Update on Coordination of International Ocean Color Remote Sensing

By the International Ocean-Colour Coordinating Group (IOCCG)

The International Ocean-Colour Coordinating Group (IOCCG)[1] is an organization of experts from both the satellite data provider (space agencies) and user communities (scientists, managers) that operates in the field of satellite ocean color and provides a critical forum for sharing, coordinating, and disseminating information related to the measurement of ocean color radiometry from space. Through the Ocean Colour Radiometry Virtual Constellation (OCR-VC), the IOCCG also provides recommendations, reports, and publications for the Committee on Earth Observation Satellites (CEOS) to foster the development of high-quality ocean color sensors capable of tracking long-term changes in the ocean basins and production of "Essential Climate Variables (ECVs)," such as chlorophyll *a* (Figure 1).

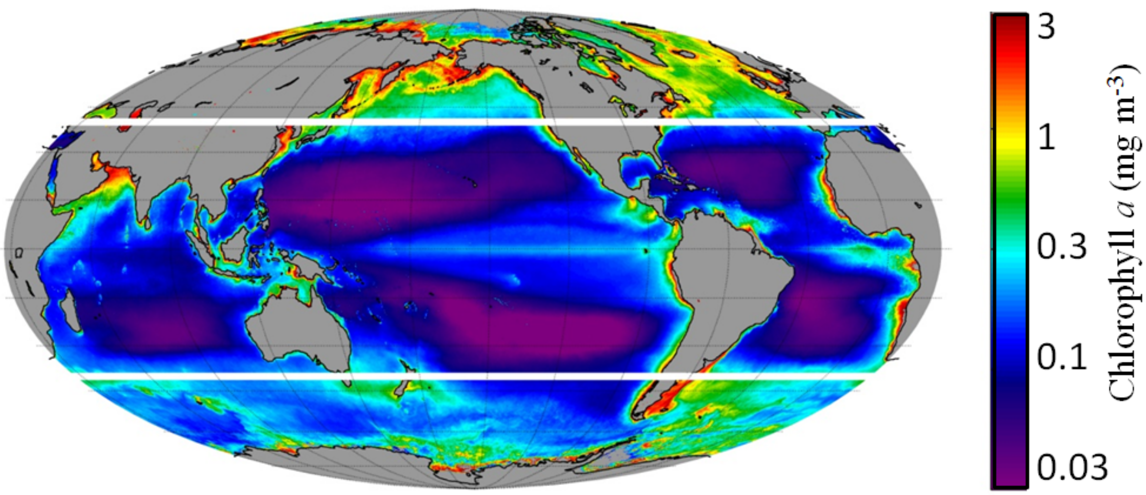

Figure 1. Global chlorophyll *a* (mg m^{-3}) derived from the long-term MODIS Aqua satellite record (2002–2014) showing the 40°N and S division (white line) dividing the higher biomass polar oceans from the largely oligotrophic central ocean gyres. Temporal calibration has become increasingly challenging for the MODIS sensor, especially in the blue channels (412, 443 nm). With recent advances, it now appears that VIIRS can provide ocean color measurements of sufficient quality to extend the multi-mission time series into the future.

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[1] The IOCCG website (http://www.ioccg.org) provides reports, lecture notes, current and future sensor specifications, computational tools, and links to publically available Ocean Colour databases, including those from current and historical sensors as well as merged products.

Recently, the IOCCG, in partnership with NASA and NOAA, hosted the second International Ocean Color Science (IOCS) meeting in San Francisco, California (15–18 June 2015), with additional sponsorship from EUMETSAT, ESA, CNES, SCOR and the Moore Foundation[2]. The primary focus of the meeting was to build and strengthen the international ocean color community by providing a forum to collectively address common issues and goals, and to foster exchange between the research community and space agency representatives. The meeting included presentations from 11 international space agencies, plenary lectures, public lectures, poster sessions, and 10 breakout sessions covering a wide range of topics aimed at producing practical recommendations for the space agencies (see http://iocs.ioccg.org/ for full meeting agenda and all presentations).

Representatives from ocean and satellite agencies from the United States (NASA, NOAA), Canada (CSA), Europe (ESA, EUMETSAT, CNES), South Korea (KIOST/KOSC), China (SOA), India (ISRO), Japan (JAXA), and Brazil (INPE) briefed the participants on current and future plans for ocean color sensors from their respective agencies[2]. There are currently nine ocean color sensors on orbit. The US ocean color sensors include MODIS-Aqua (Figure 1), MODIS-Terra, and VIIRS on S-NPP[3]. Other ocean color sensors currently producing imagery and operational products for their users include the Chinese COCTS/CZI sensors onboard HY-1B and three MERSI sensors onboard FY-3, OCM-2 from India, and the first ocean color geostationary sensor, GOCI, on the COMS satellite from South Korea. Links to the data portals for these sensors can be found on the IOCCG website[1]. The IOCCG supports all efforts to make the calibrated, geo-located radiances (Level 1-B) from all international sensors available to the global research community for algorithm development. Such data are important for development and validation of new ocean color products such as Phytoplankton Functional Types (Figure 2).

The MODIS-Aqua sensor is still operational and has provided global climate-quality data for over 12 years, well beyond its nominal mission lifetime. The sensor is aging, however, and maintenance of the temporal calibration has become increasingly challenging, especially in the blue channels (412, 443 nm) where changes in radiometric and polarimetric sensitivity cannot be fully characterized by the onboard calibration alone. On a more positive note, calibration of VIIRS on S-NPP launched in 2011 has been significantly improved over the past year, and it now appears that VIIRS can provide ocean

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[2] List of Acronyms: NASA = National Aeronautics and Space Administration. NOAA = National Oceanic and Atmospheric Administration. ESA = European Space Agency. CSA = Canadian Space Agency. EUMETSAT = European Organisation for the Exploitation of Meteorological Satellites. CNES = Centre National d'Etudes Spatiales. KIOST = Korea Institute of Ocean Science and Technology. KOSC = Korea Ocean Satellite Center. ISRO = Indian Space Research Organisation. JAXA = Japan Aerospace Exploration Agency. CONAE = Comisión Nacional de Actividades Espaciales, Argentina. INPE = National Institute for Space Research, Brazil. SOA = State Oceanic Administration of China. SCOR = Scientific Committee on Oceanic Research. OCRT = Ocean Color Research Team.

[3] NASA ocean color website: http://oceancolor.gsfc.nasa.gov/

color measurements of sufficient quality to extend the multi-mission time series into the future and support ongoing global ocean color research. Paul DiGiacomo from NOAA/NESDIS updated the participants on the status of the VIIRS ocean color data stream generated by the US Joint Polar Satellite System (JPSS) program. He reported on improvements to the data processing and accuracy, particularly over coastal and inland waters and the availability of near-real-time VIIRS ocean color data via the NOAA CoastWatch/OceanWatch Program[4]. User applications of ocean color data produced by NOAA include water and air quality monitoring, fisheries and coral reef management, and coupled ocean-atmosphere modeling supporting numerical weather prediction.

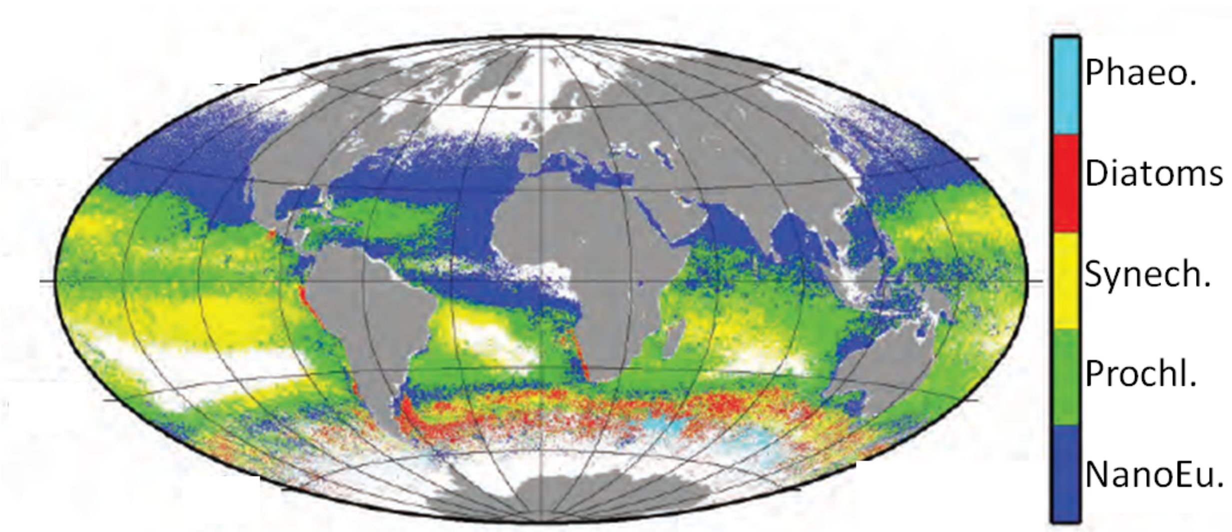

Fig. 2. Example of one of the approaches from the most recent IOCCG report (2014) for estimating phytoplankton functional groups from ocean colour satellite imagery[1]. Long-term January climatology derived from the SeaWiFS sensor (1998 – 2010) of the dominant phytoplankton groups: *Phaeocystis*, Diatoms, *Synechococcus*-like cyanobacteria, *Prochlorococcus*, and nano-eukaryotes[1]. White colour indicate regions where dominant types were not identified or imagery was not available due to sea ice or low light.

An exciting array of polar-orbiting and geostationary ocean color sensors are in development from international space agencies. Paula Bontempi of NASA Headquarters discussed preparation for a US 2021–2022 launch of a hyperspectral ocean color sensor coupled with a polarimeter currently called PACE (Pre-Aerosol Cloud and ocean Ecosystem). The first phase of the PACE science definition team has been selected and tasked with demonstrating how PACE will improve upon previous atmospheric correction approaches for ocean color data as well as build consensus for approaches to improve retrieval of inherent optical properties and phytoplankton functional types (Figure 2). NASA also funded development of three projects to further advance technology development of radiometry for vicarious calibration and is in the planning

[4] http://coastwatch.noaa.gov/; http://oceanwatch.pifsc.noaa.gov/

stages for field campaigns to collect data for algorithm development and ocean biology and biogeochemistry research, including the North Atlantic.

Philippe Goryl reported on ocean-color activities at the European Space Agency (ESA), which is preparing to launch the Copernicus Sentinel-3A satellite, carrying the OLCI sensor, in October 2015, to be followed by the launch of Sentinel-3B, carrying the same payload, in summer 2017. OLCI images will be acquired globally and processed systematically in Near Real Time at both full and reduced resolutions. ESA is also funding development of a dedicated set of software tools supporting users in the exploitation of data products of the Copernicus Sentinel satellites and has also initiated several projects aiming at establishing and maintaining SI traceability for Fiducial Reference Measurements. Ewa Kwiatkowska of EUMETSAT briefed the committee on global data dissemination plans for Sentinel-3 and invited all potential users of the data to apply directly to EUMETSAT for near-real-time data access and for time-series services.

Briefings on the spatial and spectral resolution of other current and proposed polar-orbiting satellites were also provided. Hiroshi Murakami reported on the development status of Japan's GCOM-C/SGLI mission, scheduled to be launched in 2016 with 250 m spatial resolution for detection of river outflow, regional blooms, small currents, and red tides. Zhihua Mao presented China's advances in satellite remote sensing, including the proposed launch of two ocean color satellites (HY-1C and HY-1D) in the 2017–2018 timeframe. Milton Kampel updated participants on the proposed Brazilian/Argentinian SABIA-MAR mission, scheduled to be launched at the end of 2018 and 2019, with two satellites flying as a constellation with global and coastal mission scenarios. Prakash Chauhan reported on the Indian space agency ISRO plans to launch the OCM-3 sensor in 2018, as well as high spatial resolution ocean color observations and applications from the current OCM-2 sensor. Lastly, Martin Bergeron reported on the Canadian Space Agency's support of ocean color activities within Canada, including data access and international coordination, and outlined plans for two prospective missions driven by Canadian users' desire for high spatial resolution hyperspectral data with frequent revisit time (WaterSat and the Canadian Hyperspectral Mission).

Agency representatives presented updates on the present and upcoming geostationary sensors that provide high temporal resolution imagery over the same location. YoungJe Park showed how GOCI, the Korean geostationary ocean color sensor, is stable five years after launch and is providing products such as tracking of local harmful algal blooms and dredging/dumping activities. Plans were presented for the new GOCI-II mission to be launched in 2019 with an observational interval of 10 times per day. As reported by Marina Lévy, the French space agency CNES also has plans for a geostationary ocean color sensor, OCPAI (Ocean Color Advanced Permanent Imager), representing the next generation of ocean color missions complementing low orbit observation with very high temporal and spatial resolution.

Many of these missions and products are "operational" in nature, intended to provide near-real-time imagery to monitor fronts for fisheries and identify harmful algae blooms, pollutants, and other water quality indices. Several of the planned sensors incorporate the additional sensor calibration and validation costs for producing climate quality radiometry to track long-term changes in the ocean basins. A requirement of producing quality data is also to monitor the in situ water-leaving radiance with highest accuracies at ocean sites, in what is dubbed "vicarious calibration." At the IOCS meeting, keynote speaker Kenneth Voss presented the history of the Marine Optical BuoY (MOBY) in Hawaiian coastal waters and plans to further develop vicarious calibration approaches. MOBY and BOUSSOLE in the northwestern Mediterranean Sea currently provide high-quality water leaving radiance data for use in vicarious calibration of ocean color satellite instruments.

Over the ocean, the majority of the signal reaching a space-borne sensor is actually from sunlight scattered within the atmosphere and reflection off of the sea surface that must be removed through the process of "atmospheric correction." Hence, ocean color measurements are highly sensitive to the methods and protocols for calibrating, validating, and processing the remotely sensed radiance data. Meetings such as the IOCS provide a critical interactive forum between space agencies and scientists that ultimately leads to important advances in ocean color remote sensing.