Thoughts About the Future of Satellite Ocean Color Observations

by David A. Siegel (UCSB), James A. Yoder (WHOI), Charles R. McClain (NASA/GSFC)

For more than a decade, the ocean biology and biogeochemistry community has been blessed by the wide availability of high quality, global satellite ocean color observations. These observations have enabled transformational science achievements throughout oceanography and Earth science. Any one of a large number of achievements can be cited from bio-optical oceanography to global carbon cycling and its relationship to climate change to harmful algal blooms to fishery sciences. Much of the credit must go to the successes of three ocean color instruments—GeoEye's SeaWiFS (launched in 1997), NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) on the Aqua platform and the European Space Agency's (ESA) Medium-resolution, imaging spectrometer (MERIS) on Envisat (both launched in 2002). These three satellite sensors have supplied highly precise radiometric determinations at the top of our atmosphere of the entire globe for more than a decade. It is the quality of these instruments in space, their ability to adequately sample the global ocean, as well as our ever-increasing abilities to convert these top-of-the-atmosphere signals into useful oceanographic data products that have made this promise of climate data records of our ocean biosphere a reality.

As with all things, these satellite instruments have a finite lifetime. The SeaWiFS mission is long past its expected lifetime and this year has had several spacecraft software anomalies that required it to stop imaging for several months. Similarly, MODIS/Aqua and MERIS, though in excellent health, are also beyond their expected lifetimes. Near-term plans for the U.S. have been to launch the Visible Infrared Imager Radiometer Suite (VIIRS) sensor on the NPOESS (National Polar-Orbiting Operational Environmental Satellite System) Preparatory Project (NPP) (likely launch in 2011) and NPOESS C1 (2014 launch) missions to extend the ocean color time-series started with SeaWiFS. Unfortunately, the VIIRS instrument to fly on NPP is unlikely to maintain the climate data record of the ocean's biosphere started by SeaWiFS. The issues are many, and involve aspects of sensor design and engineering, manufacturing and fabrication, and pre-launch calibration, as well as limitations on the in-flight calibration options. In particular, the integrated filter array (IFA), the component that disperses light spectrally onto the focal plane detectors, on the VIIRS flight instrument has known flaws that make it highly unlikely for VIIRS to meet the climate community's measurement requirements. There are no near-term NASA options for the U.S. science community either. The National Research Council's Earth Science and Applications Decadal Survey has placed the advanced, global ocean color mission (ACE – Aerosols, Clouds and Ecosystems) in its second tier of NASA missions with a realistic launch date no earlier than 2020 given the current budget.

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Simply stated, existing satellites are aging while the U.S. operational missions that are aimed to extend these climate data records (VIIRS on NPP and NPOESS) will not likely fill the need for climate or operational requirements. It appears likely that the ocean biology and biogeochemistry communities will face a multi-year gap in our climate data records. Last year, two of us (Siegel and Yoder) drafted a letter on behalf of the ocean biology and biogeochemistry communities to Dr. Michael Griffin, NASA Administrator, and Admiral Conrad Lautenbacher, NOAA Administrator, detailing these issues and our view of the near-term future of U.S. satellite ocean color observations (http://www.spaceref.com/news/viewsr.html?pid=25593). Briefly, we laid out three alternatives for continuity of the U.S. ocean color climate data record: 1) The VIIRS sensors will work as well as SeaWiFS (unlikely), or that existing satellite sensors will continue to work until ACE is launched (highly unlikely); 2) Launch a U.S. gap filler mission to provide high quality ocean color data continuity (which requires unbudgeted money); or 3) Recognize that a gap in U.S. ocean color data continuity will occur and understand the consequences of this inaction.

Responses to the letter have been mixed. More effort is clearly being placed on the characterization of VIIRS by the contracting team, and a calibration/validation plan for VIIRS ocean products is being formed under the leadership of Bob Arnone (Naval Research Laboratory). However, the IFA on the NPP flight unit will not be replaced, and it is the hope of

the contractors that these engineering anomalies can be corrected with software, though there is no precedent for this. Further, NPP is very far behind schedule and VIIRS still remains in its testing phase (see http://www.sciencemag.org/cgi/content/full/321/5896/1620a). As of today, there is little evidence demonstrating that VIIRS will be able to provide climate-quality ocean color observations.

International Missions

The response to the community letter also stressed that the upcoming gap can be covered by data from international ocean color missions. MERIS on Envisat is the same age as MODIS on Aqua, but ESA plans to keep it operational at least until its next mission, the Ocean Land and Color Imager (OCLI) on Sentinel-3, which may be launched as early as 2012. There has also been a much greater cooperation of U.S. and European scientists and engineers in the past year through the efforts of the NASA/NOAA/ESA MERIS data workshop this summer and ESA's GlobColour program. Further, the Indian Space Research Organization is launching a global mission this fall (OCM-2), and a request for proposals for international participation was recently released. These planned missions could help bridge the expected gaps in the climate data record from the U.S. perspective, but much coordination is needed to insure that this potential is realized.

There are other positive developments on the international front. This September, the International Ocean Colour Coordinating Group (IOCCG) received approval from the Committee for Earth Observation Satellites (CEOS) to develop a "virtual constellation" for ocean color observations. A virtual constellation is an international science program where multiple space agencies work together to add value (e.g. cross-calibration, improved validation, merge data) to individual missions that support international research and in particular, the operational needs of the Global Earth Observation System of Systems (GEOSS) program and the Global Climate Observing System. The major objective of the ocean color virtual constellation is to provide a time-series of climate-quality global measurements of ocean color radiance and derived products. Although the planning for the virtual constellation is a positive development, it is in its very early stages and its success will depend on the deployment of new missions and much international cooperation.

It seems clear that there will be a gap of U.S. ocean color data within the next decade. NASA can contribute to the international virtual constellation by flying a new U.S. mission within the next five or so years to provide climate-quality ocean color data. This mission would preferably have advanced capabilities in the UV for improved retrievals of *in situ* optically active constituents relevant to carbon cycling, such as colored dissolved organic matter (CDOM). The need for a NASA mission to follow SeaWiFS and MODIS has been articulated in the NASA Ocean Biogeochemistry Program planning document, Earth's Living Ocean: The Unseen World (http://www.icess.ucsb.edu/~davey/OBB/OBB_Report013007.pdf). The benefits of a gap filler mission are obvious, but they are balanced by the real and unbudgeted costs for this mission. If launching a U.S.-led gap filler mission is not viable, the U.S. ocean color community needs to contribute its considerable expertise to the international effort with, for example, helping to lead a Sensor Intercomparison for Marine Biological and Interdisciplinary Ocean Studies (SIMBIOS)-type program that would provide ocean color climate data records for the U.S. and international community. This program must include the calibration of multiple ocean color sensors to common standards, a vigorous field data program for vicarious calibration and product validation, new data product development and evaluation, multi-sensor data merging, multiple paths for data distribution, etc. It must be noted that a program of this scope will require substantial efforts, both financially and diplomatically, if it is to be successful in providing climate-quality data for the ocean biosphere.

Regardless of what might happen in the near-term, we are entering a new era for satellite ocean color science. The recent approval of the ocean color virtual constellation is one of any number of pieces of evidence that points to the increasing need for international cooperation. This will be especially true as we piece together climate data records from multiple satellite missions built and operated by different space agencies. But the climate-related signals that we need to measure are tiny and even the smallest differences in satellite calibration or data processing procedures can obfuscate these trends. This will require real cooperation among the many space agencies contributing to the virtual constellation, including reaching a consensus on minimum design requirements, exchanging the details of sensor pre-launch calibration and characterization data, open data policies for all satellite and field data, sharing of satellite data processing algorithms and procedures, and so on. It is only by accepting this international future and understanding its implications of how we go forward can we make actual progress towards the implementation of the planned virtual constellation of satellite ocean color observations and be able to continue our climate-scale observations of the ocean biosphere.

This letter is based upon the informed opinions of the authors and in no way represents the official positions of NASA or any other agency or organization.