Semi-Annual Report for January-June, 2001
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Abstract

The activities of the first half of 2001 were concentrated on quality assurance (Q/A) for our products from the new MODIS data stream. We have updated our Case 2 chlorophyll a algorithms for MODIS using smooth functions for the transitions between different bio-domains and also have updated the quality and product thermally driven flags document. One peer-reviewed paper has been submitted for publication, and one paper has been published. A number of posters and symposium papers were presented at several conferences.

Tasks Accomplished Since January 1, 2001

1. Field experiments

a. Ecology of Harmful Algal Blooms (ECOHAB) cruises- April 3-6, and June 5-8.

   Jennifer Cannizzaro, Dan Otis, Jim Ivey collected remote-sensing reflectance and water samples for absorption during an ECOHAB West Florida shelf experiment. The data will be used to test and adapt the global chlorophyll and CDOM algorithms for presence of bottom-reflected radiance in SeaWiFS and MODIS data.

b. Florida Shelf Lagrangian Experiment (FSLE) cruises and PHILLS hyperspectral overflights at 10 km altitude – April 24, 2001.

   Robert Steward, Jennifer Cannizzaro, David English, Daniel Otis, and Jim Ivey collected remote sensing reflectance and water samples for absorption during two FSLE experiments. The PHILLS was flown on several transects over the area with vicarious calibration measurements conducted by USF from the R/V Suncoaster. The USF slow-drop package was also deployed to collect inherent and apparent optical properties as a function of depth for an evaluation of effects of vertical structure on remote sensing spectra. These data will be used to modify MODIS algorithms for use in shallow waters. The PHILLS imagery has been successfully calibrated and will be used to evaluate MODIS sub-pixel patchiness issues.

2. Presentations & Symposiums

a. A paper entitled “MODIS Case 2 Ocean Color Algorithms: Use of MODIS SST to Condition the Bio-optical Domains via Nitrate-Depletion Temperatures” by K. Carder, R. Chen, J. Patch, and J. Brown was presented at the MODIS science team meeting in January at GSFC.

b. A Paper entitled “Particle phase function and remote-sensing reflectance model: a revisit” by Zhongping Lee, , Kendall L. Carder, Robert G. Steward, and Jennifer S. Patch was presented in Ocean Color Research meeting in San Diego, CA, May, 2001.

Using three different particle phase functions from measurements of Petzold and Kopelevich, remote-sensing reflectance (r_{rs}) spectra were calculated using HYDROLIGHT. As a normal practice, a ratio (γ) between r_{rs} and the ratio (u) of backscattering to the sum of absorption and backscattering ($u = b_b/(a+b_b)$) is further derived ($\gamma = r_{rs}/u$). The g values increase with u values, nonlinearly, but may differ a lot for some particle phase functions. It is found that an important factor affecting g value is the overall shape of particle phase function for the backward most angles. b_b describes all photons scattered backward (not necessarily upward for remote sensing), and only part of those contributes to remote-sensing reflectance.

For the same particle phase function and u values, γ seems less predicable for low u values than for high u values. This may be because for open-ocean waters (low chlorophyll concentrations) both molecular and particle scattering are contributing similarly in weight to remote-sensing reflectance, while for high u values it is the particle scattering that dominates the process. If we separate the two scattering processes in modeling r_{rs}, however, a more stable and predictable empirical function is obtained.

Applications to retrievals of absorption and scattering coefficients are discussed for different phase functions. Accuracies for retrievals of absorption coefficients and hence chlorophyll concentrations are fairly independent of the phase function involved. Backscattering accuracies, however, are quite dependent on the backward shape of particle phase functions.

c. A poster entitled “MODIS Case 2 Ocean Color Algorithms: Use of MODIS SST to Condition the Bio-optical Domains via Nitrate-Depletion Temperatures” by Kendall L. Carder, F. Robert Chen, and J. Patch was presented n Ocean Color Research meeting in San Diego, CA, May, 2001.

The nitrate-depletion temperature (NDT) for a given oceanic location is the sea-surface temperature (SST) above which the nitrate concentration becomes negligible. It indicates regions where major transitions occur in dominant species of phytoplankton. Comparing the sea-surface temperature to the nitrate-depletion temperature provides a means of estimating nutrient availability and allows partitioning into bio-optical domains, each with much narrower ranges of chlorophyll-specific absorption coefficients, $a^*_\phi(\lambda)$.

This allows the ratio of chlorophyll *a* to accessory pigments and cell optical size to change with bio-optical domain and hence the particle absorption determined from MODIS to be more accurately interpreted in terms of chlorophyll *a* concentration.

Operationally, the MODIS chlorophyll *a* algorithm (MOD_chl_a_3), released by the MODIS data archive (DAAC) in November 2000, uses weekly averaged (1^o x 1^o bins) Reynolds SST values. Chlorophyll retrievals for the New York Bight region based in part on these coarse SST fields are compared with those based on MODIS SST with ~1 km resolution. While seasonal changes away from the edges of large biomes are likely to be properly expressed even with the low-resolution Reynolds SST values, transitional regions, such as spring New York bight scenes require high-resolution synoptic SST data. The scene selected represents pigment-specific absorption coefficients (packaging values) ranging from $0.02 < a^*_\phi (443) < 0.10$ mg m^{-3} or from “packaged” or self-shaded pigments in Labrador-Current waters to “unpackaged” or unshaded pigments in Gulf Stream waters. Comparisons to retrievals using a single, “global” pigment-packaging parameterization are also shown, which contract the range of retrieved chlorophyll values by about 2X. Reprocessing of MODIS data will use the high-resolution MODIS SST values to sharpen the bio-optical effect of transitioning across SST features.

d. A poster entitled “Autonomous Marine Optical Sensor (AMOS) Network on the West Florida Shelf” by Kendall. L. Carder, and R. Steward was presented at the Ocean Color Research meeting in San Diego, CA, May, 2001.

An airborne, satellite, or any other above-water radiometer measures total upwelling reflectance, T_{rs}, at the surface less the atmospheric effects. Rrs measured on ships, buoys, and platforms is defined as T_{rs} less the contributions from the sky S_{rs} and sunglint Δ,

$$R_{rs} = T_{rs} - F(\Theta) \cdot S_{rs} - \Delta .$$

$F(\Theta)$ describes the angular dependence of the Fresnel surface reflectance. $F(\Theta)$ is usually less than 3% . Technique and instrument characterization are critical in deriving accurate reflectance measurements. Seventeen years of field experiments that collected Rrs from ships and boats have helped our lab to refine the methodology and data reduction. These measurements were made with a man-in-the-loop to discriminate against difficult samples. AMOS was constructed to simulate this sampling technique, and ancillary sensors were included to help with the data interpretation. It provides continuous measurements useful for vicarious calibration of aircraft sensors.

Rrs is controlled by absorption and scattering properties of water and its constituents, the bottom albedo and bottom depth, and it is influenced by fluorescence and Raman emissions and by the output and angles of solar radiance.

The optical properties of the target water can be derived from Rrs measurements as shown in Carder and Steward 1985, Lee et al. 1994, 1998, 1999. In general,

$$R_{rs} = g \cdot u,$$

where

$$u = \frac{b_b}{(a + b_b)},$$

and

$$g \approx g_0 + g_1 \cdot u$$

Therefore, Rrs is fundamentally determined by backscattering b_b and absorption a. Further, b_b is the sum of b_w and b_p while a=aw+ap+ad+ag. The subscripts indicate contributions by water, particulates, detritus and choromophoric dissolved organic matter(gelbstoff).

A manual Rrs measurement is done by collecting spectra from the water and from a Spectralon reflectance target, above the water at 90º to the solar plane and at 30º from nadir, and from the sky at 90º to the solar plane and 30º from zenith. These spectra are corrected for dark current and integration time to create the Trs and Srs scans. Numerical modeling routines help fine tune the Fresnel and glint factors.

The autonomous Rrs is collected in the same manner remembering that the spectrometer and Spectralon target are in a fixed orientation with respect to the platform and not the sun. The orientation of the platform to the sun is known by compass and inclinometer measurements and must be accounted for in the data reduction. Due to expense, the orientation of the Rrs sensor is fixed and can not be moved to optimize each sample. Therefore additional in water sensors were included to help characterize the reflectance.

As discussed above, backscattering and absorption are the fundamental optical properties affecting Rrs. To help quality control the autonomous Rrs measurements, the AMOS network includes sensors to collect backscatter and beam attenuance at 488 and 660nm and chlorophyll fluorescence. With these measurements it is possible to model an estimate of the reflectance which can be used to identify and flag autonomously measured Rrs that may be suspect due to high sun glint, cloud/sky reflectance, or window contamination.

e. A paper entitled “NOW-CASTING RED TIDES IN THE GULF OF MEXICO: AN OPTICAL VIEW” by Kendall Carder, John Walsh, Robert Chen, Jennifer Patch, Zhongping Lee, Cynthia Heil, and Tracy Villareal was presented n Ocean Color Research meeting in San Diego, CA, May, 2001.

Harmful algal blooms of the red-tide dinoflagellate *Karenia Brevis* are thought to have caused major mortalities of scores of manatees in southwest Florida in the past decade due to inhalation of toxic aerosols that caused pneumonia-like symptoms. They were often trapped in an estuary by blooms of *K. Brevis* , and when they swam out seeking food, their nostrils were only inches from the surface where the blooms were concentrated. This example provides an analogue to what snorkeling divers might expect, with the neurotoxin damaging lungs, eyes, and other exposed areas of the body. To fare well, full protection for divers would be required to counter the effects of swimming in infested waters. Prediction of red tides for swimmer protection is our goal.

Prediction of the likelihood of major red tides to occur in the Gulf of Mexico is aided by two precursors that are hypothesized by Walsh and Steidinger (in press) to be required before *K. Brevis* can flourish. Fortunately, both precursors can be identified optically by remote sensing. The precursors are massive influxes of iron-rich dust (e.g. Saharan dust) and *Trichodesmium. K. Brevis* and *Trichodesmium* are both slow growing species, out-competed by diatoms and most other phytoplankton when nutrients are plentiful, so they are not associated with high-runoff periods and regions. When silica is depleted, no diatoms can live, and when nitrogen in the nitrate, nitrite, and ammonium forms are gone, only nitrogen-fixers such as *Trichodesmium* can flourish. *Trichodesmium*, however, requires at least 4X the iron as other species in order to generate nitrogenase to fix nitrogen, hence the requirement of a dust precursor. They clump together using sticky, organic secretions, presumedly to exclude oxygen from the region of nitrogen fixation, which provides nitrogen-rich nutrients to the surrounding waters. If *K. Brevis* is nearby, it can benefit from this proximity. While Walsh and Steidinger have found causal implications supporting these hypotheses in data and statistics, they have not previously found both species in the same sample or major blooms juxtaposed or super-imposed. During May-July 2000 major influxes of Saharan dust to the Gulf of Mexico region are visible in SeaWiFS and AVHRR satellite imagery. Absorption at blue wavelengths infers the presence of significant iron. A massive *Trichodesmium* bloom is observed in late July from a ship in the south-central Gulf of Mexico, and it is clearly observed in SeaWiFS and MODIS satellite imagery. *Trichodesmium* has gas vacuoles that are involved in buoyancy regulation to optimize light and nutrient requirements. The contrast in refractive indices between air and water is 10X that of most naked (unarmored) phytoplankton, and even 2-3X that of siliceous- and calcareous-armored species such as diatoms and coccolithophorids. This makes them very bright reflectors per unit chlorophyll. Furthermore, diatoms are not found in clear, silica-poor waters, and coccolithophorids are not found in surface Gulf of Mexico waters in the summer and fall as they prefer cooler temperatures (~20^{o} C). Thus, the gigantic, high-scattering regions observed in the summer imagery are surely dominated by *Trichodesmium.*

By 29 September a massive red-tide bloom is seen in a MODIS image off the Texas coast juxtaposed with an even larger, offshore *Trichodesmium* bloom (Fig. 1). Furthermore, a pair of smaller blooms was also found off Florida near Tampa Bay and Charlotte Harbor, where field corroboration showed superposition and coincidence of *K. Brevis* and *Trichodesmium*. This validates for the first time the Walsh-Steidinger hypothesis. An optical cruise through the

Florida blooms provided data confirming the extremely small backscattering per unit chlorophyll proposed by the Carder-Steward (1985) optical model for *K. Brevis* blooms. The *Trichodesmium* populations were for the most part not observed at the surface, however, but were discerned optically to be at depths of 15 m based on hyper-spectral surface radiometry and models (e.g. Lee et al. 1999). Subsequent chlorophyll profiles also showed high chlorophyll concentrations centered near a 15 m depth. Evaluation of pixels on satellite imagery coincident with the field data confirmed the spectral character, size, and extent of the Florida blooms for use in better diagnosing the massive Texas blooms for which optical field data were unavailable.

Figure 2 is a simple diagram using only 3 of the 6 visible SeaWiFS bands, with the Y axis indicating brightness. In the reflectance mode, these relationships show the optical end members associated with clear Loop Current (7), clear western Gulf water (8), Texas (1,3) and Florida (2) *Trichodesmium* blooms, Texas (6) and Florida (4,5) *K. Brevis* blooms, and a Tampa Bay diatom bloom (11). Trend lines indicate mixing between *Trichodesmium* and *K. Brevis* blooms near the coasts, and between *Trichodesmium* and various clear water types (9,10) throughout much of the Gulf of Mexico. Without *Trichodesmium* mixed in, the points on the mixing lines would collapse onto a “clear-water” end member. Note that high chlorophyll values fall at left edge of the diagram. Using this type of diagram we found that much of the southern Gulf of Mexico had a detectable *Trichodesmium* presence from July until October, but *K. Brevis* blooms were only found adjacent and inshore of *Trichodesmium* locations, with mixed pixels found between the more pure end members. This preliminary diagram outlines the good news of being able to observe red tides and their precursors from space.
Now-casting the presence of Saharan dust and *Trichodesmium* from space using optical properties can now be performed regularly. Now-casting *K. Brevis* can be performed when blooms are away from shore or thick enough that bottom effects are not visible. A methodology has been developed (Lee et al., 2001; Carder et al. 2000) to correct for bottom effects on remotely sensed imagery so that early diagnosis of red tide blooms can be effected. To do so accurately requires a hyper-spectral imager such as the Coastal Ocean Imaging Spectrometer (COIS) proposed to fly on the NEMO satellite or the AVIRIS and PHILLS sensors flown on aircraft. Aircraft sensors such as PHILLS are being evaluated for use on Autonomously Piloted Aircraft (APAs) by NRL (C. Davis). Bathymetry, water properties, and bottom reflectivity all can be derived using such sensors (Lee et al.).

Sensors for validating both *Trichodesmium* and *K. Brevis* concentrations can be deployed on autonomous underwater vehicles (AUVs) as scouts for ensuring swimmer safety when redtides are predicted to be present. Evaluation of the probability of large red tides occurring in the Gulf of Mexico has been enhanced by identifying the likely red-tide precursors and defining the optical properties needed to identify them from space, aircraft and AUVs. Additional work is needed to more accurately detect red tides remotely in their early stages in near-shore waters, but accuracy can be greatly enhanced using hyper-spectral remote sensors and optical models to separate bottom effects from water-column effects on the imagery.

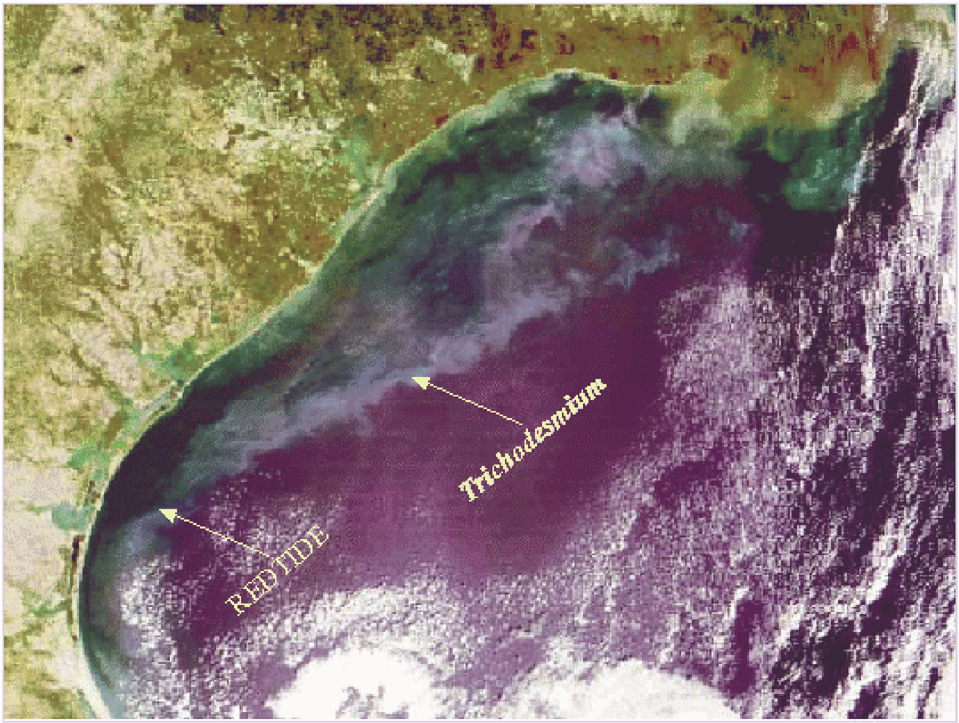

Figure 1

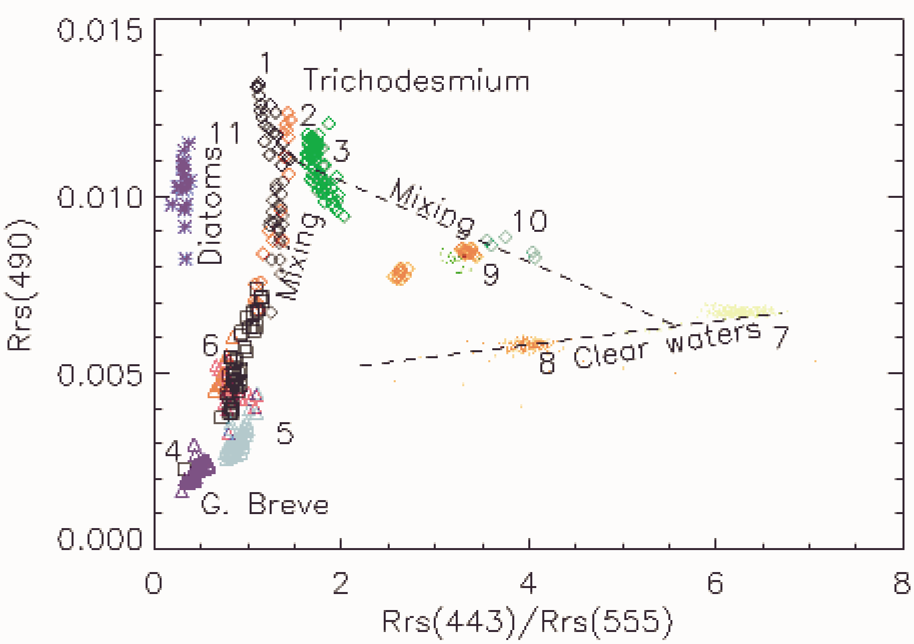

Figure 2

3. Peer-reviewed Publications

a. A paper entitled “Properties of the water column and bottom derived from AVIRIS data” by Zhongping Lee, Kendall. L. Carder, F. Robert Chen and Thomas G. Peacock is published in *J. Geophys. Res*., Vol 106 (C6), 11639 - 11652 (2001).

   Using AVIRIS data as an example, we show in this study that the optical properties of the water column and bottom of a large, shallow area can be adequately retrieved using a model-driven optimization technique. The simultaneously derived properties include bottom depth, bottom albedo, and water absorption and backscattering coefficients, which in turn could be used to derive concentrations of chlorophyll, dissolved organic matter, and suspended sediments. The derived bottom depths were compared with a bathymetry chart and a boat survey and were found to agree very well. Also, the derived bottom-albedo image shows clear spatial patterns, with end members consistent with sand and seagrass. The image of absorption and backscattering coefficients indicates that the water is quite horizontally mixed. These results suggest that the model and approach used work very well for the retrieval of sub-surface properties of shallow-water environments even for rather turbid environments like Tampa Bay, Florida.

b. A paper entitled “Effect of spectral resolution on retrievals of water column and bottom properties from ocean-color data." by ZhongpingLee, Kendall. L. Carder was submitted to Appl. Optics for publication.

   Using an optimization technique, sub-surface properties of coastal and oceanic waters were derived from measured remote-sensing reflectance spectra. These data included both optically deep and shallow environments. The measured reflectance covered a range from 400 to 800 nm with a 2 nm resolution. The inversions used data binned into 5 nm, 10 nm, and 20 nm contiguous bands. They were also binned to simulate MERIS, SeaWiFS and MODIS channels, respectively. This study is designed to evaluate the influence of spectral resolution and channel placement on the accuracy of remote-sensing retrievals, and to provide guidance for future sensor design. From the results of this study, the following were found: 1) use of 10 nm wide contiguous channels provides almost identical results as found for 5 nm contiguous channels, 2) use of 20 nm contiguous channels and MERIS provides comparable results to those with 5 nm contiguous channels for deep waters; but use of contiguous 20 nm channels perform better than MERIS for optically shallow waters; and 3) generally

SeaWiFS or MODIS cannot provide accurate bathymetry retrievals, though both work fine for deep, clearer waters (total absorption coefficient at 440 nm < 0.3 m^{-1}). Including the 645 nm MODIS "land" band in its channel set improves inversion returns for both deep and shallow waters.

4. Science Meetings

MODIS Ocean Science Team, April 3-5, 2001 at RSMAS, Miami.