

The Ecological Cycling of Colored Dissolved Organic Matter

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LONG-TERM GOALS

The prediction of water-leaving radiance in coastal waters is strongly dependent on a quantitative prediction of the depth-dependent distribution of Colored Dissolved Organic Matter (CDOM) in the water column. The goal of this project is to support and synthesize laboratory and field experiments conducted by the ONR Environmental Optics Program. Our part of this larger project is to develop a quantitative understanding of the physical, chemical, optical, and biological interactions impacting CDOM cycling, and to codify this understanding into a numerical simulation, EcoSim 2.0.

OBJECTIVES

- 1) Provide satellite image analysis and meteorological support for ONR CDOM cruises.
- 2) Provide quantitative data synthesis support for chemical, biological, and physical interactions of CDOM data.
- 3) Develop ecological equations for CDOM cycling in the coastal marine environment.

APPROACH

We hypothesize that CDOM cycling is a deterministic process, one that can be explained by physical, chemical, and biological interactions. Furthermore, coupling experimental data with environmental modeling will lead to the development of a set of ecological equations that will resolve the sources and sinks of CDOM, and the impacts on water column IOPs and AOPs. A previous one-dimensional numerical simulation of the bio-optical properties of the Sargasso Sea (Ecological Simulation 1.0 (EcoSim 1.0) Bissett et al., 1999a; Bissett et al., 1999b) suggested that the cycling of CDOM could be mathematically described and validated. In this case, the EcoSim 1.0 results were validated against the multi-year bio-optical time series program operating at the Bermuda Atlantic Time-series Station (BATS Siegel and Michaels, 1996; Siegel et al., 1995). In particular, simulated CDOM did not covary with the particulate organic absorption or the chlorophyll a concentration, as was previously assumed in these oligotrophic environments (Gordon et al., 1983; Smith, 1981).

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14. ABSTRACT The prediction of water-leaving radiance in coastal waters is strongly dependent on a quantitative prediction of the depth-dependent distribution of Colored Dissolved Organic Matter (CDOM) in the water column. The goal of this project is to support and synthesize laboratory and field experiments conducted by the ONR Environmental Optics Program. Our part of this larger project is to develop a quantitative understanding of the physical, chemical, optical, and biological interactions impacting CDOM cycling, and to codify this understanding into a numerical simulation, EcoSim 2.0.			
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Separation of the CDOM signal from the particulate signal in oligotrophic regions is important for understanding the propagation of light to depth, and its impact on water-leaving radiance signals used in satellite oceanography. These regions cover approximately 80% of the world's oceans. However, the CDOM signal can be 1-3 orders of magnitude higher on coastal shelves and near-shore regions. These higher signals result in part from the higher primary productivity found in coastal regions, but also result from the loading of CDOM from the outflows of rivers and estuaries. Prediction of in-water Inherent Optical Properties (IOPs) and the resultant water-leaving radiance (L_w) would require that we accurately address the ecological cycling of CDOM, i.e. the chemical, photochemical, biological, and physical sources and sinks of CDOM in the near-shore region.

WORK COMPLETED

The FY2001 work demonstrated the relative importance of the shoreward boundary conditions to simulating the near-shore IOPs on the WFS, and in particular the CDOM component of the absorption. In FY2003, the boundary condition was fully described by requesting data from a number of state and federal agencies and creating an ArcGIS database for geospatial analysis. This database was generated for west Florida and includes nutrient, phytoplankton, and physical parameters and accomplished in collaboration with the efforts of N00014-01-1-0456. Local and state agencies were contacted to obtain this information and include: USGS, City of Cape Coral, South Florida Water Management District (SFWMD), Florida International University (FIU)/South Florida Water Management District (SFWMD)/Southeast Environmental Research, Southwest Florida Water Management District (SWFWMD), ECOHAB, and US Army Corps of Engineers (USACOE). Nutrient data collected includes: NO_3 , NO_2 , NH_4 , NO_2+NO_3 , DIN, TON, Kjeldhal Nitrogen, TN, PO_4 , OPO_4 and Si. Physical parameters where available include: salinity, depth, discharge, longitude, latitude, agency, date, time, temperature ($^{\circ}\text{C}$) and pH. Chlorophyll concentrations and phaeo-pigment concentrations were also included where available. Absorption, attenuation, and backscatter measurements were also incorporated for select station locations. The total number of stations included in the database as of September 18, 2003 was 231 with a total of 27,475 data points. Below is a map that displays all of the current station locations (Figure 1).

This database was used to set boundary conditions for 1998 and to drive a 2-D simulation of the changes in IOPs on the WFS. This model for the simulation (EcoSim 2.0) used equations for the time-dependent change in stocks of CDOM via autochthonous and allochthonous sources and sinks. The simulation demonstrated the need to include the shoreward boundary condition to adequately understand the near-shore IOP distributions, as well as resolve the satellite estimated stocks of color on the WFS. These results were submitted for publication in a CDOM special issue of Marine Chemistry (Bissett et al., 2003).

Lastly, the sources and sink equations for CDOM were incorporated into the latest version of EcoSim 2.0, which is being distributed as open source code in the ROMS 2.0 distribution set.

RESULTS

The impact of the terrestrial CDOM boundary conditions during the fall of 1998 may be seen in the difference between the SeaWiFS estimated absorption, chlorophyll, and scattering (Figures 2 and 3). During the summer, there is very little terrestrial influence input of CDOM and the riverine input into the region is very low (Figure 4). However, after Tropical Storm Mitch moves through the Charlotte Harbor region of the WFS, there is a dramatic rise in the color associated with CDOM, which is

associated with the increase discharge from the Peace and Caloosahatchee Rivers. These different conditions are simulated on the WFS via the addition of a terrestrial boundary condition to the simulation. Figure 5 shows the difference in the predicted $a_{dg}(412)$ and that estimated from SeaWiFS.

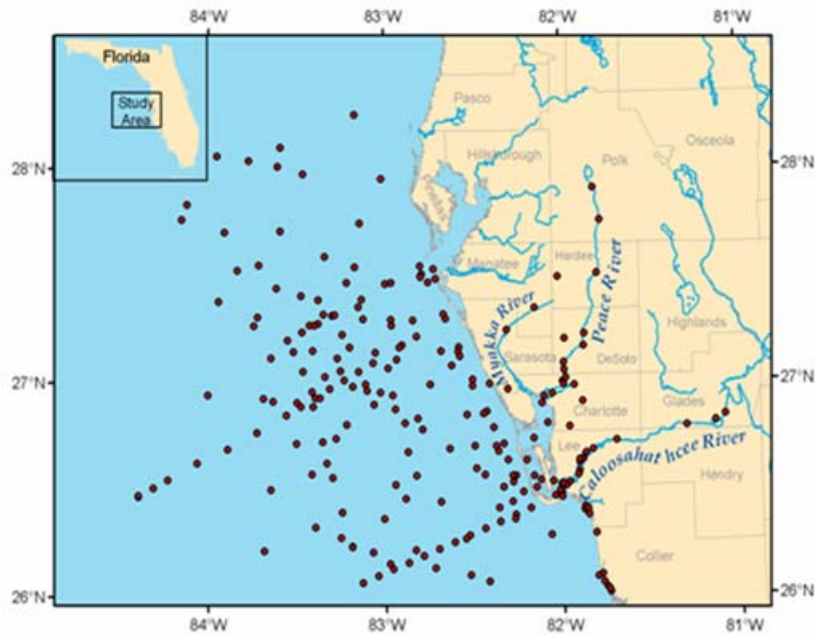


Figure 1. The West Florida Shelf GIS database of nutrient, phytoplankton, physical and optical parameters. Local and state agencies were contacted to obtain this information and include: USGS, City of Cape Coral, South Florida Water Management District (SFWMD), Florida International University (FIU)/South Florida Water Management District (SFWMD)/Southeast Environmental Research, Southwest Florida Water Management District (SWFWMD), ECOHAB, and US Army Corps of Engineers (USACOE).

The simulation was run in two separate modes. The first mode, Case 1, did not have any terrestrial influxes at the boundary. The second mode, Case 2, included the terrestrial boundary condition as pulse events on Day-of-Year 267 and 309, corresponding to the passage of Hurricane Georges and TS Mitch. During June, the boundary condition effects appear to only occur within the 10 km of our simulation domain, as the errors in the simulation diverge most significantly in this range (Figure 5a). The November 1st image and simulation results show the impacts of Mitch and clearly demonstrate the need to include the shoreward boundary condition in order to achieve a reasonable comparison to the SeaWiFS data (Figure 5b).

There were some significant difference between the satellite data and the simulated data, driven in part by the physical circulation differences between a 2-D simulation and the 3-D baroclinic circulation patterns on the WFS, as well as the lack of continued shoreward pulsing of terrestrial material after Day-of-Year 309. Figure 6 shows the SeaWiFS estimate from December and it is clearly evident that the continuation of flows after the beginning of November impact the shelf. In addition, the CDOM appears to have been southwest of our domain. The net effect of the inaccurate physics and boundary

condition description are evident in the errors from the simulation, where offshore errors are greater than the average observations, and onshore errors are less than observation (Figure 5c).

A complete description of the simulation results and the analysis of the errors may be found in a preprint of the submitted manuscript Bissett et al. (2003), which may be found at <http://www.flenvironmental.org> under Publications.

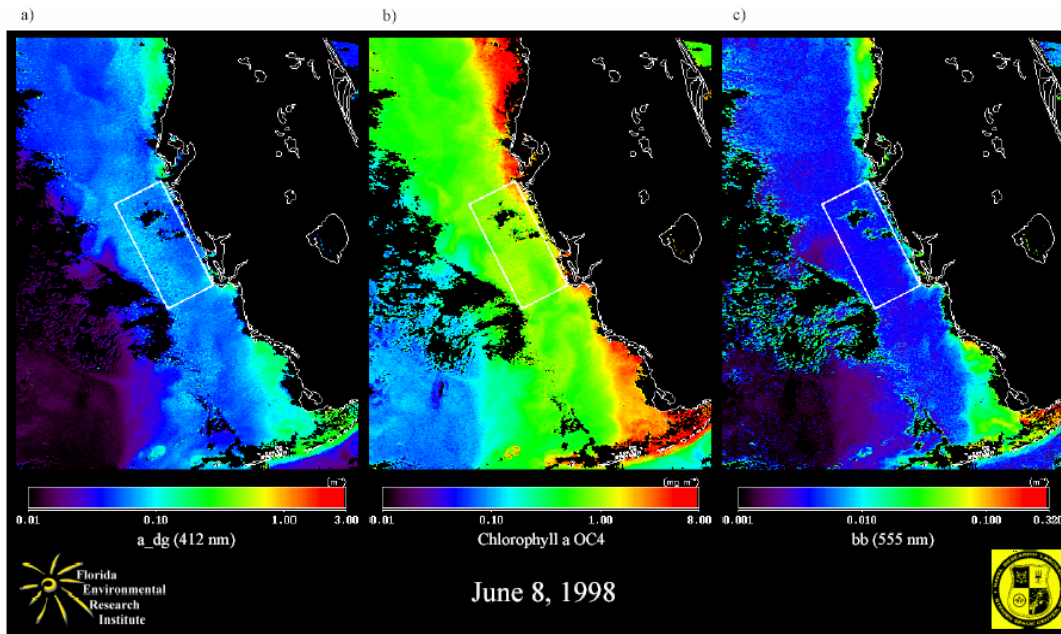


Figure 2. The West Florida Shelf, June 8, 1998. SeaWiFS estimated (a) absorption at 412m, $a_{dg}(412)$; (b) chlorophyll a (OC4 algorithm), and (c) backscattering at 555 nm, $b_b(555)$. The model domain is shown as the white box on each of the images. The SeaWiFS line plots on Figure 5 are derived by dividing the domain into 30 equally spaced lines and averaging them to create a statistically significant data set to compare against the 2-D simulation results. (a), (b) and (c) show that there is little influence from local terrestrial CDOM sources in the model domain, with the possible exception near the Charlotte Harbor region, located at the southwest corner of the model domain.

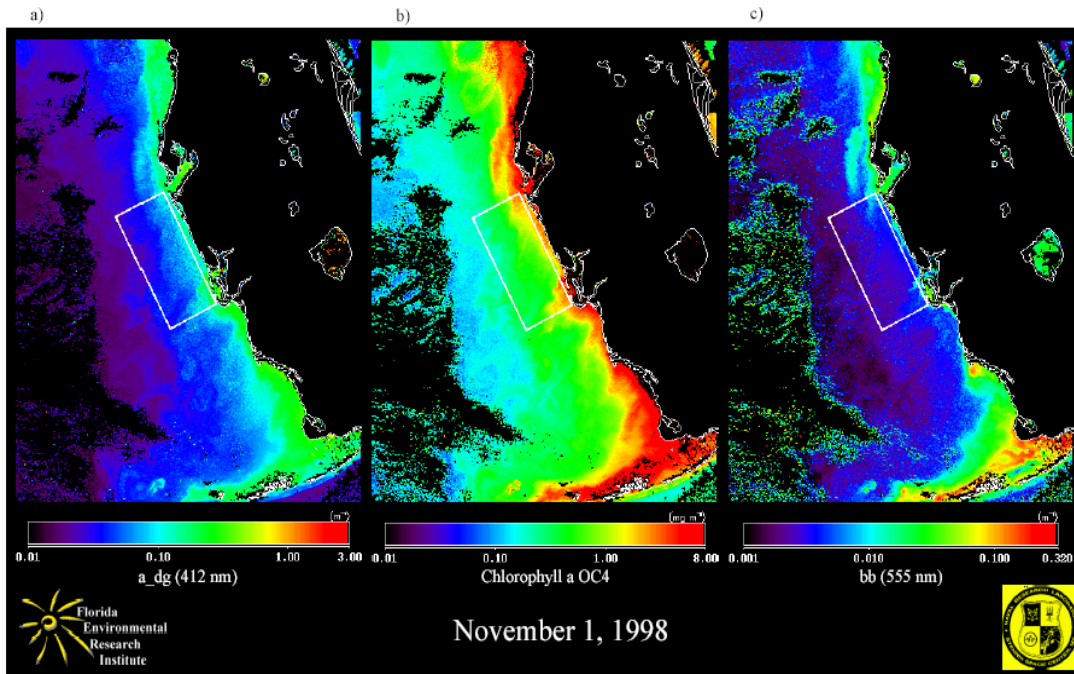


Figure 3. *The West Florida Shelf, November 1, 1998. SeaWiFS estimated (a) absorption at 412m, $a_{dg}(412)$; (b) chlorophyll a (OC4 algorithm), and (c) backscattering at 555 nm, $b_b(555)$. The model domain is shown as the white box on each of the images. The SeaWiFS line plots on Figure 5 are derived by dividing the domain into 30 equally spaced lines and averaging them to create a statistically significant data set to compare against the 2-D simulation results. (a), (b) and (c) show increased terrestrial impacts from CDOM sources in the model domain following Hurricane Georges.*

Total Nitrogen from the Peace River as Compared to Discharge from the Peace and Caloosahatchee Rivers in 1998

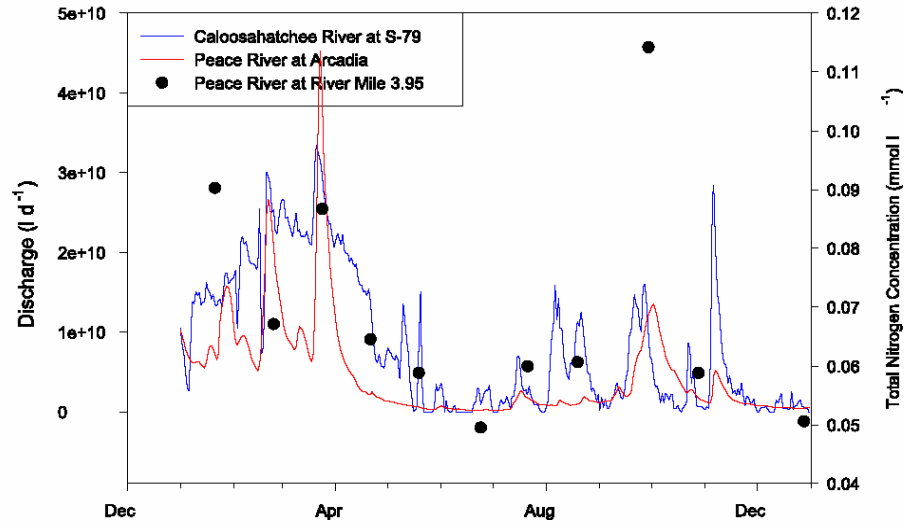


Figure 4. Fresh water flows through the head of the Peace River and Caloosatchee Estuary (lower Charlotte Harbor). The peak on November 6, 1998 of $2.84E+10Ld^{-1}$ results from TS Mitch and is mirrored by elevated flows from the Peace River in the upper Charlotte Harbor. The elevated flows continue (at decreasing rates) until December. The model only simulates pulse conditions at the peak of the flows in September and November. This inaccuracy in the boundary conditions add to the model errors seen in Figure 5 and 6.

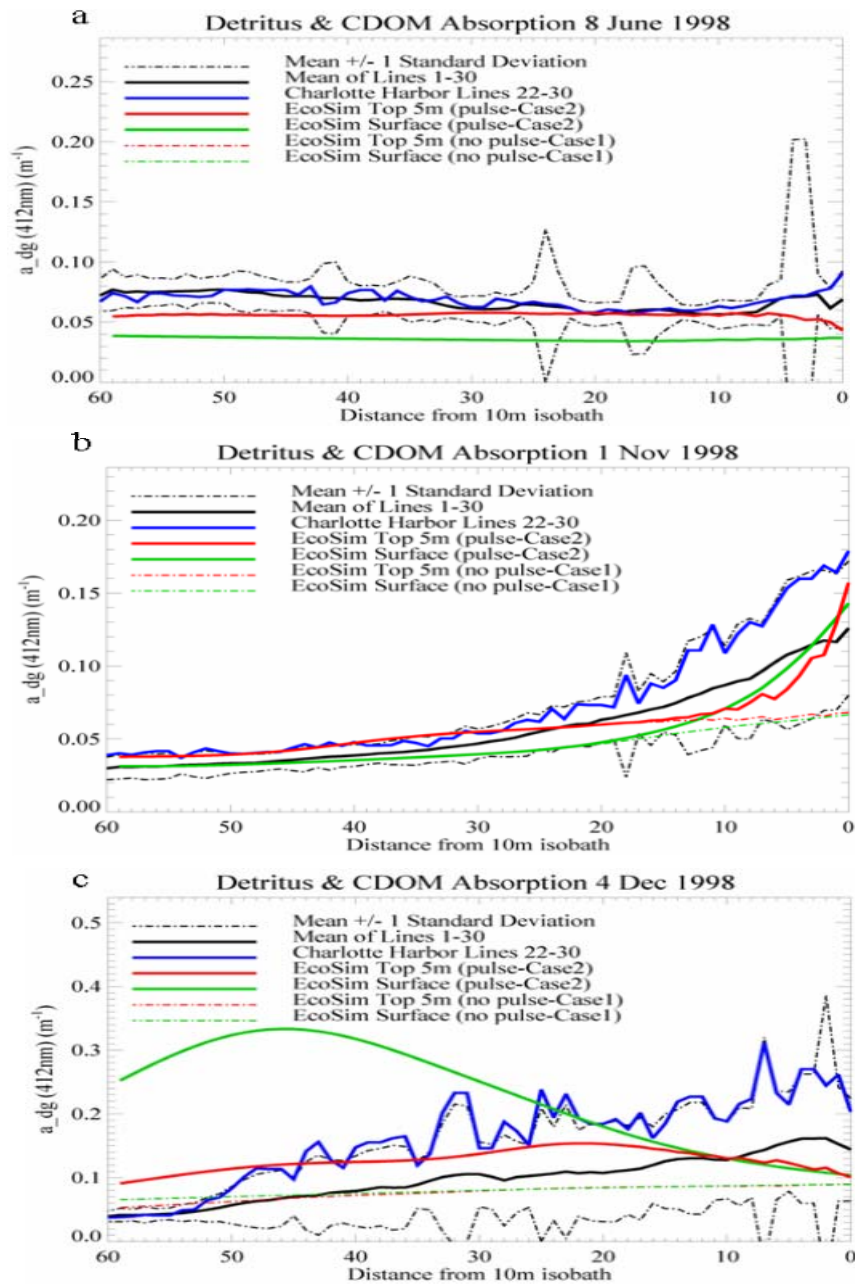


Figure 5: Simulated versus SeaWiFS CDOM absorption. (a) June 8, 1998, (b) November 1, 1998, and (c) December 4, 1998. The simulated absorption values are within 1 standard deviation of the average values across the shelf on June 8th (Figure 2) and November 1st (Figure 3). However, the December 4th comparisons shown significant differences resulting from the inability to accurately represent the baroclinic circulation with a 2-D physical circulation model, and the inaccurate description of the shoreward boundary condition during November 1998 (Figure 4).

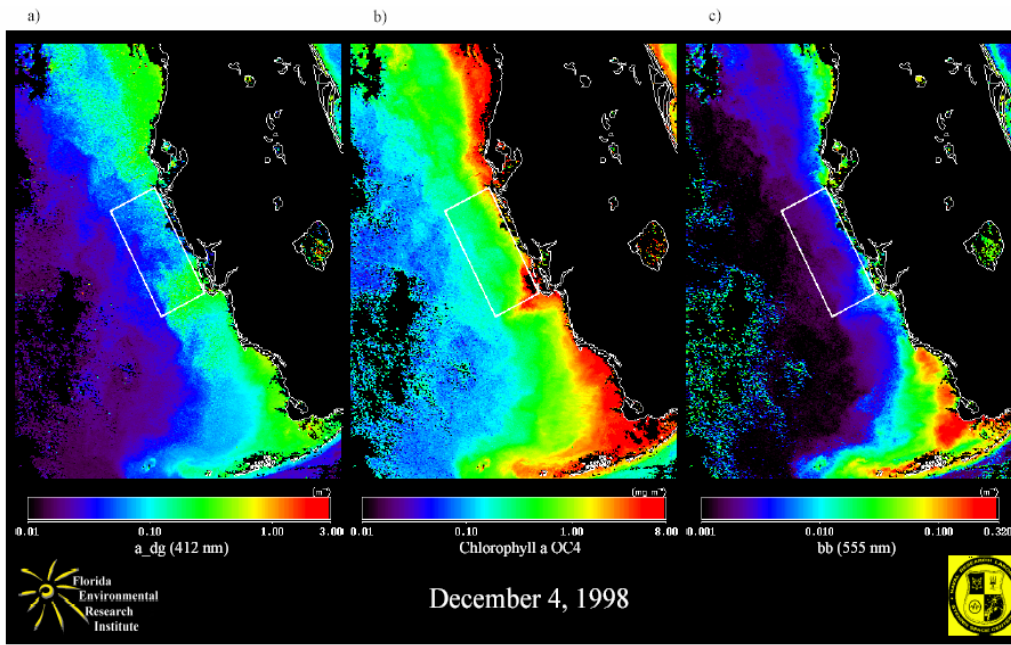


Figure 6. The West Florida Shelf, December 4, 1998. SeaWiFS estimated (a) absorption at 412m, $a_{dg}(412)$; (b) chlorophyll a (OC4 algorithm), and (c) backscattering at 555 nm, $b_b(555)$. The model domain is shown as the white box on each of the images. The SeaWiFS line plots on Figure 5 are derived by dividing the domain into 30 equally spaced lines and averaging them to create a statistically significant data set to compare against the 2-D simulation results. (a), (b) and (c) show greater terrestrial impacts from CDOM sources in the model domain following TS Mitch. The large extent of the CDOM impact is driven from the continued releases of fresh water from the West Coast of Florida (see Figure 4). The baroclinic circulation drives much of this material southeast of the study region.

IMPACT/APPLICATIONS

To forecast the clarity of the water column over both short- and long-term time horizons requires an accurate quantification of the ecological cycling of CDOM. Incorporation of a validated set of CDOM equations into a larger three-dimensional ecological simulation will increase the veracity of the predictions of Inherent and Apparent Optical Properties (IOPs and AOPs), and help achieve the goal of forecasting optical properties as a function of the biological, chemical, and physical forcing.

TRANSITIONS

The ES2 code has been open-sourced and is part of the distributed ROMS code (<http://marine.rutgers.edu/po/models/roms/index.php>). The development of this physical model and its transition to the Terrain-following Ocean Modeling System (TOMS) is also being supported by ONR.

RELATED PROJECTS

1) Mary Ann Moran (U of Georgia) and Richard Zepp (EPA) are conducting laboratory and field measurements on the photolysis of CDOM, as well as the bacterial utilization of in situ and photodegraded CDOM.

2) William Miller (Dalhousie, CA) is conducting experiments on the photolysis of CDOM as a function of the spectral distribution of irradiance.

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HONORS/AWARDS/PRIZES

2003 Small Business of the Year, Semi-Finalist, Florida Environmental Research Institute, W. Paul Bissett, Ph.D., Executive Director, Greater Tampa Chamber of Commerce.