MODIS Semi-annual Report January-June, 2003 (due July 15)
INVESTIGATOR: Frank Hoge

Objectives: To (1) develop algorithms for retrieval of phycoerythrin pigment and to (2) validate this product and other MODIS Ocean Discipline Products such as Chlor_a_2, Chlor_MODIS, Chlor_a_3, CDOM absorption coefficient, and Chlorophyll Fluorescence Line Height (FLH).

Progress:

Robust new methods for airborne validation of MODIS Ocean Discipline Products: Chlor_a_2, Chlor_MODIS, Chlor_a_3, CDOM absorption coefficient, and Chlorophyll Fluorescence Line Height (FLH) have been developed during this period. The FLH validation by airborne laser-induced chlorophyll fluorescence is the focus of this reporting period.

Chlorophyll Fluorescence Line Height (FLH) Validation by Airborne Lidar.

The progress on this validation method is best described by a published manuscript: Frank E. Hoge, Paul E. Lyon, Robert N. Swift, James K. Yungel, Mark R. Abbott, Ricardo M. Letelier, Wayne E. Esaias , Validation of Terra-MODIS Phytoplankton Chlorophyll Fluorescence Line Height. I. Initial Airborne Lidar Results , Appl. Opt. **42**, 2767-2771 (2003).

The manuscript is included below:

Validation of Terra-MODIS Phytoplankton Chlorophyll Fluorescence Line Height (FLH): 1. Initial Airborne Laser Results

Abstract

The Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the Terra spacecraft contains spectral bands that allow retrieval of solar-induced phytoplankton chlorophyll fluorescence emission radiance. Concurrent airborne laser-induced (and water-Raman normalized) phytoplankton chlorophyll fluorescence data is used to successfully validate the MODIS chlorophyll fluorescence line height (FLH) retrievals within Gulf Stream, continental slope, shelf, and coastal waters of the Middle Atlantic Bight (MAB) portion of the western North Atlantic Ocean for 11 March 2002. Over the entire ~480 km flight line a correlation coefficient of $r^2 = 0.85$ results from regression of the airborne laser data against the MODIS FLH. It is also shown that the MODIS FLH product is not influenced by blue-absorbing chromophoric dissolved organic matter (CDOM) absorption. These regional results strongly suggest that the FLH methodology is equally valid within similar oceanic provinces of the global oceans.

I. Introduction.

Remote sensing of solar-induced phytoplankton chlorophyll fluorescence emission at ~683nm has had recurring study over the past several decades [Neville and Gower 1977; Gower 1980; Gower and Borstad 1990; Letelier and Abbott 1996; Gower, Doerffer, and Borstad 1999; Bricaud, Morel and Barale 1999; Bezy, Delwart and Rast 2000; Matthews, Duncan and Davison 2001]. The MODIS sensor on the Terra spacecraft launched on December 17, 1999 is the first satellite realization of the chlorophyll fluorescence line height (FLH) method. The European Space Agency's Medium Resolution Imaging Spectometer (MERIS) carries similar technology as does NASA's MODIS recently launched (4May 2002) aboard the Aqua spacecraft. The satellite proliferation of solar-induced phytoplankton chlorophyll fluorescence emission spectral sensors suggests wide-area methods be employed for their validation. It is the object of this paper to apply well known airborne lidar methods [Hoge et al., 1999a; Hoge et al., 1999b; Hoge

et al., 2001; Wright et al., 2001] to validation of the Terra-MODIS phytoplankton chlorophyll fluorescence line height retrievals.

II. Instrumentation

A. Terra-MODIS. This sensor has been described [Esaias et al., 1998]. The spectral bands and algorithm for retrieval of the phytoplankton chlorophyll fluorescence emission line height have been reported [Letelier and Abbott 1996]. [**more discussion of the algorithm ??]

B. Airborne Oceanographic Lidar (AOL). The newest version of the AOL has been described [Wright et al., 2001]. Briefly, however, 532nm laser pulses are transmitted vertically downward into the ocean to induce chlorophyll (and phycoerythrin pigment fluorescence emission [Hoge et al., 1998]) from waterborne phytoplankton and water Raman emission from the surrounding sea water molecules. The concurrent chlorophyll (~670-690nm) and phycoerythrin (~540-595nm) fluorescence, and water Raman spectral emissions (~645nm) are collected by a telespectroradiometer. The pigment fluorescence signals are normalized by the water Raman signal to remove the spatial water column variability.

Also, 355nm laser pulses are simultaneously transmitted into an adjacent portion the ocean to induce the broad spectrum chromophoric dissolved organic matter (CDOM) fluorescence (~360-650nm) and water Raman emission (~404nm) from the surrounding water molecules. The CDOM fluorescence peak at ~450nm is normalized by the water Raman signal at ~404nm to remove the spatial variability of the water column. The resulting CDOM fluorescence-to-Raman ratio, $F_{CDOM}(450)/R(404)$, is used to calculate the CDOM absorption coefficient via a linear algorithm [Hoge et al 1993; Hoge et al., 1995].

III. Results.

A. Comparison of MODIS FLH with Airborne Laser-Induced Chlorophyll Fluorescence

Figure 1 shows the MODIS solar-induced chlorophyll fluorescence line height [w/m^2/nm/sr] image of the Middle Atlantic Bight portion of the western North Atlantic Ocean for March 11, 2002. Shown thereon is the northerly outbound flight line terminating within the northwestern portion of the Gulf Stream and the southerly inbound flight line segments returning across Gulf Stream, slope, shelf and coastal water masses. At the time of satellite passage the airborne lidar occupied the outbound portion of the flight line. The entire airborne validation flight was conducted from 10:07AM to 12:03AM EST thus some satellite-airborne disagreement is expected from water mass changes during the longer airborne mission. The annoying sensor-induced striping in the MODIS FLH image has been retained to confirm the validation under worst-case satellite data acquisition and processing conditions.

Figure 2 shows a profile plot of the MODIS FLH extracted from the image along the concatenated outbound and inbound flight track lines and plotted together with the airborne laser-induced (and water Raman normalized) chlorophyll fluorescence. The airborne chlorophyll fluorescence regression against the MODIS FLH is shown in the rightmost panel with a correlation of $r^2 = 0.85$. Without the Terra-MODIS striping artifact the correlation would perhaps be higher. In the oligotrophic Gulf Stream at ~215km along track location, the FLH reaches it's lowest values but the satellite/airborne agreement is still quite good albeit highly variable.

B. Performance of the MODIS FLH Algorithm in the Presence of CDOM absorption

Figure 3 shows the MODIS FLH plotted together with the 412nm CDOM absorption coefficient. The CDOM absorption coefficient is derived from the lidar CDOM fluorescence/water Raman ratio [Hoge et al., 1995]. The profile plot suggests that CDOM absorption produces no discernible influence on the FLH retrieval even in CDOM-laden coastal regions. This lack of CDOM influence is further corroborated by noting that (1) the FLH-CDOM correlation is only $r^2 = 0.276$ (right-most panel) and (2) the CDOM absorption coefficient at ~683nm is computed to be only ~1% of the 412nm value (based on an exponential model spectral slope of 0.017/nm).

IV. Discussion and Conclusions.

Comparisons of Terra-MODIS chlorophyll fluorescence line height with airborne laser-induced (and water Raman normalized) chlorophyll fluorescence yield very favorable correlation: $r^2 = 0.85$ in the coastal, shelf, slope, and Gulf Stream waters of the Middle Atlantic Bight portion of the western North Atlantic Ocean.

The concurrent airborne laser-induced chromophoric dissolved organic matter fluorescence comparison with MODIS FLH yields very poor correlation and suggests that CDOM absorption at 412nm over a ~6X range of 0.03-0.19 m^{-1} has no discernible influence on the FLH retrievals in the red region. This experimental validation of the low impact by CDOM absorption at 412nm confirms what one would theoretically expect on the basis of exponential absorption models of CDOM with a slope of 0.017/nm : ~100X less absorption at the chlorophyll emission spectral location, ~683nm, produces little influence on the FLH retrievals.

These findings suggest that the Terra-MODIS algorithm will perform equally well in other oceanic provinces having water types that range from coastal to oligitrophic. The results also indicate that airborne laser-induced fluorescence methods are an acceptable method for validation of passively retrieved chlorophyll fluorescence line height. Accordingly, airborne data in other oceanic regions outside the Middle Atlantic Bight are being sought to provide additional analyses. It is also expected that future airborne underflight of Terra-MODIS contemporaneous with the newer Aqua-MODIS and MERIS satellite sensors will provide rather vibrant intercomparisons.

V. Acknowledgements

***please suggest acknowledgments...

VI. References

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CAPTIONS:

Figure 1.

Terra-MODIS fluorescence line height image of the Middle Atlantic Bight portion of the western North Atlantic Ocean for 11 March 2002. The airborne lidar occupied the northerly Outbound flight line as the satellite passed overhead. The annoying MODIS instrument artifact called "striping" is still under study but does not severely hinder the validation results presented herein. The flight lines were designed to traverse four distinct water masses: coastal, shelf, slope, and Gulf Stream.

Figure 2
MODIS chlorophyll fluorescence line height extracted from the image in Figure1 along the entire outbound and inbound flight track lines. The airborne laser-induced (and water Raman normalized) chlorophyll fluorescence is also plotted for direct comparison. The regression of the MODIS FLH and airborne laser chlorophyll fluorescence in the rightmost plots yields a correlation coefficient of $r^2 = 0.85$.

Figure 3
Performance of the Terra-MODIS FLH algorithm in highly absorbing CDOM laden waters. The CDOM absorption coefficient at 412nm is derived from the lidar CDOM fluorescence/water Raman ratio [Hoge et al., 1995]. The CDOM absorption coefficient at ~683nm is ~1% of the 412nm value and produces no discernible influence on the FLH retrievals even in the coastal region (see 460-470 Km along-track distance locations).

Problems: Considerable time was expended this reporting period in the preparation of MODIS Re-compete Proposals. Normal work levels should resume during the next reporting period.

Future Research Efforts: The remaining product validations Chlor_a_2, Chlor_MODIS, Chlor_a_3, CDOM absorption coefficient will be refined and are expected to be detailed during the next reporting period.