Advances in Ocean Biogeochemistry from MODIS

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Since the launches of the MODIS sensors on the Terra (2000) and Aqua (2002) platforms following the SeaWiFS launch in 1997, NASA has supported three sensors with ocean color capabilities. At present, all three sensors continue to provide global data. These data sets are constantly being improved as new calibration techniques, atmospheric correction methodologies, and biogeochemical algorithms are developed. MODIS provides additional capabilities over SeaWiFS (e.g., chlorophyll-a fluorescence line height (FLH) and sea surface temperature (SST)) from which new insights into marine biogeochemistry can be derived. Also, the 250 and 500 meter resolution bands have applications in coastal and estuarine studies. One of the major challenges encountered with multiple sensors is deriving consistent data products across missions (e.g., normalized water-leaving radiances (Lwn) and chlorophyll-a), due to differences in the sensor performance, design, and orbit. In this presentation, we will review the status of both MODIS sensors, the results of the recent reprocessing of all three sensors, new interpretations and applications for the FLH product and the utilization of short wave infrared bands (SWIR) for aerosol correction over turbid water.

Early in the MODIS/Terra program, it became clear that the ocean biology data products were significantly different from those of SeaWiFS, even though the atmospheric correction algorithm and vicarious calibration data source (the Marine Optical Buoy, MOBY) were the same. At that time, the two data sets were being processed by different teams using different processing systems. Early problems with the MODIS/Terra on-orbit calibration and spacecraft anomalies confused the issues. In 2004, processing of MODIS/Terra ocean color data was discontinued, so that the focus could be on the much more stable MODIS/Aqua. Reanalysis and implementation of the MODIS prelaunch characterization data, refinements to the solar calibration, and other algorithm improvements removed most of the differences between MODIS/Aqua and SeaWiFS. Some algorithm changes were incorporated into both SeaWiFS and MODIS (e.g. a bidirectional reflectance distribution function (BRDF)), which also improved the agreement. Inclusion of a stray light mask around clouds in the MODIS processing removed a large difference in the aerosol optical depth global mean values. These improvements were not the result of tuning one sensor using data from the other, but from using the differences to infer sources of error, which lead to modifications in certain algorithms (e.g., the MODIS polarization tables and stray light mask).

MODIS/Terra proved much more difficult because sensor degradation was more severe and differed from the degradation of MODIS/Aqua. In fact, degradation of MODIS/Terra was such that the solar calibration data proved inadequate in tracking the degradation at the accuracy required for ocean color. The mirror sides were experiencing time-dependent changes affecting polarization sensitivity as well as response-versus-scan angle (RVS). SeaWiFS has a very well-characterized calibration drift which is tracked using monthly lunar imaging, low sensitivity to polarization due to the incorporation of a polarization scrambler, and a very stable RVS largely because of the rotating-telescope design. A method was developed to characterize the MODIS/Terra polarization and RVS sensitivity changes over time using SeaWiFS global Lwn data. The analyses showed very large detector-dependent changes in MODIS/Terra polarization parameters and RVS over time, which, when corrected yielded excellent agreement with SeaWiFS, as expected, but even better agreement with MODIS/Aqua ocean products. A similar analysis of MODIS/Aqua data showed relatively small changes in polarization and RVS characteristics, which helps explain the agreement between SeaWiFS and MODIS/Aqua without such adjustments.

The near-infrared (NIR) subsurface reflectance in turbid waters is finite, not zero as is the case in clear open ocean water. NIR bands are used for the aerosol correction, so water-leaving radiance in the NIR is attributed to aerosol radiance leading to substantial errors in the derived products. This finite reflectance in the NIR can be modeled and removed in low to moderately turbid waters like the lower Chesapeake Bay. However, in highly turbid waters, such as many river plumes (e.g., the Mississippi River delta), longer wavelength bands in the SWIR may be needed. Recent studies using the MODIS 1240, 1640, and 2130 nm bands show promise for this application, although the MODIS SWIR bands have low signal-to-noise and are not optimal for ocean aerosol corrections.

The MODIS/Aqua FLH product was intended to provide both an independent metric of surface chlorophyll concentration and an index of phytoplankton physiological status. Early analyses suggested that utility of the fluorescence product would likely be restricted to waters with chlorophyll concentrations exceeding 1 mg m^{-3} (e.g., coastal waters and large bloom events). However, recent studies have shown that coastal applications are greatly complicated by particulate scattering contamination of the FLH product, while in the open ocean there appears to be no discernable lower limit in chlorophyll concentration where the fluorescence product is robust. Global analysis of chlorophyll fluorescence over the MODIS Aqua record show that fluorescence quantum yields are enhanced under iron-limiting growth conditions, suggesting that these MODIS Aqua products may be useful for mapping iron stress regions and monitoring changes in this distribution. These new results provide an exciting and unique tool for probing further into the processes regulating global phytoplankton populations and their feedbacks to climate.

Thus, after much effort, the MODIS Aqua and Terra ocean color data sets now provide high quality data products for coastal applications and research related to climate, biogeochemistry, and ecosystem dynamics. Together with SeaWiFS, there have been many lessons learned and new methodologies developed which need to be incorporated into future mission designs and calibration and validation strategies.