are available at only two selected scan angles. On MODIS Terra, a prelaunch contamination incident caused an even stronger degradation than for MODIS Aqua, which also led to a strong change of the polarization characteristics with time. An additional problem with MODIS on Terra is that the solar diffuser door is open permanently (after a mechanism malfunction in 2003), which leads to an increase in the rate of degradation of the solar diffuser BRDF. The situation for VIIRS is similar, the solar diffuser is protected only by a screen (VIIRS design choice). Note that the solar diffuser door on MODIS Aqua is still operating without problems. NASA’s ocean-colour processing uses SeaWiFS and MODIS Aqua data to cross-calibrate MODIS Terra. NASA MODIS Calibration Support Team uses desert reflectances to improve the MODIS Aqua calibration of the shorter wavelengths (currently 412nm and 443nm).

Hiroshi Murakami from JAXA presented the calibration approach for SGLI, which may launch as early as 2015. SGLI has multiple on-board calibration functions: a solar diffuser, a lamp (LED), and a black body. A maneuver is planned for evaluating the BRDF of the solar diffuser after launch. Additionally, the GCOM-C satellite will perform a monthly pitch maneuver so that SGLI can measure the lunar irradiance at a constant phase angle. Pre-launch characterizations such as polarization sensitivity, SNR, and straylight aspects haven been completed for the engineering model.

In the second part of the session, Tim Hewison and Ewa Kwiatkowska (both from EUMETSAT) presented potential frameworks for further calibration work: GSICS (Global Space-based Intercalibration System) and a new inter-agency task force on satellite sensor calibration, respectively. GSICS is an international collaborative effort initiated in 2005 by WMO and the CGMS. Its goal is to intercalibrate TOA radiances for different sensors mainly for Climate and Meteorological purposes. The GSICS group has a successful history with Infrared sensors and Geostationary sensors. Its plans for low Earth orbit sensors intercalibration are in an early stage. The calibration teams of each ocean-colour sensor are encouraged to join GSICS to help develop these plans.

The INSITU-OCR white paper suggested the creation of a permanent calibration task force (this point was also highlighted on the recent IOCCG Report#13). It should have close interaction with the extended ocean-colour community to take into account the community's feedback and recommendations regarding the accuracy and quality of calibration and characterization of individual instruments. Calibration and characterization expert activities should include interactions on specific technical problems, hands-on work with data and prototyping, and delivery of solutions and transfer of the solutions to operations. These suggestions provoked a lively discussion, which will be summarized in the following paragraphs.

There was consensus that we are working on common issues, and that sharing expertise would be beneficial for all involved. We do need a platform to share information and go into detail for focused tasks. There was agreement that we should meet regularly, e.g. by regular web meetings, plus at least for each IOCS meeting. In-person meetings were generally viewed as more productive, especially for hands-on work on specific problems, but most members find it difficult to get international travel approved in a time of tight budgets. It was decided to have an initial telecon to define future activities, e.g. instrument characterization issues are an obvious area that received widespread support from all involved. It is important to note that we will not just work on radiometric calibration, but on instrument characterization in general (such as e.g. straylight, polarization, spectral response, BRDF, etc.). Furthermore, it is very important that the space agencies clearly support this kind of activity. In the case the work is to be carried out by contractors, such work should be included in the contract language.

No consensus was reached on the exact goals of the task force. Mentioned in the discussion were: a) Improve instrument characterization (e.g. straylight, polarization, etc.) b) Absolute calibration c) Vicarious calibration d) Inter-calibration e) Essential Climate Variables f) Documentation. It is likely that the group will focus to work on improving instrument characterization first and expand its activities to other tasks later.

Even more controversial was the most appropriate framework for the group. Everybody agreed on the fact that we need to avoid duplication. Regarding existing groups, one option would be a new group under the CEOS-IVOS working group or under the CEOS OCR-VC. Feedback from CEOS-IVOS mentioned that that group is not focused on ocean colour, which could be problematic because radiometric characterization may not be as crucial for them as it is for ocean colour. So a potential option could be to simply join CEOS-IVOS by creating a dedicated sub-group. Another option is a task force directly related to IOCCG/INSITU-OCR. No consensus was reached - our group needs further guidance from the IOCCG on the most appropriate framework.

7. Poster Sessions

Two poster sessions were conducted during the course of the meeting. On Monday afternoon posters were presented in the topical area of "Algorithms and Products", and on Tuesday afternoon posters were presented in the four other topical areas shown below. All posters were on view during the coffee breaks and throughout the entire three-day meeting. Poster abstracts, listed in alphabetical order by author or by topical area, can be downloaded from the meeting website: http://iocs.ioccg.org/abstracts/browse-approved-abstracts/

The posters were grouped into the following five topical areas:

- algorithms and products (60 posters)
- satellite instrument calibration (5 posters)
- *in situ* data and protocols for Cal/Val (25 posters)
- data infrastructure, formats and distribution (3 posters)
- applications, user services and tools (21 posters)