

## **Semi-Annual Report for January-June, 2003**

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### **Abstract**

The activities of the first half of 2003 were concentrated on quality assurance (Q/A) for our products from the MODIS data stream. We have validated all our MODIS products: Case 2 chlorophyll a algorithms (MOD21), Phytoplankton absorption coefficient at 675 nm, Total Absorption coefficient at 412 nm, Total Absorption coefficient at 443 nm, Total Absorption coefficient at 488 nm, Total Absorption coefficient at 531 nm, and Total Absorption coefficient at 551 nm(MOD 36); Instantaneous photosynthetically available radiation(IPAR), Instantaneous absorbed radiation by phytoplankton for fluorescence(ARP)(MOD22); and Epsilon of clear water aerosols at 531 and 667 nm(MOD39). One peer-reviewed paper has been submitted for publication and two have been accepted for publication. Two symposium papers were presented at the Ocean Color conference in Miami in April and three papers were presented at the New Orleans TOS meeting. Two proposals have been submitted to NASA.

### **Tasks Accomplished Since January 1, 2003**

#### **1. Field experiments**

- a. David English collected remote-sensing reflectance and water samples for absorption spectra during an ECOHAB West Florida shelf "red-tide" experiment onboard R/V Suncoaster between 02/10/03-02/11/03. The underway system was also used recording backscattering, gelbstoff fluorescence, and chlorophyll fluorescence records which were calibrated and converted to gelbstoff absorption at 400 nm and chlorophyll..
- b. Dan Otis collected remote-sensing reflectance and water samples for absorption spectra on R/V Suncoaster during a West Florida to Mississippi transit experiment from 7/12/03 to 7/22/03. The underway system was also used.

These data will be used to test and adapt the global chlorophyll and CDOM algorithms for presence of bottom-reflected radiance and turbid water in SeaWiFS and MODIS data. The data will also be used for testing our red tide algorithm and for model comparison.

#### **2. Presentations & Symposiums**

- a. A paper entitled 'REMOTE DETECTION OF RED TIDE BLOOMS ON THE WEST FLORIDA SHELF: A NOVEL CLASSIFICATION TECHNIQUE' by Jennifer P. Cannizzaro, Kendall L. Carder, F. Robert Chen, Cynthia A. Heil was presented at the Ocean Color conference in Miami on April 2003.

The red tide dinoflagellate *Karenia brevis* (previously known as *Gymnodinium breve*) blooms regularly along the West Florida Shelf (WFS), often causing widespread ecological and economical damage to coastal communities. Current techniques for monitoring *K. brevis* blooms are either laborious and subject to bias (light microscopy) or lack species-specificity (chlorophyll biomass). Blooms of *K. brevis* impart a variety of colors to surface waters, which suggests that remote-sensing of ocean color may provide a means for identifying these blooms from space. However, if ocean color imagery are to be used for monitoring red tide blooms, then a method for distinguishing between major bloom-forming algal classes (i.e. dinoflagellates and diatoms) is required. Between 1999 and 2001, a large bio-optical data set (n=257) containing remote-sensing reflectance, absorption, backscattering, and chlorophyll concentration data was collected along the WFS as part of the Ecology of Harmful Algal Blooms (EcoHAB) program. Since phytoplankton absorption coefficients are highly correlated to chlorophyll concentration, absorption by phytoplankton pigments can not be utilized as the sole basis for algal classification from space. This is because the major pigments found in *K. brevis* also occur in other classes of algae. Red tide blooms, however, exhibit relatively low chlorophyll-specific detrital absorption and low phaeopigment to chlorophyll ratios consistent with regions containing small quantities of suspended sediment and/or exhibiting low grazing pressure. Consequently, chlorophyll-specific backscattering coefficients in *K. brevis* blooms are relatively low compared to diatom-dominated regions. A classification technique for identifying waters dominated by *K. brevis*, diatoms, and oligotrophic phytoplankton (i.e. prochlorophytes and cyanophytes) is introduced based on differences observed in chlorophyll-specific backscattering in October 2000. Application of this technique to SeaWiFS and MODIS imagery collected in 2001 together with in situ *K. brevis* cell concentrations provides validation of this method and shows the origin and transport of a major *K. brevis* bloom along the WFS.

b. A paper entitled ‘Performance of the MODIS Semi-Analytical Ocean Color Algorithm FOR Chlorophyll-*a*’ by Kendall L. Carder, F.R. Chen, J.P. Cannizzaro, J.W. Campbell, and B.G. Mitchell was presented in Ocean Color conference in Miami on April, 2003.

The Moderate Resolution Imaging Spectroradiometer (MODIS) semi-analytical (SA) algorithm calculates the spectral absorption properties of surface waters, splitting them into those associated with phytoplankton,  $a_{ph}(\lambda)$ , colored dissolved organic matter or gelbstoff,  $a_g(\lambda)$ , and water,  $a_w(\lambda)$ . The phytoplankton absorption coefficient,  $a_{ph}(675)$ , is then used to derive the concentration of chlorophyll-*a*,  $Chlor\_a\_3$ . The SA algorithm is designed to respond to variable ratios of  $a_{ph}(\lambda)$  to  $a_g(\lambda)$  and to wide ranges in the chlorophyll-specific phytoplankton absorption coefficient,  $a^*_{ph}(\lambda)$ , for a given chlorophyll-*a* level. Spatial and temporal differences in MODIS Terra chlorophyll-*a* retrievals are examined between  $Chlor\_a\_3$  and an empirical algorithm,  $Chlor\_a\_2$ , developed to mimic the performance of the Sea-viewing Wide Field-of-View Sensor (SeaWiFS) OC-4 chlorophyll-*a* algorithm.

**C.** A paper entitled ‘The ROSEBUD Remotely Operated Vehicle: a Versatile Platform for Optical Oceanography’ by T. Peacock, D. Costello, K. Carder and E. Kaltenbacher was presented in TOS meeting in New Orleans.

The University of South Florida has deployed the ROSEBUD Remotely Operated Vehicle (ROV) for nearly a decade. ROSEBUD was conceived, designed and constructed to be a cost-effective, low-maintenance, "pick-up truck" ROV capable of deploying a diverse array of optical oceanographic instrumentation while only requiring a small (34') surface-support vessel, the R/V Subchaser. To date, ROSEBUD has been deployed scores of times and collected thousands of data points in water ranging from Chesapeake Bay to the Exuma Islands. The latest series of deployments involved rather significant modifications to accommodate deployment of the FLASH ROBOT payload, the Fast Laser Assessment of Ship Hulls (FLASH) configuration of the Real-time Ocean Bottom Optical Topographer (ROBOT). ROBOT is a laser-line imaging system developed at the University of South Florida that acquires 3-dimensional imagery of underwater surfaces.

In this contribution, specifications for the ROSEBUD vehicle were detailed. Additionally, the various payloads and ancillary optical instrumentation were described with emphasis on the FLASH ROBOT payload and the Bottom Classification and Albedo Package (BCAP) payload. Finally, a representative sampling of the diverse scientific results was presented.

**d.** A paper entitled ‘Measurement and Prediction of Optical Environments Associated with Underwater Inspection’ by K. Carder, D. Costello, D. English, P. Reinersman, and W. Hou was presented at a TOS meeting in New Orleans.

The University of South Florida has deployed optical sensor payloads on Unmanned Underwater Vehicles (UUVs) for nearly a decade. The payloads include a suite of Inherent and Apparent Optical Property (IOP, AOP) sensors and two novel imaging systems. The Real-time Ocean Bottom Optical Topographer (ROBOT) payload, for example, is a laser-line imager for acquiring 3-D images of the ocean bottom. The Fast Laser Assessment of Ship Hulls configuration (FLASH ROBOT) is an upward-looking version with utility in harbor security. The Bottom Classification and Albedo Package (BCAP) payload collects multi-channel (6), intensified bottom imagery in both reflective and fluorescence modes and has utility in bottom object detection and classification.

A challenge in any form of underwater imaging, including simple video, is to parameterize performance characteristics in terms of environmental variables. Collateral to that challenge is the need for predictive capabilities for a wide variety environmental conditions, modeling capabilities to simulate different environments, and novel approaches to extract information from various forms of imagery. To that end, we combine laboratory and field measurements with modeling efforts including IOP and AOP calculation from remote sensing imagery, prediction of the ambient light field beneath ships and in channels, and automated target recognition using 3-dimensional data. The goal of these efforts is to combine available remotely sensed and in-situ measurements with predicted environmental parameters to allow the selection of assets for underwater inspection that are appropriate to expected environmental conditions.

e. A paper entitled ‘Optical Oceanography using Unmanned Underwater Vehicles’ by English, D., K. Carder, D. Costello, W. Hou was presented at a TOS meeting in New Orleans.

The University of South Florida has deployed optical sensor packages on Unmanned Underwater Vehicles (UUVs) for almost a decade. The UUVs include Autonomous Underwater Vehicles (AUVs) operated by Florida Atlantic University, and an Autonomous Guided Underwater Vehicle (AGUV) and Remotely Operated Vehicles (ROVs) operated by the University of South Florida. The sensor packages have included the Real-time Ocean Bottom Optical Topography and the Benthic Classification and Albedo Package (BCAP), which collects downwelling irradiance, upwelling radiance, multichannel video, scattering, and fluorometry. The goals of these deployments have been to develop the capability to map the bottom albedo, the location of exceptional objects on natural or manmade surfaces, the light field of the water column, and some of the inherent optical properties (IOPs) of the water column. Techniques have been developed to estimate Apparent Optical Properties (AOPs) from BCAP measurements of the environmental light field. The direct measurements, combined with the derived AOPs and IOPs and other shipboard observations, have provided essential parameters for models of visibility, heat budgets, and water circulation. They have also been used to validate above-water remote sensing observations, to classify the bottom composition, and to detect distinctive objects on a sea bottom.

An underlying assumption in many research efforts involving radiative transfer in water is that light penetrating the ocean surface decays exponentially with depth. This is inherent in the definition of diffuse attenuation and, to first order, this assumption is useful. Pragmatically, however, comprehensive interpretation of in situ measurements of oceanic light spectra is complicated by a myriad of physical, chemical, and bio-optical phenomena that may significantly alter the physical and spectral structure of the light fields.

In this work a Remotely Operated Vehicle was utilized to collect hyperspectral profiles of downwelling irradiance and upwelling radiance in a relatively deep (102m) deployment in the clear waters of Exuma Sound. These spectra were utilized in a methodology developed to minimize the effects of wave focusing of downwelling light and to maximize the information provided by inelastic contributions (i.e. Raman, pigment, and gelbstoff fluorescence). The method relies on the calculation of polynomial equations (here, to 2<sup>nd</sup> order) that describe irradiance (or radiance) as a function of depth in semi-log space at each wavelength. Spectra that describe the spectral behavior of the polynomial coefficients are then assembled and the upwelling, downwelling and reflectance spectra can be calculated for any depth. Derivations of the polynomial equations with respect to depth yield local diffuse attenuation coefficients. Analysis of the changes with depth of the attenuation coefficients and reflectivity (especially in wavebands affected by inelastic phenomena) provides insight into active biological and chemical processes.

The method is fully described, limitations including the need to address the spectral resolution of different sensors are noted, and radiative transfer modeling results (Hydrolight) are compared to field data for this deep-water environment. Hydrolight results utilizing an Angstrom exponent for Raman scattering of 5 and exponentially increasing CDOM concentration with depth agree well with field data except for insufficient CDOM fluorescence efficiency.

f. A paper entitled "A Compact Sensor for Real-time 3-D Imaging applications in Aqueous Environments" by E. Kaltenbacher, L. Langebrake, D. Costello, K. Carder, J. Patten, and J. Kloske. Was also presented in TOS meeting in New Orleans.

Mapping bottom features, both natural and man-made, has value in many civilian and military applications. Bottom-feature maps, for example, would be of great value in the efforts to clean up artillery ranges such as Vieques, Puerto Rico and Kaho'Olawe, Hawaii. To map any significant area, however, requires a fast and automated method of bottom feature extraction. Common systems utilized include high-frequency acoustics, video, and active line-scan imagers. 3-D systems (e.g. line-scan imagers) have the ability to detect the volumetric shape of even camouflaged objects, whether naturally or purposefully camouflaged. The active, bi-static configuration of most line-scan imagers also allows operation in low-light and turbid conditions.

Automated detection of a feature, however, is a challenge in all but the simplest systems. Moment invariant functions provide excellent descriptors of typical man-made shapes such as cylinders, quadrilaterals, and spheroids in 3-dimensions and/or object profiles in 2-dimensions. In this effort, we utilize field images acquired using the ROBOT laser-line imager and identify feature invariants for future automated processing in both 2-D and 3-D imagery. Incomplete shapes due to partial burial are also used to identify invariants expected in actual applications.

### 3. Peer-reviewed Publications

a. A paper entitled “A novel technique for detection of the toxic dinoflagellate, *Karenia brevis*, Jennifer P. Cannizzaro\*, Kendall L. Carder, F. Robert Chen, Cynthia A. Heil, and Gabriel A. Vargo was submitted to the *Continental Shelf Research* EcoHAB special issue in June 2003

*Karenia brevis*, a toxic dinoflagellate species that blooms regularly in the Gulf of Mexico, frequently causes widespread ecological and economical damage to coastal communities. Between 1999 and 2001, a large bio-optical data set consisting of remote-sensing reflectance, absorption, and backscattering spectral measurements and chlorophyll *a* concentrations was collected on the central West Florida Shelf as part of the EcoHAB (Ecology and Oceanography of Harmful Algal Blooms) and HyCODE (Hyperspectral Coupled Ocean Dynamics Experiment) programs. Model simulations indicate that absorption due to phytoplankton, detritus, and gelbstoff cannot account for the factor of 3 to 4 decrease in remote-sensing reflectance spectra,  $R_{rs}(\lambda)$ , observed in waters containing greater than  $10^4$  cells  $l^{-1}$  of *K. brevis*. Chlorophyll-specific particulate backscattering coefficients,  $b_{bp}^*(\lambda)$ , measured inside *K. brevis* blooms, though, were significantly lower than values measured in high-chlorophyll estuarine waters, typically dominated by diatoms. Since deviations in  $b_{bp}^*(\lambda)$  can explain the observed decrease in  $R_{rs}(\lambda)$  according to model simulations, a classification technique for identifying waters containing greater than  $10^4$  cells  $l^{-1}$  of *K. brevis* is developed based on these results. In addition, a method for quantifying chlorophyll concentrations in *K. brevis* blooms using fluorescence line height (FLH) data is introduced. The classification technique is successfully applied to SeaWiFS (Sea-viewing Wide Field-of-view Sensor) data acquired in late August 2001 and validated using *in situ* *K. brevis* cell concentrations. All stations containing greater than  $10^4$  cells  $l^{-1}$  of *K. brevis* were successfully flagged using this technique.

b. A paper entitled “Columnar aerosol single-scattering albedo and phase function retrieved from sky radiance over the ocean: Measurements of African dust” by Christopher Catrall, Kendall L. Carder, and Howard R. Gordon has been published in *Journal of Geophysical Research*, vol 108, No. D9, 4287, doi:10.1029/2002JD002497, 2003.

The single-scattering albedo and phase function of African mineral dust are retrieved from ground-based measurements of sky radiance collected in the Florida Keys. The retrieval algorithm employs the radiative transfer equation to solve by iteration for these two properties which best reproduce the observed sky radiance using an assumed aerosol vertical structure and measured aerosol optical depth. Thus, no assumptions regarding particle size, shape, or composition are required. The single-scattering albedo, presented at fourteen wavelengths between 380 and 870 nm, displays a spectral shape expected of iron-bearing minerals but is much higher than current dust models allow. This indicates the absorption of light by mineral dust is significantly overestimated in climate studies. Uncertainty in the retrieved albedo is less than 0.02 due to the small uncertainty in the

solar-reflectance-based calibration ( $\pm 2.2\%$ ) method employed. The phase function retrieved at 860 nm is very robust under simulations of expected experimental errors, indicating retrieved phase functions at this wavelength may be confidently used to describe aerosol scattering characteristics. The phase function retrieved at 443 nm is very sensitive to expected experimental errors and should not be used to describe aerosol scattering.

Radiative forcing by aerosol is the greatest source of uncertainty in current climate models. These results will help reduce uncertainty in the absorption of light by mineral dust. Assessment of the radiative impact of aerosol species is a key component to NASA's Earth System Enterprise.

#### **4. Proposals**

- a. A proposal entitled "*Maintenance and Refinement of MODIS Semi-analytical Algorithms for chlorophyll, CDOM absorption, total absorption, and absorbed radiation by phytoplankton.*" was submitted to NASA on April, 2003 for 10/01/03 to 9/30/06 for the amount of \$900,000.00.
- b. A proposal entitled "*Quantifying HAB Concentrations and Chlorophyll a in Coastal Waters*", was submitted to NASA on April, 2003 for 10/01/03 to 9/30/06 for the amount of \$487,285.00.