Semi-Annual Report for January-June, 2002

Kendall L. Carder, University of South Florida

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Abstract

The activities of the first half of 2002 were concentrated on quality assurance (Q/A) for our products from the new MODIS data stream. We have updated our Algorithm Theorectical Basics Documents to Version 6: ATBD19 for 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); ATBD20 for Instantaneous photosynthetically available radiation(IPAR), Instantaneous absorbed radiation by phytoplankton for fluorescence(ARP)(MOD22); and ATBD 21 for Epsilon of clear water aerosols at 531 and 667 nm(MOD39). We also are continuously collecting *in situ* data for calibration/validation of our products. Five peer-reviewed papers have been submitted for publication, four have been accepted for publication. A number of symposium papers were submitted for presentation at the Ocean Optics conference in New Mexico in November 2002 and at COSPAR in Houston, Texas in October 2002. Our satellite-based redtide discrimination work was featured in an article by Evelyn Yobe in NASA's Earth Observatory for July 9, 2002. The URL for NASA Earth Observatory is http://earthobservatory.nasa.gov/Study/Redtide.

Tasks Accomplished Since January 1, 2002

1. Field experiments

a. An underway system was used to collect data on R/V Bellows during an EcoHAB West Florida shelf experiment from 1/31/02 to 2/2/02.

b. During a "Black Water" event R/V Subchaser sampled the Florida Bight between 2/29 to 2/30/02, with Tom Peacock, Jim Ivey and David English collecting remote-sensing reflectance and water samples for absorption(ap, ad, and ag), and chlorophyll. An optical, slow drop package, and the underway system were used. This resulted in the publication (Hu et. al., EOS83(26), 2002).

c. David English collected remote-sensing reflectance and water samples for absorption during an ECOHAB West Florida shelf "red-tide" experiment onboard R/V Suncoaster between 6/29/02-7/2/02. 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 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 accepted for presentation at the Ocean Optics conference in New Mexico on November 2002.

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 **'**ABSORPTION MEASUREMENTS IN OPTICALLY CLEAR WATERS' by James E. Ivey, Kendall L. Carder, Feng-I R. Chen, and Zhongping Lee was accepted for presentation at the Ocean Optics conference in New Mexico on November 2002.

In optically clear waters (defined as a-aw < 0.05/m), an exact determination of absorption due to constituents other than water (a-aw) is difficult due to the extremely small values. Algorithms for determination of a-aw, that employ the inversion of apparent optical properties, remote sensing reflectance (Rrs), and diffuse attenuation coefficient (Kd), provide the highest signal-to-noise ratios due to effective optical path lengths of greater than 10 meters. Measures of a-aw by in-situ and bench spectrophotometers are limited by path lengths of 25 cm (accuracy is +/-0.005/m) and 10 cm (accuracy +/-0.0465/m). Optical measurements were collected near Lee Stocking Island, Bahamas during the Coastal Benthic Optical Properties experiment. Values of a-aw were determined using 3 Rrs inversion algorithms, 3 Kd inversion algorithms, an in-situ spectrophotometer, and a laboratory spectrophotometer. Only a-aw values at 440 nm were compared since not all the techniques were hyperspectral, and the signal-to-noise ratio was highest at this wavelength. Treating the average of all techniques as the "standard" provides absolute percent differences of less than 18% for all except for spectrophotometric methods. The average a-aw values determined by Rrs differed by less than 6% from the average determined by the Kd methods for values ranging down to 0.01/m. The 18% difference requires measurements with resolutions of better than 0.0018/m, significantly greater than the spectrophotometric methods allow. The lowest absolute percent differences from the mean were obtained by the MODIS Rrs (9.5%) and the Kd optimization (13.3%) methods. All approaches have different noise sources (e.g. wave focusing, sun glint, variable cloudiness, scattering corrections), and the use of three different approaches helps to minimize errors associated with any one method at a given station. sources of errors are discussed in this paper with suggested areas for improvements to particular methods.

C. A paper entitled ‘USE OF UNMANNED UNDERWATER VEHICLES TO DETERMINE THE SPATIAL DISTRIBUTION OF REFLECTANCE AND OPTICAL PROPERTIES’ by David C. English, Weilin Hou, and David K. Costello was accepted for presentation at the Ocean Optics conference in New Mexico on November 2002.

Remote sensing from aircraft or spacecraft allows synoptic observation and monitoring of large areas of sea surface. An accurate atmospheric correction process is necessary for accurate interpretation of remote sensing data, and vicarious calibration is helpful in assessing the validity of the atmospheric correction. These validation measurements of water column or bottom properties must be made upon or within the water column. Use of an Unmanned Underwater Vehicle (UUV) as a platform for measuring the in-water light field reduces the effects of ship shading and allows many small spatial-scale measurements to be made over an area several hundred meters in size. During three field exercises (1998-2000) at Lee Stocking Island, Bahamas, measurements of hyperspectral downwelling irradiance and upwelling radiance, water depth, chlorophyll fluorometry, and 6 spectral-channel video from a downward viewing camera, were collected from several UUVs operated by Florida Atlantic University and the University of South Florida. Data from UUV deployments in May 2000 show the spatial variation of remote sensing reflectance and near-surface optical properties 1) along a 600-meter transect through waters of 15 to 23 m depth and 2) over a sand and coral reef bottom. Combining hyperspectral light-field measurements with knowledge of the UUV's position in the water column allows an estimation of bottom albedo. The continuous spectral video allows interpolation of the periodic hyperspectral upwelling-radiance data to spatial scales of about a meter. The resulting UUV spatial resolution would allow comparison of water depths, upwelling radiances, bottom albedos, and water column optical properties to airborne radiometric imagery.

d. A paper entitled 'USING SEAWIFS IMAGERY AND OPTICAL PROPERTY MEASUREMENTS TO INVESTIGATE THE BAHAMA BANKS AS A SOURCE OF GELBSTOFF TO THE SURROUNDING DEEP OCEAN' by Daniel B. Otis(presenter), Kendall L. Carder, David C. English, James E. Ivey, Jennifer Patch, F. Robert Chen, and Hari Warrior was accepted for presentation at the Ocean Optics conference in New Mexico on November 2002.

Optical property measurements were made on the Great Bahama Bank adjacent to Lee Stocking Island and offshore in Exuma Sound during the CoBOP field experiments of 1999 and 2000. A comparison of these two regions shows that the Bahama Banks are an important source of CDOM, or gelbstoff to the nearby deep ocean. Mean values of absorption due to gelbstoff at 440nm were around 0.03 per meter on the banks and around 0.01 per meter offshore. Ratios of dissolved to particulate absorption at 440nm were found to range from around 0.75 to 2.75, indicating that the study area is not a Morel Case 1 environment, but is instead Case 2, as dominated by gelbstoff. Evidence of plumes rich in color advected off the banks and into the surface waters of Exuma Sound was found using SeaWiFS imagery. Depth profiles of salinity and inherent optical properties provide evidence of both surface and subsurface plumes of saline, gelbstoff-rich water originating on the banks and flowing into Exuma Sound. The influence of solar heating and especially nocturnal evaporative cooling on the shallow banks can account for both warmer surface plumes, and cooler, denser plumes which sink to depth. Both surface plumes and those that sink to depth represent the export of dissolved organic matter, and therefore carbon, into the deep ocean. This environment differs from many coastal regions in that the source of gelbstoff is not freshwater runoff, but is instead the primary production associated with sediments, seagrass beds, and coral reefs located on the shallow banks.

e. A paper entitled 'MEASUREMENT AND INTERPRETATION OF DIFFUSE ATTENUATION AND REFLECTANCE IN CLEAR, DEEP-WATER ENVIRONMENTS: THE EFFECTS OF TRANS-SPECTRAL PHENOMENA' by David K. Costello, Kendall L. Carder, James Ivey, David C. English, Thomas G. Peacock, and Weilin Hou was accepted for presentation at the Ocean Optics conference in New Mexico on November 2002.

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^{nd} 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 Angstrum 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 ‘Coastal Bottom Feature Classification Using 2-D and 3-D Moment Invariants’ by Weilin Hou, Kendall L. Carder, D. K. Costello was accepted for presentation at the Ocean Optics conference in New Mexico in November 2002.

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.

g. A paper entitled ‘Compression of Autonomous Hyperspectral Data’ by Robert G. Steward and Kendall L. Carder was accepted for presentation at the Ocean Optics conference in New Mexico in November 2002.

Collection of hyperspectral data from satellites, remote towers and buoys, autonomous underwater vehicles and aircraft requires a high bandwidth communications link and/or large capacity data storage . The former requirement is especially important to make near-realtime data useful to resource managers and law enforcement, as well as scientists conducting experiments and modeling. The inherent size of hyperspectral data sets can easily overwhelm communications links such as GOES and line-of-sight radios. One method of improving the data transmission efficiency is data compression. While complex data compression algorithms may be implemented if sufficient computing power is available, a typical autonomous platform will usually be controlled by an 8 or 16-bit microprocessor with limited program memory. Several data compression techniques that are suitable for embedded controllers have been evaluated with representative hyperspectral data from an autonomous platform. A technique that applies a fifth order polynomial fit to the normalized data has been developed that gives compression rates of up to 98% for hyperspectral irradiance with an RMS error of less than 2%. The technique is relatively simple to program and execute in embedded controllers as compared to more powerful compression algorithms such as those base on wavelets and principle component analysis.

h. A paper entitled ‘Performance of MODIS Semi-Analytic Ocean Color Algorithms: Chlorophyll *a*, Absorption Coefficients, and Absorbed Radiation by Phytoplankton’ by K. Carder, F. R. Chen, J. Cannizzaro, and J. Campbell was accepted for presentation at the Ocean Optics conference in New Mexico in November 2002.

The MODIS semi-analytic (SA) algorithm calculates the spectral absorption properties of surface waters, splitting them into those associated with phytoplankton, $a_\varphi(\lambda)$, colored dissolved organic matter or gelbstoff, $a_g(\lambda)$, and water, $a_w(\lambda)$. Total absorption is necessary for calculating the light absorbed with depth for heat budget models. $a_\varphi(\lambda)$ is absorption primarily due to pigments and when combined with the instantaneous photosynthetically available radiation (IPAR) can provide the absorbed radiation by phytoplankton (ARP) from the top attenuation depth at 678nm. Dividing the fluorescence line height by ARP provides the quantum fluorescence efficiency. For the Arabian Sea, fluorescence efficiency values in December 2000 ranged from about 0.25% to more than 5%, within the range of expected values. $a_\varphi(675)$ is used to derive the concentration of chlorophyll *a*, chlor_a_3. The SA algorithm is designed to respond to variable ratios of $a_\varphi(\lambda)$ to $a_g(\lambda)$ and to wide ranges in the chlorophyll-specific absorption coefficients for a given chlorophyll level. MODIS also uses an empirical algorithm, chlor_a_2, to mimic the performance of the SeaWiFS OC-4 chlorophyll *a* algorithm, providing continuity of chlorophyll estimates beyond the life expectancy of SeaWiFS. Both the chlor_a_3 and chlor_a_2 algorithms provide nearly identical modal chlorophyll values for the northern (0.087 mg m^{-3}) and southern (0.078 mg m^{-3}) central gyres in December 2000. However, the global mean value for chlor_a_3 is higher (0.294 mg m^{-3}) than for chlor_a_2 (0.231 mg m^{-3}). This difference can be explained by the Southern Ocean where chlor_a_2 and OC-4 values are on average about half of field and chlor_a_3 values due to lower chlorophyll-specific absorption coefficients typical of this region. This causes global primary production models based on ocean chlorophyll fields to provide 20-30% larger estimates in December when using chlor_a_3 retrievals than when using chlor_a_2 or OC-4 retrievals. The chlor_a_2 and OC-4 algorithms, however, in the future can be adjusted to fit high latitude chlorophyll data using sea surface temperatures in a manner analogous to that used by chlor_a_3.

i. A paper entitled 'A MODULAR, HYBRID METHOD FOR SOLVING THE RADIATIVE TRANSFER EQUATION WITH ARBITRARY GEOMETRY IN 1, 2, OR 3 DIMENSIONS' by Phillip N. Reinersman, and Kendall L. Carder was accepted for presentation at the Ocean Optics conference in New Mexico in November 2002.

Monte Carlo (MC) methods are currently the only means of solution of the Radiative Transfer Equation (RTE) in 2 or 3 dimensional regions with arbitrary geometries. While capable of achieving solutions of the RTE to great accuracy, MC methods are time consuming and generally provide the desired quantities at only one or a few locations in the modeled environment. We are developing a solution method conceptually similar to Finite Element Methods in which the modeled environment is partitioned into contiguous elements. The optical response function for each element is determined by MC methods. Optical sources are applied to the boundary and/or interior of the modeled environment and the array of elements is iteratively relaxed to convergence. Once converged, the radiance distribution is known through out the modeled environment. Light fields for scenes with variable bathymetry, bottom features, and suspended, submerged objects will be discussed.

j. A paper entitled 'AN IMPROVED OPTICAL MODEL FOR HEAT AND SALT BUDGET ESTIMATION FOR SHALLOW WATERS: THE BAHAMAS BANKS' by Hari Warrior was submitted to Ocean Optics conference in New Mexico in November 2002 for presentation.

The total radiation from the sun can be divided into short-wave and long-wave components. The long-wave radiation that reaches the sea surface is absorbed completely in the top meter or two of the water column whereas short-wave radiation penetrates the ocean waters and influences the heat budget of the water column. Previous models of the attenuation of radiation components in deep water have been developed, but coupling of models effectively with satellite retrievals of optical properties for shallow waters is needed. Most of the light models used by even the most accepted ocean models such as the Princeton Ocean Model (POM) produce quite erroneous results for shallow waters because they over-simplify the effect of bottom absorption and reflection. This affects the accuracy of water properties like increased salinity of shallow waters leading to the production of thermohaline plumes off the shallow banks. It also has an effect on the water vapor budget of the atmosphere above these waters leading to implications in local weather dynamics and rainfall. A model of the Bahamas near Andros Island provides sharp thermal gradients that depend on water depth and bottom albedo. We have chosen to use for local short-term simulations, a modified 1-dimensional ocean model called the General Ocean Turbulence Model (GOTM) similar to the POM. 60-hour simulations were made starting from 0600 hours on 15 April 2001 with temperature of 26.5°C. Actual meteorological data were used for cases with coral sand bottom, sea-grass bottom and no bottom. Temperatures increased over time by up to 1.5°C over shallow coral sand bottoms. On the other hand, over sea grass bottoms, temperature increased up to 3.0°C, reaching about 29.5°C. A comparison with AVHRR images taken for April 2001 demonstrates the validity of our optical modification of GOTM and clearly demonstrates the warm pools of shallow water on the Bahamas banks.

k. A paper entitled 'ILLUMINATION AND TURBIDITY EFFECTS ON OBSERVING FACETED BOTTOM ELEMENTS WITH UNIFORM LAMBERTIAN ALBEDOS' by Kendall L. Carder, Cheng-Chien Liu, Zhongping Lee, David C. English, James Patten, F. Robert Chen, James E. Ivey, and Curtiss O. Davis was accepted for presentation at the Ocean Optics conference in New Mexico in November 2002.

PHILLS aircraft images with 1.2-m resolu-tion were collected near Lee Stocking Island (LSI), Bahamas and exhibited wave-like features for bright sand bottoms during times when solar zenith angles were large. The image contrast between leading and trailing wave facets approached a 10-15% difference due to algae accumulations in wave troughs or topographic variations of the bottom. Reflectance contrast for blue light was greater than for red and green wavelengths when algae or detritus was present in the troughs. However, the contrast at green and red wavelengths was greater than at blue wavelengths when caused by the interplay between bottom topography and oblique illumination. A three-dimensional Backwards Monte Carlo (BMC) model was developed to evaluate the effect of oblique illumination on wave-like topographic features for various values of water clarity and bottom albedo. An inverse optical modeling approach, previously developed for flat, horizontally homogeneous bottoms, was applied to the BMC results. Bathymetric estimates for bright facets tilted 10° toward the sun were slightly smaller than actual depths, while shaded-facet depth estimates were too high by about 5%. Larger errors were associated with albedo retrievals, where shaded facets produced albedo estimates up to 15% lower than actual values. Errors increased with tilt angles up to 20° but decreased with sea and sky turbidity. Averaging sun-lit and shaded pixels before running the inverse model reduced the uncertainty of bathymetric and albedo estimates due to sand-wave topography to about 2% and 5%, respectively. Based on model results, much of the wave-like variability observed in the PHILLS imagery is consistent with sand waves observed with oblique lighting with wave crests normal to the solar principal plane. Sand waves up to 80-cm in height and 15-m in length were measured by the Real-time Ocean Bottom Optical Topographer (ROBOT).

3. Peer-reviewed Publications

a. A paper entitled “Fast and Accurate Model of Underwater Scale Irradiance” by Cheng-Chien Liu, Kendall. L. Carder, Richard Miller and James E. Ivey is accepted for publishing in *Applies Optics,* Vol 41, No. 24, 20 Aug. 2002.

A spectral model of scalar irradiance with depth is applied to calculations of photosynthetically available radiation for a vertically homogeneous water column. It runs more than fourteen thousand times faster than the full Hydrolight code, while it limits the percentage error to 2.20% and maximum error to less than 4.78%. The distribution of incident sky radiance and the effects of a wind-roughened surface are integrated into the model. It can be applied to case 1 waters as well as case 2 waters that happen to be gelbstoff rich, and the volume-scattering phase function can be generated dynamically based on the backscatter function. This new model is both fast and accurate and is, therefore, suitable for use interactively in models of the oceanic system, such as biogeochemical models or the heat budget part of global circulation models. It can also be applied by use of remote-sensing data to improve light-field calculations as a function of depth, which is needed for the estimation of global ocean carbon production and the ocean heat budget.

b. A paper entitled “Solar-reflectance-based calibration of spectral radiometers” by Christopher Cattrall, Kendall L. Carder, Kurtis J. Thome and Howard R. Gordon has been accepted by Geophysical Research Letters for publication**.**

A method by which to calibrate a spectral radiometer using the sun as the illumination source is discussed. Solar-based calibrations eliminate several uncertainties associated with applying a lamp-based calibration to field measurements. The procedure requires only a calibrated reflectance panel, relatively low aerosol optical depth, and measurements of atmospheric transmittance. Further, a solar-*reflectance*-based calibration (SRBC), by eliminating the need for extraterrestrial irradiance spectra, reduces calibration uncertainty to approximately 2.2% across the solar-reflective spectrum, significantly reducing uncertainty in measurements used to deduce the optical properties of a system illuminated by the sun (e.g., sky radiance). The procedure is very suitable for on-site calibration of long-term field instruments, thereby reducing the logistics and costs associated with transporting a radiometer to a calibration facility.

c. A paper entitled “Columnar aerosol single-scattering albedo and phase function retrieved from sky radiance over the ocean: Measurements of African dust” by Christopher Cattrall, Kendall L. Carder, and Howard R. Gordon has been accepted with revision by Journal of Geophysical Research for publication.

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 (±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.

d. A paper entitled "Illumination and turbidity effects on observing faceted bottom elements with uniform Lambertian albedos' by Kendall L. Carder, Cheng-Chien Liu, Zhongping Lee, David C. English, James Patten, F. Robert Chen, James E. Ivey, and Curtiss O. Davis was Accepted by Limnology and Oceanography for publication.

Aircraft images were collected near Lee Stocking Island (LSI), Bahamas with wave-like features for bright sand bottoms during times when solar zenith angles were large. The image contrast between leading and trailing wave facets approached a 10-15% difference due to algae accumulations in wave troughs or topographic variations of the bottom. Reflectance contrast for blue light was greater than for red and green wavelengths when algae or detritus is present in the troughs. However, the contrast at green and red wavelengths was greater than at blue wavelengths when caused by the interplay between bottom topography and oblique illumination. A three-dimensional Backwards Monte Carlo (BMC) model was developed to evaluate the effect of oblique illumination on wave-like topographic features for various values of water clarity and bottom albedo. An inverse optical modeling approach, previously developed for flat, horizontally homogeneous bottoms, was applied to the BMC results. Bathymetric estimates for bright facets tilted 10° toward the sun were slightly smaller than actual depths, while shaded-facet depth estimates were too high by about 5%. Larger errors were associated with albedo retrievals, where shaded facets produced albedo estimates up to 15% lower than actual values. Errors increased with tilt angles up to 20° but decreased with sea and sky turbidity. Averaging sun-lit and shaded pixels before running the inverse model reduced the uncertainty of bathymetric and albedo estimates to about 2% and 5%, respectively, comparable to previous field evaluations of the inversion model.

e. A paper entitled 'Deriving inherent optical properties from water color: A multi-band quasi-analytical algorithm for optically deep waters' by ZhongPing Lee, Kendall L. Carder, Robert A. Arnone was accepted for publication in Applied Optics.

For open-ocean and coastal waters, a multi-band quasi-analytical algorithm is developed to retrieve absorption and backscattering coefficients, as well as absorption coefficients of phytoplankton pigments and gelbstoff. This algorithm is based on remote-sensing reflectance models derived from the Radiative Transfer Equation, and values of total absorption and backscattering coefficients are analytically calculated from values of remote-sensing reflectance. In the calculation of total absorption coefficient, no spectral models for pigment and gelbstoff absorption coefficients are used. Actually those absorption coefficients are spectrally decomposed from the derived total absorption coefficient in a separate calculation. The algorithm is easy to understand and simple to implement. It can be applied to data from past and current satellite sensors, as well as data from hyperspectral sensors. The algorithm is applied to simulated data and field data, both non-"Case 1", to test its performance. The results are quite promising: ~8% errors for total absorption and total scattering coefficients, with twice that error for turbid waters. More tests with field data are planned to validate and improve this algorithm.