Chapter 14

Bermuda Bio Optics Project

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14.1 INTRODUCTION

The Bermuda BioOptics Project (BBOP) is a collaborative effort between the Institute for Computational Earth System Science (ICESS) at the University of California at Santa Barbara (UCSB) and the Bermuda Biological Station for Research (BBSR). This research program is designed to characterize light availability and utilization in the Sargasso Sea, and to provide an optical link by which biogeochemical observations may be used to evaluate bio-optical models for pigment concentration, primary production, and sinking particle fluxes from satellite-based ocean color sensors. The BBOP time-series was initiated in 1992, and is carried out in conjunction with the U.S. JGOFS Bermuda Atlantic Time-series Study (BATS) at the Bermuda Biological Station for Research. The BATS program itself has been observing biogeochemical processes (primary productivity, particle flux and elemental cycles) in the mesotrophic waters of the Sargasso Sea since 1988. Closely affiliated with BBOP and BATS is a separate NASA-funded study of the spatial variability of biogeochemical processes in the Sargasso Sea using high-resolution AVHRR and SeaWiFS data collected at Bermuda (N. Nelson, P.I.). The collaboration between BATS and BBOP measurements has resulted in a unique data set that addresses not only the SIMBIOS goals but also the broader issues of important factors controlling the carbon cycle.

14.2 RESEARCH ACTIVITIES

BBOP personnel participate on all BATS cruises, which are conducted monthly with additional cruises during the spring bloom period, January through May. Table 1 contains a list of data products relevant to SIMBIOS. The BBOP project collects continuous profiles of apparent optical properties (AOPs) in the upper 140m and deployments are planned to optimize match-ups with the BATS primary production incubations and with SeaWiFS overpasses. In 1999, a free-falling Satlantic profiling radiometer system (SPMR/SMSR s/n 028) became our primary profiling instrument. The primary optical measurements are downwelling vector irradiance and upwelling radiance, $E_d(z,t,l)$ and $L_u(z,t,l)$, respectively. Derived products include remote sensing reflectance ($R_{rs}(z,l)$) and down- and upwelled attenuation coefficients ($K_d(z,l)$, $K_u(z,l)$). The sampling package also includes a second mast-mounted radiometer with wavebands matching those on the underwater instrument for measuring incident downwelling vector irradiance, $E_d(0^+,t,l)$. The instruments are calibrated three times annually at UCSB. Sky radiance measurements were collected early in the year, but the Microtops photometer began malfunctioning and it was returned to the project in the spring of 2003.

Bottle samples for fluorometric chlorophyll-*a* and inherent optical properties (IOPs) are also collected. Chlorophyll-*a* is collected once or twice daily during each cruise. Discrete samples for determining the absorption spectra of particulates, $a_{ph}(z,l)$ and $a_d(z,l)$, and CDOM ($a_g(z,l)$) are collected according to Nelson *et al* (1998). Particulate absorption spectra are determined using the quantitative filter technique (Mitchell, 1990) (with a regionally specified beta correction factor) and CDOM absorption according to Nelson *et al* (1998). During the past year, BBOP has participated in 14 BATS cruises. We have submitted 260 optics profiles, 70 fluorometric Chlorophyll-a profiles, 150 IOP spectra, and 4 Microtops scans for sky radiance.

14.3 RESEARCH RESULTS

Instrument Calibration

We have continued our documentation of the long-term calibration behavior of our SPMR systems using several lamps traceable to our own NIST standard. Channels greater than 500nm continue to show no obvious drift, and overall scatter is ~1% and ~2% for irradiance and radiance detectors, respectively. The coefficients of variation these channels are less than 1%. In general, the radiance channels are more stable than the irradiance channels. This suggests that the fault is most likely to be the materials used in the cosine collectors. The tendency for the UV and blue channels to vary more than the red is in part due to the lower output of calibration lamps at lower wavelengths. The most extreme changes were noted at the shortest UV channels in both irradiance heads: up to 50-60% for Ed325 and Es325, and about half that for Ed340 and Es340. It appears that this decrease in sensitivity occurred during the first year, and that these sensors are now stabile, although the response is still quite variable. The additional year of data now shows that two UV radiance and the blue irradiance channels have undergone significant drift toward lower sensitivity. The drift in the blue radiance sensors was less apparent, and smaller, about 1-2%, not significantly different from variation observed in the green-red channels. All affected data for these channels was recalculated using a predicted coefficient rather than a long-term average, and resubmitted.

Collaborative and Project-Related Activities

As in past years, the BBOP data set 1) contributed to the validation of satellite data products within in the SIMBIOS project and 2) used to make original contributions to scientific literature. In particular, BBOP is among the clearest ocean sites observed within the SIMBIOS program on a consistent basis. This means that BBOP has consistently been the clear water end member in match-up analyses made between field and satellite observations. The present version (August 2003) of the SIMBIOS SeaWiFS LAC-field observation match-up data set (Bailey et al. 2000) contains 383 independent field and satellite observations of water-leaving radiance. Thirty of these observations are from the BBOP project. As always these data are available via the world wide web (www.icess.ucsb.edu/bbop.html).

A primary science result from BBOP has been the observation that the optical properties of open ocean are greatly affected by concentrations of colored dissolved organic materials or CDOM (Siegel and Michaels, 1996; Nelson et al. 1998; Nelson and Siegel, 2002; Siegel et al. 2002). We have shown that CDOM dominates the optical properties in the blue region of the spectrum using knowledge gained at BBOP and available field and satellite data sets (many field observations were supported by the SIMBIOS program). Globally, 45% of the non-water absorption at 440 nm is due to CDOM (Siegel et al. 2002). Retrieval algorithms for CDOM were developed (Maritorena et al. 2002) and used to assess its global distribution and variability (Siegel et al. 2002). We have recently shown that the open ocean source of CDOM is the heterotrophic cycling of DOM by bacteria (Nelson et al. 2003) where CDOM can be created and destroyed by microbes. The interesting result from these microbe batch culture experiments is that the net CDOM produced mirrors the “complexity” of the DOM source (i.e., high molecular weight DOM leads to more long-lasting CDOM produced). We are presently testing these hypotheses on a new project looking at open ocean CDOM cycling supported by NSF.

Our work on CDOM has lead us to consider its interactions with other photoactive materials. One interesting candidate is dimethyl sulfide (DMS). Using existing time series (Dacey et al. 1998) and new experimental data, we have calculated the rates that DMS is photolysed by exposure to ultraviolet radiation (Toole et al. 2003). Using these results and new observations of microbial DMS (and DMSP) cycling by bacteria, we have made new and important estimates of the biological cycling of DMS (Toole and Siegel, 2003). Our supports the notion that DMS is important as an intracellular anti-oxidant removing radicals and superoxides within a cell. (Sunda et al. 2002). These results have a critical bearing on how climate feedbacks due to marine emissions of DMS might occur (Toole and Siegel, 2003).

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Table 14.1: Partial List of Measurements Made by BBOP & BATS

BBOP	
Direct Measurements:	
$E_d(z,l)$	Downwelling vector irradiance (325, 340, 380, 412, 443, 488, 510, 555, 565, 665 & 683 nm)
$E_d(0^+,l)$	Incident irradiance (325, 340, 380, 412, 443, 488, 510, 555, 565, 665 & 683 nm)
$L_u(z,l)$	Upwelling radiance (325, 340, 380, 412, 443, 488, 510, 555, 565, 665 & 683 nm)
chl-fl(z)	Chlorophyll fluorescence with a WetStar fluorometer
T(z) & S(z)	Temperature and conductivity with Ocean Sensors probes (calibrations by Satlantic)
$a_{tp}(l)$	Particulate absorption spectrum by QFT
$a_d(l)$	Detrital particle absorption spectrum by MeOH extraction
$a_{ys}(l)$	Colored dissolved absorption spectrum
chl-a(z)	Discrete chlorophyll *a* determinations via Turner fluorometry
Primary Derived Products:	
$L_{wN}(l)$	Normalized water leaving radiance (325, 340, 380, 412, 443, 488, 510, 555, 565, 665 & 683 nm)
$R_{RS}(0^-,l)$	In-water remote sensing reflectance (325, 340, 380, 412, 443, 488, 510, 555, 565, 665 & 683 nm)
$K_d(z,l)$	Attenuation coefficient for $E_d(z,l)$ (325, 340, 380, 412, 443, 488, 510, 555, 565, 665 & 683 nm)
$K_l(z,l)$	Attenuation coefficient for $L_u(z,l)$ (325, 340, 380, 412, 443, 488, 510, 555, 565, 665 & 683 nm)
$a_{ph}(l)$	Phytoplankton absorption spectrum (= $a_p(l) - a_{det}(l)$)
<PAR(z)>	Daily mean photosynthetically available radiation at depths of the *in situ* C^{14} incubations

U.S. JGOFS BATS (NSF) AND RELATED BIOGEOCHEMISTRY SAMPLING PROGRAMS	
Primary Production (*in situ* ^{14}C incubation)	Sinking flux (sediment trap array)
Phytoplankton pigments (fluorometric & HPLC)	Nutrients (NO_3+NO_2, SiO_4, PO_4)
CO_2 system (alkalinity, TCO_2 and pCO_2)	Continuous atmosphere & surface pCO_2
Dissolved oxygen (continuous & discrete)	Zooplankton biomass & grazing
POC & PON (POP infrequently)	DOC & DON (DOP infrequently)
Full water column, WOCE-standard CTD profile	Bacterial abundance and rates
Validation spatial cruises (5 days, 4cruises/year)	Deep ocean sediment sinking fluxes

This Research was Supported by
the NASA Contract # 00200

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