# MODIS Land Bands for Ocean Remote Sensing Applications

Bryan A. Franz, P. Jeremy Werdell, Gerhard Meister, Ewa J. Kwiatkowska, Sean W. Bailey, Ziauddin Ahmad, and Charles R. McClain
**NASA Ocean Biology Processing Group**

## INTRODUCTION

NASA's Ocean Biology Processing Group (OBPG) provides the global processing and distribution of ocean color products from MODIS, SeaWiFS, and other ocean color capable sensors. The OBPG developed the Multi-Sensor Level-1 to Level-2 code (MSL12, Franz 2006) to standardize the atmospheric correction and production of ocean color products from various space borne sensors. The MODIS instrument was designed with 36 spectral channels to support observation of clouds and land as well as oceans. The traditional channels used for ocean color observation are the 9 bands in the visible to near infrared (NIR) spectral regime from 412-869 nm, which have a spatial resolution of approximately 1 km at nadir. These ocean bands were designed with high sensitivity over the range of reflectance typical of open ocean observations with maritime atmospheric conditions. Over highly turbid coastal and inland waters it is possible for this dynamic range to be exceeded, such that the bands saturate and the true signal is unknown. Other bands on MODIS were specifically designed for land and cloud observations, with both increased spatial resolution and reduced sensitivity over a broader dynamic range. These land/cloud bands overlap the spectral range of the ocean bands and extend into the short-wave infrared (SWIR), from 469 to 2130 nm, with a spatial resolution of 250 to 500-meters at nadir. A number of investigators have looked to exploit this additional information for ocean application. Recently, Wang & Shi (2005) demonstrated an approach for utilizing the SWIR bands to improve the performance of the Gordon & Wang (1994) atmospheric correction algorithm over turbid or highly productive waters typically found in coastal environments. The OBPG has now enhanced MSL12 to support the 250 and 500-meter (HIRES) bands of MODIS (Table 1). This effort included characterization of the radiometric response of the HIRES bands in a manner consistent with that done for the standard ocean bands (e.g., relative spectral response, polarization sensitivities, vicarious calibration). The appropriate software and tables were created to facilitate the atmospheric correction and retrieval of oceanic optical properties at the additional wavelengths. A mechanism was also developed for accessing the increased spatial resolution, and options were added for utilizing the SWIR information for atmospheric correction. The OBPG is distributing these enhanced capabilities through the SeaWiFS Data Analysis System (SeaDAS) software package (**http://oceancolor.gsfc.nasa.gov/seadas/**) to provide the research community with a tool for evaluating and developing applications of the HIRES bands to ocean remote sensing. Here we demonstrate the application of these new capabilities to the coastal and inland waters of the Chesapeake Bay region.

***Table 1: Extended MODIS Band Suite for Oceans***

| Band Number | Wavelength (nm) | Band Width (nm) | Spatial Resolution (m) | SNR at $L_{typ}$ | $L_{typ}$ mW cm$^{-2}$ µm$^{-1}$ sr$^{-1}$ | $L_{max}$ mW cm$^{-2}$ µm$^{-1}$ sr$^{-1}$ | Notes |
|---|---|---|---|---|---|---|---|
| 8 | 412 | 15 | 1000 | 1773 | 7.84 | 26.9 | 1 |
| 9 | 443 | 10 | 1000 | 2253 | 6.99 | 19.0 | 1 |
| 3 | 469 | 20 | 500 | 556 | 6.52 | 59.1 | |
| 10 | 488 | 10 | 1000 | 2270 | 5.38 | 14.0 | 1 |
| 11 | 531 | 10 | 1000 | 2183 | 3.87 | 11.1 | 1 |
| 12 | 551 | 10 | 1000 | 2200 | 3.50 | 8.8 | 1 |
| 4 | 555 | 20 | 500 | 349 | 3.28 | 53.2 | |
| 1 | 645 | 50 | 250 | 140 | 1.65 | 51.2 | 3 |
| 13 | 667 | 10 | 1000 | 1962 | 1.47 | 4.2 | 1 |
| 14 | 678 | 10 | 1000 | 2175 | 1.38 | 4.2 | 1 |
| 15 | 748 | 10 | 1000 | 1371 | 0.889 | 3.5 | 1 |
| 2 | 859 | 35 | 250 | 103 | 0.481 | 24.0 | |
| 16 | 869 | 15 | 1000 | 1112 | 0.460 | 2.5 | 1 |
| 5 | 1240 | 20 | 500 | 25 | 0.089 | 12.3 | |
| 6 | 1640 | 35 | 500 | 19 | 0.028 | 4.9 | 2 |
| 7 | 2130 | 50 | 500 | 12 | 0.008 | 1.7 | |

[1] Standard bands for ocean color, [2] 1640 channel not functional on MODIS/Aqua, [3] Never saturated

## PROCESSING EXAMPLES

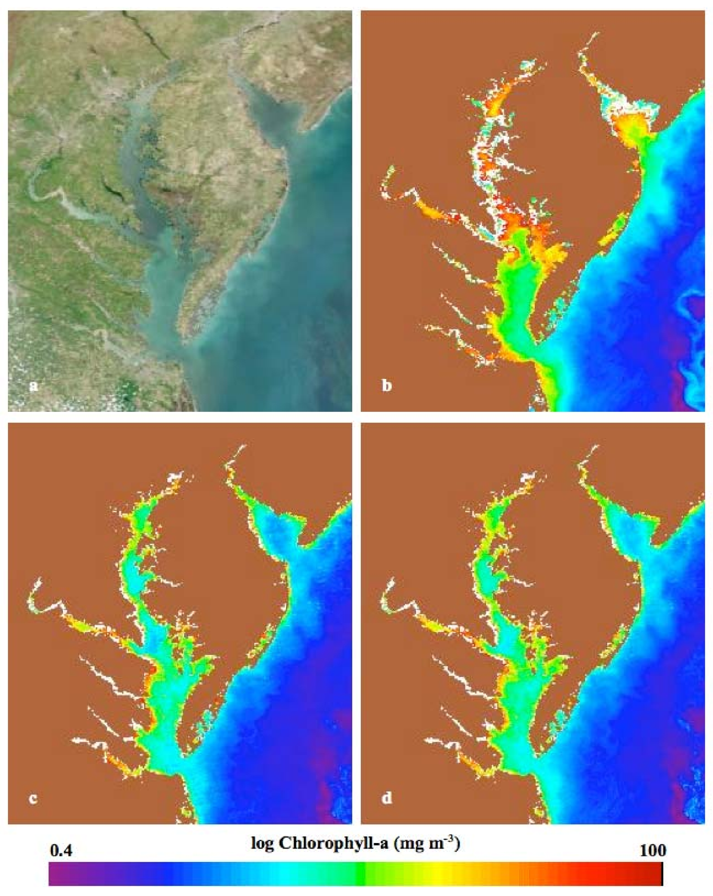


***Figure 1: (a) a true color view of the Chesapeake Bay on 28 April 2003 derived from surface reflectance in MODIS bands at 469, 555, and 645 nm; (b) chlorophyll-a derived from the OC3 algorithm (O'Reilly, 2000) using the standard NIR-based aerosol correction; (c) & (d) chlorophyll-a derived from the OC2 & OC3 algorithms, respectively, using the SWIR-based approach for aerosol correction. OC2 uses 500-meter bands at 469 and 555 nm, while OC3 uses 1km bands at 443, 488, and 551 nm.***

***Figure 2: Quasi-true-color image of Chesapeake Bay on 5 April 2004, derived from MODIS/Aqua bands at 645, 555, and 469 nm. Data was processed at 250-meter resolution and mapped to 255-meter.***

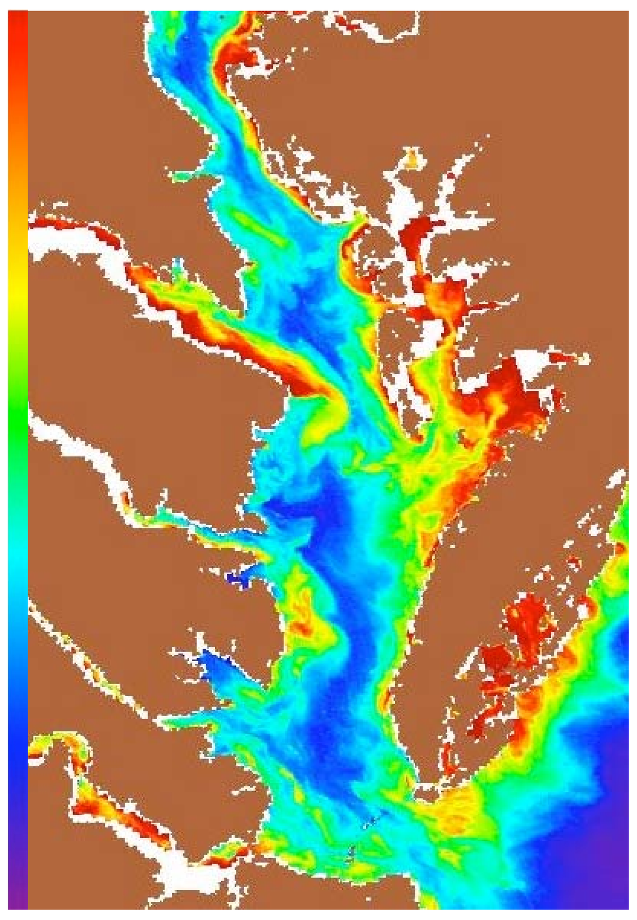

***Figure 3: Normalized water-leaving radiance at 645-nm derived from scene of Figure 3. Data was processed at 250-meter resolution and mapped to 255-meter. Scale is -0.1 to 3.0 mW cm$^{-2}$ um$^{-1}$ sr$^{-1}$.***

## VALIDATION ANALYSIS

A series of MODIS/Aqua scenes for the Chesapeake Bay was processed to derive OC3 chlorophyll concentration, with processing performed using both the standard NIR atmospheric correction based on Gordon & Wang (1994) and Stumpf (2003) (herein referred to as GWNIR) and a modified Gordon & Wang correction using the SWIR bands at 1240 and 2130 nm to determine the aerosol properties (GWSWIR). The dataset was then geographically stratified into upper, middle, and lower regions of the Bay, and Monthly mean chlorophyll retrievals from all available, relatively cloud free scenes were generated for each region. The resulting time-series was compared to contemporaneous *in situ* measurements collected by the Chesapeake Bay Program (1993) and Harding et al. (2003).

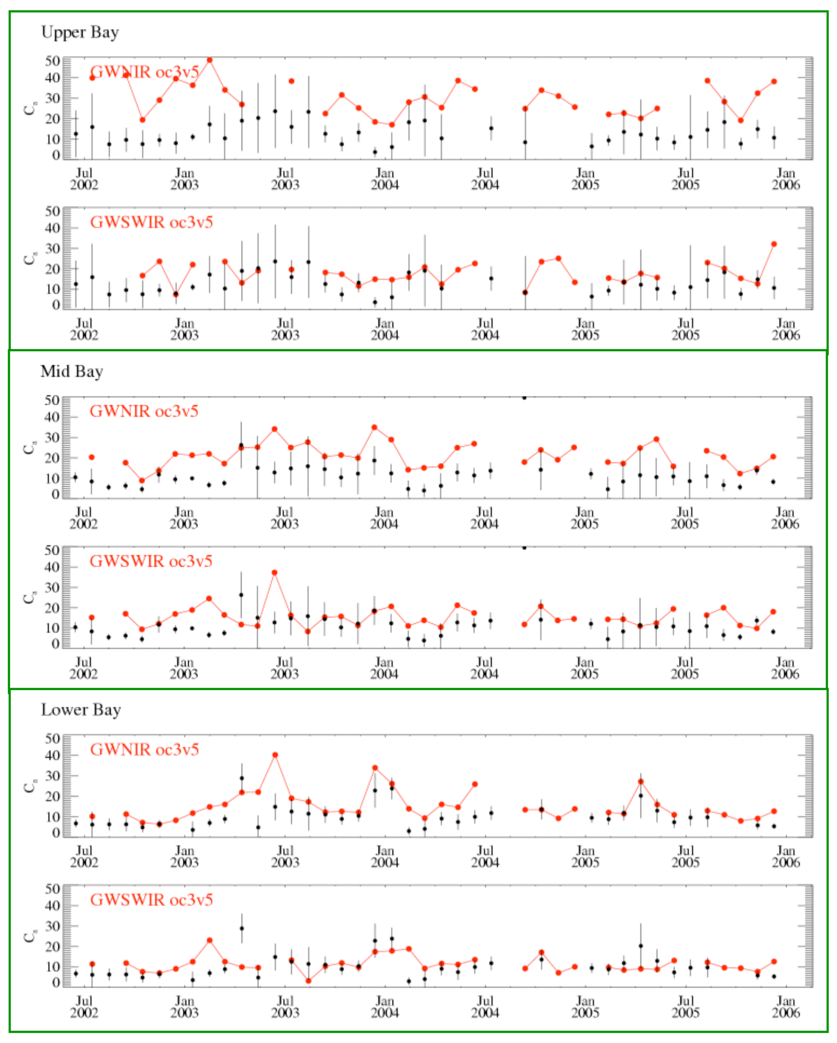


***Figure 4: Time-series of monthly mean chlorophyll-a for Chesapeake Bay. Symbols in black show in situ measurements with vertical bars to indicate 1 standard deviation. Red symbols and lines show MODIS/Aqua retrievals using the standard atmospheric correction (GWNIR) and the SWIR-based (GWSWIR) for the upper, middle, and lower regions of the Bay. MODIS chlorophyll was derived using the OC3 algorithm. Units are mg m$^{-3}$.***

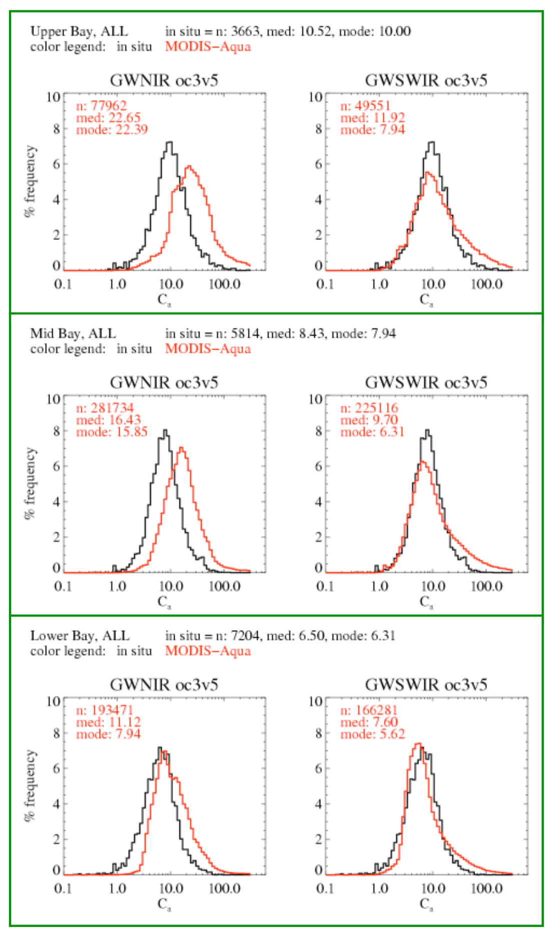


***Figure 5: Frequency distributions of chlorophyll-a for Chesapeake Bay. Lines in black show in situ measurements, while red lines show MODIS/Aqua retrievals using the standard atmospheric correction (GWNIR) and the SWIR-based correction (GWSWIR) for the upper, middle, and lower regions of the Bay. MODIS chlorophyll was derived using the OC3 algorithm. Units are mg m$^{-3}$***

***Table 2: Median Percent Difference Between MODIS/Aqua and In Situ Chlorophyll Measurements for Chesapeake Bay by Region and Season***

| Region | Method | All | Spring | Summer | Fall | Winter |
|---|---|---|---|---|---|---|
| Upper | GWNIR | 115.3 | 141.5 | 104.7 | 185.8 | 151.2 |
| | GWSWIR | 13.3 | 25.2 | 20.5 | 48.6 | 35.8 |
| Middle | GWNIR | 94.9 | 87.7 | 122.2 | 113.9 | 148.4 |
| | GWSWIR | 15.1 | -5.6 | 19.9 | 31.3 | 62.2 |
| Lower | GWNIR | 71.1 | 110.8 | 71.4 | 43.2 | 123.0 |
| | GWSWIR | 16.9 | 4.0 | -4.6 | 13.5 | 72.0 |

## DISCUSSION

Comparing Figures 1b and 1d, a significant reduction in the high chlorophylls can be seen when using the SWIR-based atmospheric correction. Those high chlorophylls are often in locations that can be expected to have a high concentration of suspended matter (i.e., shorelines and rivers), where the standard atmospheric correction tends to underestimate the scattering contributions from the water in the NIR and attribute the excess radiance to aerosols. This overestimation of aerosols and associated misidentification of aerosol type results in underestimation of the water leaving radiances in the visible bands and skews the spectral distribution toward the green. In contrast, the GWSWIR correction appears to produce a more uniform distribution of chlorophyll for this scene when using the same chlorophyll algorithm, and retrieval failures were significantly reduced relative to GWNIR. In addition, comparison between Figures 1c and 1d indicates that the 500-meter bands at 469 and 555 nm have sufficient fidelity to produce meaningful chlorophyll concentrations similar to the standard 1km OC3 chlorophyll algorithm. As a demonstration of the enhanced resolution capabilities, the quasi-true-color image of Figure 2 shows patterns in the water that can be qualitatively associated with river plumes carrying sediments and dissolved organic matter into the Bay. For the same region, Figure 3 shows the retrieved water-leaving radiance for the 250-meter band at 645 nm, where the fine structure of the river plumes is more discernable and quantifiable.

For a more quantitative assessment, Figure 4 demonstrates that the SWIR-based atmospheric correction reduces systematic bias between the satellite retrieved chlorophyll and field data, relative to the standard NIR-based algorithm. This is further illustrated in Figure 5, where the data from all months have been combined to form a set of frequency distributions. For the complex and sediment laden waters of the upper and middle bay, the histograms show that the GWSWIR correction significantly improves agreement between MODIS retrievals and *in situ* measurements. Even in the more oceanic waters of the lower Bay, where the mode of the distributions already showed good agreement with *in situ* for either correction method, the GWNIR approach resulted in an elevated median relative to the *in situ* distribution that was substantially reduced by application of the GWSWIR correction. This improvement is summarized by median percent difference (defined as MODIS minus *in situ* over *in situ*) in Table 2. Here it can be seen that the differences over the full time-series were reduced from a worst case of 115% in the upper Bay region to less than 17% for all regions. Furthermore, the SWIR-based approach results in substantial improvements in the MODIS to *in situ* agreement for every season and all regions.

The OBPG has enhanced the standard MODIS ocean color processing capabilities to utilize some additional bands originally designed for land and cloud applications. It was shown that these bands could be used to develop new ocean products at spatial resolutions as high as 250 meters, or four times the resolution of standard MODIS ocean products. Furthermore, the expanded spectral range extends into the SWIR, allowing for the operation of an alternative atmospheric correction algorithm. This SWIR-based correction was shown to significantly improve agreement between MODIS and *in situ* chlorophyll measurements in the complex and highly reflective waters of the Chesapeake Bay and would likely perform well in other coastal and inland waters where the standard atmospheric correction approach suffers. We have incorporated these new capabilities into the MSL12 processing code, which is freely distributed through SeaDAS, thereby providing the research community with an opportunity to further evaluate the alternative algorithms and perhaps develop new ocean applications using the extended spectral band suite.

## REFERENCES

Chesapeake Bay Program (1993). Guide to using Chesapeake Bay Program Water Quality Monitoring Data. CBP/TRS 78/92, Chesapeake Bay Program, Annapolis, Maryland, 127 pp.
Gordon, H.R., and M. Wang (1994). Retrieval of water-leaving radiance and aerosol optical-thickness over the oceans with SeaWiFS – a preliminary algorithm. *Appl. Opt.*, 33, 443-452.
Harding, L.W. and A. Magnuson (2003). Bio-Optical and Remote Sensing Observations in Chesapeake Bay, NASA TM-2003-212251, pp 84-97.
O'Reilly, J.E. and 24 co-authors (2000). *SeaWiFS Postlaunch Calibration and Validation Analyses, Part 3.* NASA Tech. Memo. 206892, Vol. 11, NASA Goddard Space Flight Center, Greenbelt, Maryland, pp 24.
Stumpf, R.P., R.A. Arnone, R.W. Gould, P.M. Martinolich, V. Ransibrahmanakul (2003). A Partially Coupled Ocean-Atmosphere Model for Retrieval of Water-Leaving Radiance from SeaWiFS in Coastal Waters, NASA/TM-2003-206892, Vol. 22, NASA Goddard Space Flight Center, Greenbelt, Maryland, pp. 51-59.
Wang, M. and W. Shi (2005). Estimation of ocean contribution at the MODIS near-infrared wavelengths along the east coast of the U.S.: Two case studies, Geophys. Res. Lett., 32, L13606.