

Assessing Requirements for Sustained Ocean Color Research and Operations

Satellite measurements of ocean color provide a unique global perspective on the health of marine ecosystems, their contributions to the global cycle of nutrients, oxygen, and carbon, and their responses to long-term climate change. However, the nation is at risk of losing access to ocean color data because existing satellite sensors are aging and planned new satellite missions might not be able to acquire data at the accuracy levels required for climate research. This report reviews the minimum requirements to sustain global ocean color measurements for research and operational use, and to identify options to minimize the risk of an ocean color data gap.

With the launch of the first ocean color satellite in 1978, scientists gained a new window on the ocean. Looking back at Earth from space allowed researchers to visualize entire ocean basins at once, obtaining a global perspective of the vast ocean.

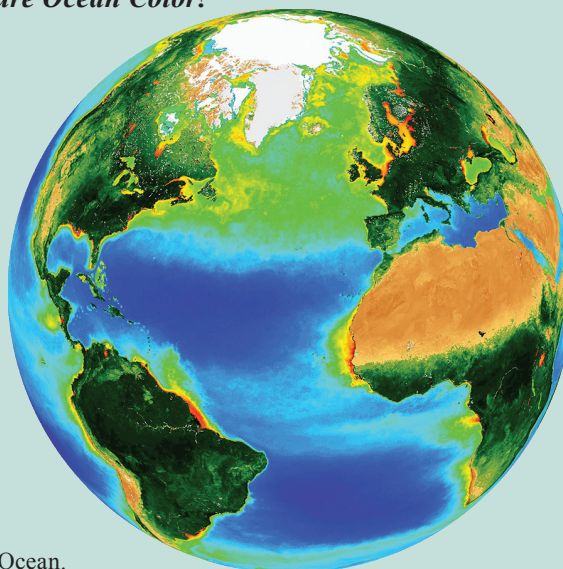
Ocean color satellites measure how green the ocean is from the chlorophyll pigments contained in microscopic plants and bacteria called phytoplankton (see Box 1). These data provide insight into the health of ocean ecosystems and their responses to stresses such as increased ocean temperature, ocean acidification, marine pollution, and overfishing. Because of the vast area covered by the ocean, it is

impossible to observe global scale changes in phytoplankton abundance and productivity of marine ecosystems using ships alone.

When the National Aeronautics and Space Administration (NASA) launched the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) in 1997, it became the gold standard for measuring ocean color. With the retirement of SeaWiFS in December 2010, the nation is now at risk of losing its window to the global ocean. The MODIS (Moderate Resolution Imaging Spectroradiometer) sensor on NASA's Aqua satellite is currently the only U.S. sensor remaining in orbit that is capable of measuring ocean color, but it is already several years

Box 1. Why Measure Ocean Color?

Marine phytoplankton, microscopic algae that live in the ocean's surface waters, carry out about half of all global primary production—the process by which carbon dioxide is taken up by plants and converted to new organic matter by photosynthesis. These organisms form the base of the marine food web, and their uptake of carbon dioxide has helped to moderate the rate of human-induced climate change. Ocean color satellites monitor phytoplankton abundance in the ocean's surface waters by measuring the concentration of chlorophyll. In addition, related parameters derived from the ocean color satellite signal can be used to monitor oil spills, harmful algal blooms, and the health of important fisheries' habitat.



Map of chlorophyll concentrations in the upper Atlantic Ocean. Red and yellow areas indicate high, green intermediate, and blue low chlorophyll concentrations. SOURCE: SeaWiFS Project, NASA Goddard Space Flight Center; and GeoEye.

beyond its intended lifetime. Furthermore, researchers are concerned that a new sensor planned for launch in fall 2011 may not be able to make ocean color measurements at the level of accuracy required for climate research.

Given the importance of maintaining the record of ocean color data, the National Oceanic and Atmospheric Administration, the National Aeronautics and Space Administration, the National Science Foundation, and the Office of Naval Research requested the National Research Council convene a committee of experts to review the minimum requirements to sustain global ocean color measurements for research and operational applications, and to identify options to minimize the risk of a data gap.

Setting the Standard for Ocean Data

Over the past decade, SeaWiFS and MODIS have generated high-quality, and well-calibrated ocean color data needed to investigate links between long-term climatic trends and phytoplankton abundance. Arriving at the currently available climate-quality data is a complex, challenging, and collaborative effort between a highly dedicated team at NASA and the academic community (see Box 2). From this process the report has drawn lessons and identified key factors to maintain the data stream at the current level of accuracy. In order to sustain the flow of high-quality ocean color data, the committee found that ocean color mission would need to meet at least the following requirements:

- The sensor is well characterized and calibrated prior to launch
- Post-launch vicarious calibration is performed with in situ instruments that meet stringent standards in order to set the sensor's gain factors
- The sensor stability and rate of degradation are monitored using monthly lunar views
- At least six months of overlap is allowed for the transfer of calibrations between the expiration of one sensor and the launch of a new sensor to ensure continuous climate data records

Vicarious calibration: a technique that uses natural sites on Earth's surface for the calibration of sensors.

Lunar views: a spacecraft maneuver that involves pointing the sensor at the surface of the moon once a month as a reference standard.

- There is ongoing development and validation of atmospheric correction, bio-optical models and ocean color products
- Data is periodically reprocessed during the mission
- All raw, meta- and processed data products are archived, made freely available, and distributed rapidly and efficiently
- Research is continued to improve algorithms and products
- All aspects of the mission are documented, and made accessible

Losing the Window on the Global Ocean

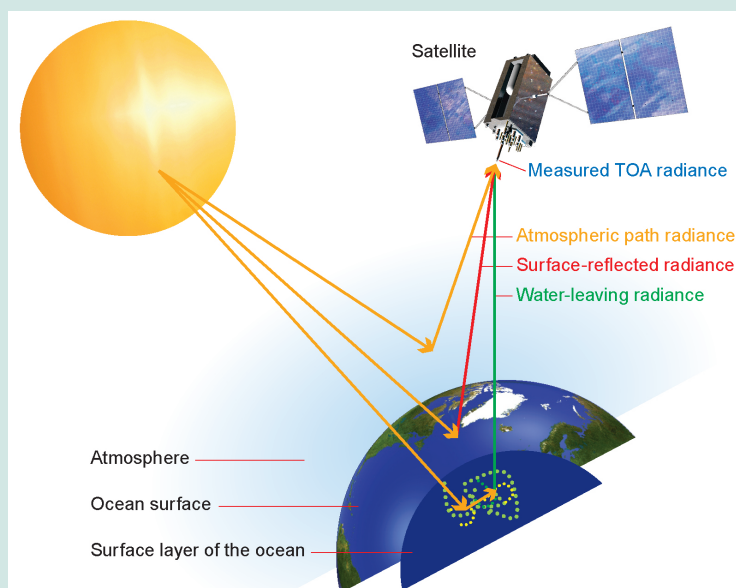
Designed to be in use for just five years, SeaWiFS actually operated for 13 years before being taken out of commission in December 2010. Currently, MODIS is the only U.S. sensor in orbit that is capable of collecting data accurate enough to inform scientists who track climatic changes, resource managers who monitor and protect coastal waters among others.

New U.S. missions are planned to replace the defunct SeaWiFS sensor and the aging MODIS sensor. The next is the launch of the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor by the National Oceanic and Atmospheric Administration (NOAA), scheduled for fall 2011. However, the research community has questioned the ability of VIIRS to deliver high-quality data due to a manufacturing error in one of its optical components. Based on the committee's assessment, the mission meets only a few of the accuracy requirements listed above. Because VIIRS represents the only opportunity for the United States to be able to sustain the current time series of high-quality ocean color measurements from U.S.-operated sensors until the end of the decade, the committee suggested immediate improvements that could help improve the accuracy of this, and future VIIRS missions:

- Implement spacecraft maneuvers as part of the mission, including monthly lunar views to quantify sensor stability
- Form a calibration team with the responsibility and authority to interact with the team generating raw data, and with the mission personnel responsible for the sensor, to provide the analy-

Box 2. Making Sense of the Ocean Color Signal

Deriving the desired information from ocean color satellite measurements is a multi-stage process. Ocean color sensors measure the radiance at the top of the atmosphere, which is the sum of three radiance sources: water-leaving radiance, radiance reflected from the sea surface, and radiance scattered by the atmosphere. The most important of measure for ocean color is water-leaving radiance, but this is no more than 10 percent of the total signal. To isolate water-leaving radiance from the rest of the signal, scientists remove the contributions of surface glint and atmospheric path radiance from the measured total, a process known as atmospheric correction. To correctly interpret water-leaving radiance, the instrument gain factor has to be set using a vicarious calibration and the sensor degradation has to be factored into the correction scheme using the information from the monthly lunar views. Only then can the water-leaving radiance be converted to phytoplankton abundance using empirical algorithms.



SOURCE: Adapted from <http://www.gps.gov/multimedia/images>.

ses needed to assess trends in sensor performance and evaluate anomalies

- Implement a vicarious calibration process and team using an approach established by the Marine Optical Buoy (MOBY), a buoy that floats on the ocean surface and measures light at a fixed surface over time to produce internationally accepted standards for calibration
- Implement a process to engage experts in the field of ocean color research to revisit standard algorithms and products, including those for atmospheric correction, to ensure consistency with those of heritage instruments and for implementing improvements;
- Form a data product team to work closely with the calibration team to implement vicarious and lunar calibrations, oversee validation efforts, and provide oversight of reprocessing
- Provide the capability to reprocess the mission data multiple times to incorporate improvements in calibration, correct for sensor drift, generate new and improved products for other essential reasons.

The Need for Collaboration

Both NASA and NOAA support ocean color applications, with NASA focused primarily on research and development, and NOAA focused on operational uses. Because both agencies support climate research, they share a common interest in developing climate data records.

To implement the suggested improvements to the VIIRS sensor, NOAA would need to build capacity, particularly in the areas of processing and calibrating ocean color data. Because NASA is already an internationally recognized leader in producing well-calibrated ocean color data products, the committee found it would be more cost-effective for the two agencies to work in partnership. To move towards such a collaboration, both agencies would need to identify effective ways to satisfy their requirements for ocean color data from VIIRS, and consider how best to produce, archive, and distribute data of shared interest.

No matter how well VIIRS performs, the data requirements for ocean color applications are so diverse that a single satellite sensor cannot meet all ocean color needs. For example, advancing research on the global carbon cycle will require greater spectral resolution than is currently available, but not necessarily higher spatial resolution except for

in coastal regions. Fisheries resource managers, on the other hand, would greatly benefit from higher spatial (and spectral) resolution, and would be best served by a geostationary satellite, which would not support studies of the global carbon cycle due to its fixed location.

Non-U.S. sensors planned for the future—from Japan, South Korea, and India, and by the European Space Agency—could meet the many demands of the U.S. ocean color community. However, users need rapid, routine access to all levels of ocean color data, and to date, timely access to data from foreign sensors has been difficult to negotiate. To make non-U.S. sensors a viable option in replacing or augmenting data availability, the committee suggested that NOAA and NASA coordinate full access to data from non-U.S. sensors, ensure that sufficient personnel and financing are provided to collect independent calibration and validation data, and produce and distribute data products required by U.S. users.

Moreover, the report recommends that a mission-centric planning approach be replaced by a data-centric focus. To that effect, a national planning body is required that ensures continuous funding that extends beyond the lifetime of any particular satellite mission. With representatives from federal agencies, academic institutions and

the private sector, this group could provide the necessary long-range planning to meet U.S. user needs, supply external advice to individual missions, interact with foreign partners, and develop consensus views on data needs and sensor requirements.

Advancing Ocean Color Research

While this study focuses on requirements to maintain the current capabilities in the near-term, the full potential that ocean color remote sensing has to offer can only be explored with major advances in sensor technology, algorithm development, and atmospheric corrections. The need for more advanced capabilities will become even more urgent with global changes that might render current empirical algorithms for deriving ocean color products invalid. The report concludes that the ever broadening user community that depends on accurate and timely ocean color data highlights the urgency of fixing the VIIRS sensor and developing the next generation capability. NASA's climate continuity and decadal survey missions PACE/ACE, GEOCAPE and HypSIRI are required to advance ocean color science and to extend and improve operational and research uses of the data.*

* Pre-Aerosol-Clouds-Ecosystem/ Aerosol-Clouds-Ecosystem; Geostationary Coastal and Air Pollution Events; Hyperspectral Infrared Imager.

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*Resigned from the committee to take a position with NASA

The National Academies appointed the above committee of experts to address the specific task requested by the National Oceanic and Atmospheric Administration; National Aeronautics and Space Administration; National Science Foundation; and the Office of Naval Research. The members volunteered their time for this activity; their report is peer-reviewed and the final product signed off by both the committee members and the National Academies. This report brief was prepared by the National Research Council based on the committee's report.



For more information, contact the Ocean Studies Board at (202) 334-2714 or visit <http://dels.nas.edu/osb>. Copies of *Assessing Requirements for Sustained Ocean Color Research and Operations* are available from the National Academies Press, 500 Fifth Street, NW, Washington, D.C. 20001; (800) 624-6242; www.nap.edu.

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