THE CEOS CONSTELLATION FOR OCEAN COLOUR RADIOMETRY (OCR)
PROPOSAL SUBMITTED BY JAMES A. YODER, CHAIR
INTERNATIONAL OCEAN COLOUR COORDINATING GROUP (IOCCG)
ON BEHALF OF CEOS AGENCIES REPRESENTATIVES
PREPARED TO PARTICIPATE IN AN OCR STUDY TEAM
SEPTEMBER 2008

Mission Statement and Anticipated Outcomes.

The OCR Virtual Constellation (OCR-VC) will provide calibrated ocean-colour radiances (OCR) at key wavelength bands. Ocean colour radiance is the wavelength-dependent solar energy captured by an optical sensor looking at the sea surface. These water-leaving radiances contain latent information on the optical constituents of the sea water, in particular the pigments (primarily chlorophyll-a) contained in the phytoplankton. At satellite altitudes the relatively weak OCR signal (10-20% of incident solar radiation) also has to propagate through the atmosphere before detection.

The key space segment capabilities are the current and future polar-orbiting global OCR satellite missions (see figure 1). Of specific interest are SeaWiFS, MERIS on Envisat, MODIS-Aqua, OCM on Oceansat-2, OLCI on Sentinel 3A and 3B, SGLI on GCOM-C, VIIRS on NPOESS-C1, possibly VIIRS on NPP, and future NASA and CNES instruments under consideration. Other instruments such as China's COCTS and Korea's planned GOCI are also of interest but are not collecting global data.

In addition to the space segment, projects such as the former NASA-supported SIMBIOS project, the current ChloroGIN Project (multiple sponsors, see description below), the ESA-supported GlobColour Project (see description below) and the European Commission/ESA/EUMETSAT-supported GMES Marine Core Service will be required to calibrate across sensors, validate data products and generate global and regional products from merged data sets.

Cross-calibrated OCR from multiple satellites will be merged to provide a Fundamental Climate Data Record (FCDR) of water-leaving radiances from which scientific data products related to marine ecosystems and ocean biogeochemistry for near-surface global ocean and coastal waters are calculated. Wavelengths centered at 412, 443, 490, 510, 531, 555, 620, 670, 681 and 709 nm are the most useful for deriving OCR data products (see next paragraph). To accurately calculate the effect of the atmosphere on the water-leaving radiance reaching satellite altitudes requires additional measurements in the near-infrared.

The most important OCR data products currently in use are phytoplankton chlorophyll-a concentration, coloured organic matter (COM), particulate organic carbon, and suspended sediments. Other products are in development. OCR data products are the only

measurements related to biological and biogeochemical processes in the ocean that can be routinely obtained at ocean basin and global ocean scales.

The Global Climate Observing System (GCOS) requirements for OCR provide a concise summary statement as to the value of OCR data. (GCOS-107 (WMO/TD No. 1338, September 2006) in section 3.2.4 ECV Ocean Colour, Ocean colour, and oceanic chlorophyll-a concentration derived from ocean colour): "The primary benefits of OCR to GCOS are climate monitoring; chlorophyll-a linked to carbon-cycling including between the ocean and the atmosphere; and ocean particulate carbon estimated from ocean colour. Other applications include essential information for natural living-resource management and monitoring of the health of coastal seas."

GEO Requirements Addressed.

Products derived from OCR are specified in the GEO 2007-2009 Work Plan, "Towards Convergence" (27 March 2008) under 4 societal benefit areas: health, climate, ecosystems and agriculture. A draft of the GEO 2009-2011 Work Plan was recently released and is organized somewhat differently than the GEO 2007-2009 plan. The GEO 2009-2011 draft plan strongly supports the rapid development of virtual constellations including ocean colour radiometry (AR-09-02). The updated GEO plan points out the OCR-VC provides for "scientific data products related to marine ecosystems and ocean biogeochemistry for near-surface global ocean and coastal waters" and this simple statement summarizes the key data products that contribute to the tasks listed below from the GEO 2007-2009 plan.

The tasks from the final GEO 2007-2009 that involve ocean colour radiometry measurements are described below.

Health. Task HE-07-02 (Environment and health monitoring and modeling) includes a requirement for new observations characterizing atmospheric, soil, river and coastal pollution. Chlorophyll-a based on OCR has been used as an index of coastal eutrophication – a widespread type of coastal pollution caused by excess nutrient inputs. Harmful algal blooms (HABS) are also a form of coastal pollution.

Task HE-07-03 (Multihazard Risk Reduction due to Atmospheric Aerosols) has a goal of bringing all players interested in applying an integrated aerosol observational approach (including modeling) to reducing risks with respect to multiple hazards of aerosols. OCR imagery is used for large-scale aerosol mapping, including intercontinental movement of dust storms.

Climate. Task CL-06-01 (Sustained Reprocessing and Reanalysis Efforts) to ensure the development of international mechanisms to coordinate and maintain sustained data reprocessing and reanalysis efforts. This would include the provision of consistent, long time-series of satellite records, which is one of the primary goals of the OCR-VC .

Task CL-06-02. Establish actions securing the provision of key data for climate studies and forecasting from satellite systems. OCR data is essential for the goals of GCOS.

Task CL-06-05 (GEOSS IPY Contribution) includes a requirement to enhance the utilization of Earth observations in all appropriate realms (including, marine ecosystem change).

Task CL-06-06 (Global ocean observation system) is a broad requirement to enhance and improve coordination of coastal and marine climate observations which links back to the GCOS requirements for OCR as summarized above.

Ecosystems. Task EC-06-01 (Integrated global carbon observations) is a requirement to support integrated global carbon observations. OCR products are used to estimate particulate and dissolved organic carbon in the ocean and along with SST for satellite-based calculations of pCO_2 in surface ocean waters.

Task EC-06-02 (Ecosystem classification) requires the establishment of an *ad hoc* ecosystems classification task force, including ocean ecosystems, to create a robust and viable classification scheme for ecosystems. OCR is now being used for such a purpose, and the IOCCG currently has an ocean ecosystem classification working group developing a report on how OCR is being used for ocean ecosystem classification.

Task EC-06-07 (Regional networks for ecosystems). ANTARES, which is cited as an example under this task, was founded by IOCCG and still has a close affiliation with IOCCG. It has been successfully extended into the global-scale ChloroGIN network. Workshops to strengthen observing capacity (for OCR) in developing countries have been an IOCCG activity for more than a decade with major workshops held in Southeast Asia, Africa, and South America.

Task EC-07-01 (Global Ecosystem Observation and Monitoring Network). OCR is the only global measurement related to ocean ecosystem processes, and thus OCR measurements are an essential component of global ocean and coastal monitoring.

Agriculture Task AG-06-02 (Data Utilization in Aquaculture). Consult with scientists and experts from the fisheries, aquaculture, coastal zone management and Earth observation communities at international and regional levels to identify opportunities for enhanced utilization of Earth observations in fisheries and aquaculture. See below for description of the SAFARI project.

Task AG-07-01 (Improving Measurements of Biomass). Task includes marine biomass. OCR imagery is used for determining phytoplankton biomass which is at the base of ocean food webs and ultimately sustains all fisheries.

Programmes Cooperating with IOCCG of Direct Relevance to GEO Tasks.
Projects such as those described below are expected to be an important component of the OCR-VC activities to provide calibrated and validated data, to link measurements across

multiple satellite instruments for long time series required for climate impact studies, to develop and to refine data products for scientific and operational users including for some of the GEO societal benefit areas.

SIMBIOS. NASA's SIMBIOS project was supported from 1998-2003. It was based at NASA-Goddard and also supported scientists from U.S. universities and encouraged participation by non-U.S. scientists. The project had multiple activities including:

- Development and documentation of the SeaWiFS Bio-optical Archive and Storage System (SeaBASS). SeaBASS is an archive of very high quality bio-optical and other *in situ* measurements for validating satellite OCR products.
- Development of sun photometer calibration and data analysis procedures to support satellite OCR calibration and validation procedures, and development of a data base of sun photometer measurements.
- Development and revision of protocols for *in situ* measurements related to calibration and validation of satellite OCR products.
- Development and support of a website for diagnostic data sets to facilitate comparison of OCR measurements from different sensors.
- Evaluation of satellite OCR data merger strategies and procedures.

Although the SIMBIOS project ended in 2003, some of the activities (e.g. maintaining SeaBASS) were transferred to other NASA projects.

SAFARI Project The SAFARI Project (Societal Applications in Fisheries & Aquaculture using Remotely-Sensed Imagery) was established in November 2007 as an element of GEO Task AG-06-02, which calls for consultation at the international level to identify opportunities for enhanced utilization of Earth Observation (EO) data in fisheries and aquaculture. The project is under the leadership of Trevor Platt, Bedford Institute of Oceanography, Canada (B.I.O.) and former Chair of IOCCG, and is funded by the Canadian Space Agency, with additional support provided by IOCCG, B.I.O. and GEO. Remote sensing, in particular ocean-colour radiometry (OCR), is emerging as an important tool for fisheries research and management because of its high spatial and temporal resolution and low incremental cost. The primary objective of the SAFARI Projective is to accelerate the assimilation of EO into fisheries research and ecosystem-based fisheries management on a world scale by facilitating the application of rapidly-evolving satellite technology to fisheries management questions.

An international workshop on the "Use of Remotely-Sensed Data as an Aid to Fisheries Research and Fisheries Management" was recently hosted by the SAFARI Project, and an outline for a report on this topic was drafted at the workshop, with input from all invited participants. This report represents one of the deliverables of GEO Task AG-06-02, and will be published by the IOCCG in early 2009. Other components of the SAFARI Project will include remote-sensing information sessions for the fishing community and an International Symposium on Remote Sensing and Fisheries, scheduled for early 2010.

ChloroGIN Network The Chlorophyll Global Integrated Network (ChloroGIN) is a combined POGO-GEO-GOOS initiative addressing GEO Task EC-06-07. ChloroGIN was established to develop a global network of *in situ* oceanographic measurements in conjunction with satellite-derived estimates, and to coordinate activities to strengthen observing capacity in developing countries. One of the key features of the network is that it is being developed using existing local capabilities. The core products provided include chlorophyll, sea surface temperature and light penetration. ChloroGIN was inspired by the ANTARES network of Latin America, which was created under the auspices of the IOCCG.

Currently, there are three ChloroGIN regional centres (Latin America, southern Africa, and India) that are linked by good communications to three northern centres (PML in the UK, the European Commission, and USA). Each of these centers has its own set of priorities e.g. for ChloroGIN-Africa the priorities include harmful algal blooms, while the Indian node of ChloroGIN uses satellite data for identifying potential fishing zones for the benefit of local fishermen. ChloroGIN is fulfilling a need to integrate *in situ* and remotely-sensed observations into a single network, and to work towards timely delivery of data and information for the benefit of society.

ESA's GlobColour Project. The 3-year ESA funded GlobColour Project was established in November 2005 to develop a satellite-based, ocean-colour data set to support global carbon-cycle research, and to satisfy the scientific requirement for a long (10+ year) time-series of consistently calibrated global ocean-colour information with the best possible spatial coverage. This was achieved by merging data from the SeaWiFS, MODIS-Aqua and MERIS missions. In setting up the GlobColour project, three user organizations were invited to help specify detailed user requirements as well as to act as a channel to the broader end-user community, and to provide feedback and assessment of the results. The International Ocean Colour Coordinating Group (IOCCG) provided an understanding of the global user needs and advice on best practice within the ocean-colour science community, the International Ocean Carbon Coordination Project (IOCCP) provided access to the carbon cycle modeling community, and the National Centre for Ocean Forecasting (NCOF) provided an understanding of physical oceanography requirements.

The first year of the project was a feasibility demonstration phase. Error statistics and inter-sensor biases were quantified by comparison with in situ measurements from moored optical buoys and ship-based campaigns, and used as an input to the merging. The second year was dedicated to the generation and validation of the time series. Quality control was provided through the Diagnostic Data Sets (sub-areas with extensive in-situ data collection). The Full Product Set covers global daily merged, ocean-colour products for the time period 1997-2007, and is now freely available on the GlobColour website.

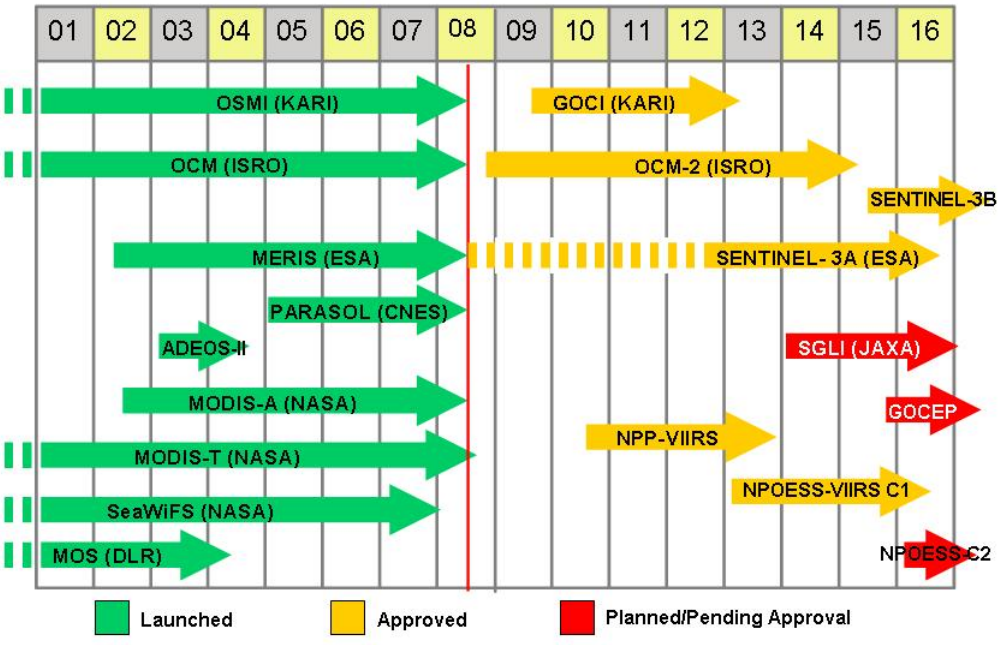
The GlobColour service distributes global daily, 8-day and monthly data sets at 4.6 km resolution for, chlorophyll-a concentration, normalized water-leaving radiances (412, 443, 490, 510, 531, 555 and 620 nm, 670, 681 and 709 nm), diffuse attenuation

coefficient, coloured dissolved and detrital organic materials, total suspended matter or particulate backscattering coefficient, turbidity index, cloud fraction and quality indicators. Error statistics from the initial sensor characterization are used as an input to the merging methods and propagate through the merging process to provide error estimates for the output merged products. These error estimates are a key component of GlobColour as they are invaluable to the users; particularly the modelers who need them in order to assimilate the ocean colour data into ocean simulations. An intensive validation phase was also undertaken to assess the quality of the data set. In addition, inter-comparisons between the different merged datasets helped in further refining the techniques used.

In 2008, the project continues by merging MERIS and MODIS-Aqua ocean-colour data with a global daily delivery in near-real-time, primarily to support operational oceanography. In the future this will feed into the EU GMES Marine Core Service that will provide (in 2009) a suite of services to support Europe's decision makers. Future availability of MERIS ocean-colour data will be assured with the launch of the first Sentinel-3 satellite in 2012.

Description and Timelines of Current and Future Satellite Programmes

Figure 1. Timeline of current and future satellite programs that involve instruments for OCR.



ISRO's Oceansat-2 Mission: Oceansat-2 will carry three instruments including the OCM-2 ocean-colour sensor. OCM-2 is similar to OCM-1 apart from the 765 nm band being moved to 740 nm to avoid O2 absorption, and the 670 nm band being replaced by 620 nm for better quantification of suspended sediments. Modes of operation would include local area coverage at 360 m (real time transmission) and global area coverage at 4-km (on-board recording). Launch is anticipated in 2008/2009.

NOAA VIIRS (Visible/Infrared Imager/Radiometer Suite): VIIRS is a multi-purpose instrument which includes an ocean colour capability. The first VIIRS will fly on the NPOESS Preparatory Project (NPP) with a scheduled launch in 2010. VIIRS is designed to have similar capabilities for ocean colour as the current MODIS instruments. However, VIIRS on NPP will not be capable of providing climate-quality ocean-colour data, and thus will be less capable than MODIS-Aqua. Subsequent VIIRS instruments are anticipated to have better performance specifications than VIIRS on NPP with the NPOESS-C3 being the first platform opportunity for VIIRS following NPP. NPOESS-C3 is scheduled for launch in 2013.

ESA Sentinels: Sentinel-3 will substantially increase the ability to provide, on a sustained basis, reliable, frequent, consistent, timely and long-term collections of remotely-sensed OCR and other ocean data of uniform quality. The Sentinel-3 payload comprises a Cryosat-derived Radar Altimeter and two imagers, a MERIS-like Ocean and Land Colour Instrument (OLCI), and an AATSR-like Sea and Land Surface Temperature Radiometer (SLSTR). The OLCI provides similar but enhanced ocean colour capabilities as MERIS. Two satellites are planned (Sentinels-3A and -3B), each designed with a 7-year lifetime, with the first satellite scheduled for launch in 2012 and the second in 2015. Sentinel-3 has a high-inclination sun-synchronous frozen orbit with 14+7/27 revolutions per day with a mean altitude of 815 km and a local equatorial crossing time of 10:00 am enabling near-complete global coverage and mitigating sun glint, morning haze and cloud-cover impact. The baseline of two satellites simultaneously in-orbit with 180_ dephasing supports full imaging of the oceans within 2 days

JAXA GCOM-C: The next Japanese ocean-colour mission is the Global Change Observation Mission for Climate research (GCOM-C). The mission will consist of three satellite series for 13 years from early 2014. GCOM-C will carry the second generation Global Imager (SGLI) which is a radiometer of 380-12,000 nm wavelength, 1150-1400-km swath width, and 10:30 am descending orbit. Features of SGLI are 250 m spatial resolution (500 m for thermal infrared) and polarization/along-track slant view channels (red and near-infrared), which will improve coastal ocean, land, and aerosol observations.

Data from SeaWiFS, Polder I and II, OCTS, MODIS-Aqua and Terra, GLI, MERIS and from future missions including SLGI, OCM, VIIRS and ESA Sentinels comprise a multi-decadal time series of OCR measurements. Projects such as NASA's SIMBIOS and ESA's GlobColour are required to re-process and then merge measurements across

satellite instruments for a consistent, calibrated time series required for climate data records that meet GCOS requirements and for other applications.

Assuming that most or all of the sensors illustrated in the figure are successfully launched, the potential impediments to success are: (1) lack of timely access to and sharing of data, including Level-0 satellite data, (2) lack of developing and sharing in-situ data bases, ocean colour radiances and derived products of sufficient quality to use for calibrating and validating satellite data products (such as was done by NASA's SIMBIOS project and currently by ChloroGIN) and (3) difficulty of sustaining projects such as GlobColour for merging data across satellite sensors to support global and regional scientific data products. CEOS can help avoid the impediments to success by encouraging member agencies to promote timely access to and sharing of data, and to cooperate to establish appropriate ground segments required to overcome impediments (2) and (3) listed above.

Proposed Study Leads

IOCCG membership includes representatives from space and other government agencies as well as scientists and others representing scientific and operational user communities. IOCCG working groups generally consist of scientists. However, we propose that the leads for the OCR-VC come from implementing organizations; specifically those individuals from space and other government agencies representing their governments on IOCCG. To date, the following IOCCG members have confirmed that their agency will participate in the OCR-VC:

Yu-Hwan Ahn, Korea Ocean Research and Development Institute (KORDI)
Paula Bontempi, NASA
Paul M. DiGiacomo, NOAA
Nicholas Hoepffner, Joint Research Centre, EU
Milton Kampel, INPE - Brazilian Space Research Institute
Hiroshi Murakami, JAXA/EORC
Rangnath R. Navalgund, Space Applications Centre, ISRO
Peter Regner, ESA-ESRIN
Eric Thouvenot, CNES

We anticipate that others will join as well. This group would form the leadership of the OCR-VC supported as *ad hoc* members by the IOCCG Chair (currently Dr. James Yoder) and Executive Scientist (Dr. Venetia Stuart). Our plan is to select 2 from the leadership group to serve as the co-chairs with a rotation every 2-3 years.

Schedule

Assuming that the initial proposal is approved at SIT-22, the OCR-VC leadership group will begin to prepare the Study Report. The goal would be to have a final version of the Study Report for submission to SIT following the next IOCCG annual meeting to be held

at the Second Institute of Oceanography (SIO) in Hangzhou, P.R. China 20-22 April 2009.