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December 16, 2001

Dr. Steven G. Ackleson
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Dear Dr. Ackleson:

On behalf of Dr. Heidi M. Sosik and Robert J. Olson, please find enclosed a copy of the final report and the SF 298 form for ONR Grant N00014-95-1-0333 entitled "Response of Particulate Properties to Coastal Mixing Processes".

Sincerely,

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Copies: S. Ferreira, WHOI Grant & Contract Services
DTIC
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ONR, Boston

Response of Particulate Optical Properties to Coastal Mixing Processes

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Award #: N000149510333
http://www.whoi.edu/science/B/sosiklab/cmo.htm

LONG TERM GOALS

Our long term goals are to develop a better understanding of the relationships between upper ocean optical properties and particulate and dissolved seawater constituents, and to determine how these relationships are influenced by physical processes. Specific long term objectives include both predicting and modeling optical variability relevant for biological processes, such as phytoplankton photosynthesis, and retrieval of information about the biomass and activity of plankton from optical measurements.

OBJECTIVES

Spatial and temporal variability in particulate and dissolved material is a major source of optical variability in the upper ocean. The primary objective of our work is to examine the interaction between physical processes and the properties, abundance, and optical importance of different particle types in coastal ocean waters. Specific project objectives are to refine individual particle measurement methods and develop approaches to use individual particle results for interpretation of both inherent and apparent bulk optical properties. The project comprises a combination of instrument development and field studies in coastal waters of the eastern US continental shelf.

APPROACH

The approach we have taken employs techniques for characterizing and assessing the optical properties of particles, using both in situ and shipboard instrumentation and both bulk and single particle methods. Our primary tools are flow cytometry for assessing individual particle light scattering and fluorescence properties, spectrophotometry for measuring bulk dissolved and particulate absorption spectra (including separation of phytoplankton pigment absorption from the bulk absorption via methanol extraction), and spectral underwater radiometry. We conducted flow cytometric and spectrophotometric measurements both on discrete water samples and with in situ instruments. In situ measurement provides the opportunity for relatively unperturbed sampling, with generally greater spatial resolution, while analysis of discrete water samples allows more detailed characterization of optically significant seawater constituents. We used our sampling methods during the Coastal Mixing and Optics (CM&O) field study in continental shelf waters south of Cape Cod, MA (40° 30′ N, 70° 30′ W). Work to interpret our field observations has included a combination of laboratory studies, modeling based on Mie theory, and radiative transfer modeling with Hydrolight (Sequoia Scientific, Inc).

WORK COMPLETED

Our work this year has focused on interpretation of individual particle optical properties from flow cytometry measurements and the effects of different particle types on bulk inherent and apparent optical properties. We have finalized the method for estimating diameter and refractive index (both real and imaginary parts) from the flow cytometric measurements. Improvements in the method which we have implemented in the last year include application of empirical correction factors to the phytoplankton cell scattering properties adjusting for apparent effects of inhomogeneity and non-sphericity; these corrections are now applied before Mie theory calculations are made to estimate diameter and refractive index.

Using the results for individual particle size and refractive index to calculate absorption and scattering efficiencies, we have compiled budgets of inherent optical properties by summing over all particles. These budgets have been prepared for all samples from both the 1996 R/V Seward Johnson (SJ9610) cruise and the 1997 R/V Knorr (KN150) cruise. On-going work includes comparison of these budgets to independent absorption and scattering measurements made at sea on discrete samples and with in situ ac-9 meters. In addition, we are conducting Hydrolight simulations to reconstruct apparent optical properties, such as spectral diffuse attenuation coefficients and remote sensing reflectance; the inherent optical properties used as input for these simulations come from the individual particle budgets, and the results are compared to independent radiometric measurements.

In addition, our work describing bulk optical variability during the late summer and spring periods was published (Sosik et al. 2001); we have finalized a manuscript describing laboratory experiments on diel variations in phytoplankton optical properties (DuRand et al. for submission to Journal of Phycology); and a paper describing the size and refractive index derivations is nearly complete (Green et al for submission to Limnology and Oceanography).

RESULTS

Based on comparison of forward and side angle light scattering estimates from flow cytometry and from Mie theory modeling (based on independent assessments of particle size and optical properties), we discovered that there are systematic biases in the modeled values for phytoplankton cells that are not evident for standard plastic microspheres or for oil droplets in suspension (Green et al. 2000). This led to the derivation of the scattering corrections for phytoplankton cells. We have verified that these corrections are useful for a variety of phytoplankton cell types and growth conditions (Fig. 1), which is very important for their robust application to natural samples.

Once size and refractive index was estimated for each particle, we calculated its contribution to the total scattering coefficient in a volume of seawater and then summed these contributions over all particles present in the samples. Based on these computations, we have reconstructed estimated contributions of various particle types (bacteria, cyanobacteria, eukaryotic phytoplankton, and detrital particles) to the total scattering coefficient (Fig. 2). In an example from the spring cruise, it is apparent that eukaryotic phytoplankton and detrital particles dominate in the upper and lower portions of the water column, respectively. At this time of year, cyanobacteria abundances are very low and, despite their high abundance (10^6 or more), heterotrophic bacteria contribute little to total scattering.

We are in the process of completing Hydrolight simulations that will allow us to quantify the contributions of these specific particle types to the magnitude and time variability of apparent optical properties. These results will be finalized and prepared for publication in conjunction with the completion of Rebecca Green's (former AASERT-supported student working on this project) Ph.D. dissertation in the next 9 months.

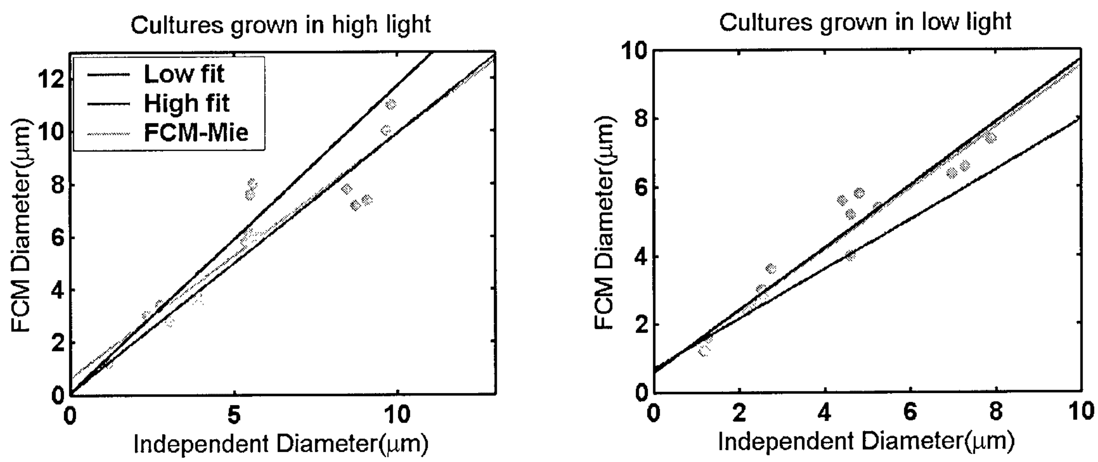

Figure 1. Relationships between measured cell diameter and estimates from three sources: 1) our new FCM-Mie approach (green), 2) an empirical calibration for cells grown in high light (red), and 3) an empirical calibration for cells grown in low light (blue). Results are shown in application to the culture grown under high light (left) and low light (right). The empirical fits only work well for one light condition, while the FCM-Mie approach applies equally well for both high and low light cultures. This is an important finding because previous work with empirical calibration has been limited due to uncertainty about the growth conditions in the ocean; our new method should provide more reliable size estimates for natural phytoplankton communities.

IMPACT/APPLICATIONS

This project includes the development of improved techniques for analyzing marine particles and characterizing their optical properties. Our ability to independently quantify size distributions for phytoplankton and non-phytoplankton particles is a new contribution that will lead to better understanding of optical variability in the ocean.

TRANSITIONS

We have several on-going collaborations with other investigators participating in the CM&O program. Our results from sampling on mooring-turnaround cruises have been used by Dr. Tommy Dickey's group at UCSB for interpretation of observations from moored sensors. Radiometry results from the main optics cruises have been provided to Dr. Ron Zaneveld at OSU for investigating relationships among diffuse attenuation for irradiance, remote sensing reflectance and absorption and scattering coefficients. Some results have been transferred to Dr. Allan Robinson's group at Harvard for use in coupled physical – optical modeling and we have shared pigment, nutrient and size distribution results with Dr. Wilf Gardner's group at TAMU. We have also provided AOP data to Drs. Janet Campbell and Tim Moore at UNH, who are working on fuzzy logic techniques for water type classification.

AOP data, collected in 1996 and 1997 on New England shelf; submitted to World Wide Ocean Optics Database (WOOD), contact: Jeffrey Smart.

AOP data, collected in 1996 and 1997 on New England shelf; submitted to NASA SeaWiFS Bio-Optical Archive and Storage System (SeaBass) database, contact: Brian Schieber (when submitted)/Sean Bailey (present).

RELATED PROJECTS

This project is closely tied with a NASA New Investigator Program award (Sosik) for investigating the regulation of local biological production of particles at the CM&O site and for exploring the effects of changes in particle properties on ocean color. In addition, Olson and Sosik are independently funded (NSF & NOAA/NURP) to continue development of the in situ flow cytometer for deployment at the LEO-15 site. Due to the interdisciplinary nature of the Coastal Mixing and Optics research initiative, this project is also closely tied to several others funded by ONR; specific collaborations and exchanges have taken place with C. Roesler (pigment and particle absorption), S. Pegau and R. Zaneveld (IOP/AOP relationships), T. Dickey and G. Chang (particle absorption and modeling of primary production), and W. Gardner and J. Blakely (water properties and particle size distributions).

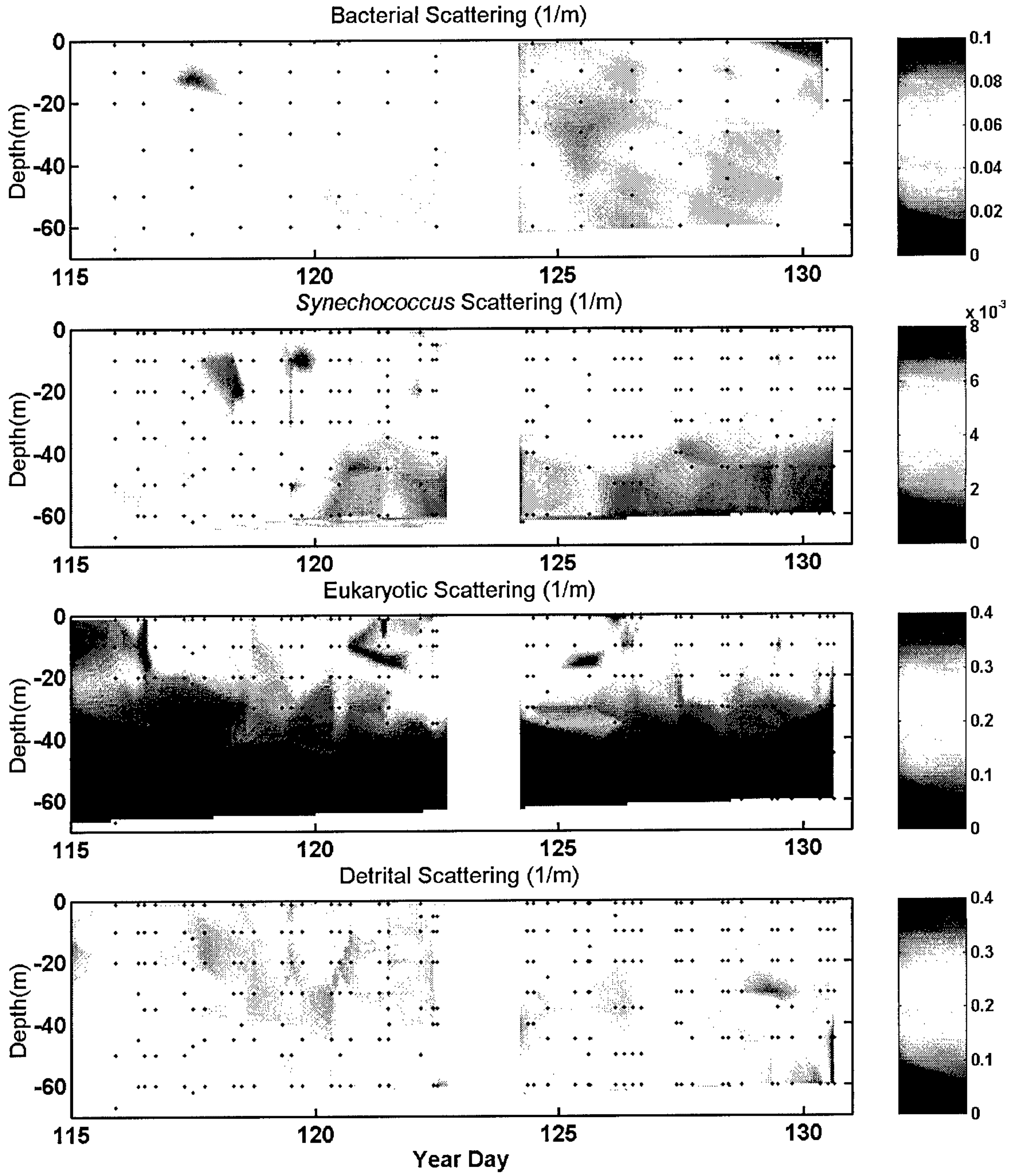

Figure 2. Depth and time distributions of the contribution of different particle types to bulk light scattering during the spring 1997 CMO optics cruise. Scattering estimates were derived based on application of Mie theory to flow cytometric measurements as described by Green et al. (2000); total values result from summing the contributions of each individual particle. In this case eukaryotic phytoplankton (third panel from top) and detrital particles (bottom panel) contribute the most to total particle scattering, with the phytoplankton tending to dominate in the near surface layer and the detritus most important at depth. Temporal variations are affected by water mass advection and changes associated with the progression of a phytoplankton bloom in the latter part of the sampling period.

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Sosik, H. M., R. E. Green, W. S. Pegau and C. S. Roesler. 2000. Temporal and vertical variability in optical properties of New England shelf waters during late summer and spring. In press.

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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for revie gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regardin of the collection of information, including suggestions for reducing the burden, to Washington Headquarters Services, Directorate 12 15 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, & to the Office of Management & Budget Paperwork F			
1. Agency Use Only	2. Report Date November 2001	3. Report Type and Dates Covered Final Report	
4. Title and Subtitle: Response of Particulate Optical Properties to Coastal Mixing Processes			5. Funding Numbers N00014-95-1-0333
6. Author(s) Heidi M. Sosik			
7. Performing Organization Name(s) and Address(es) Woods Hole Oceanographic Institution			8. Performing Organization Report Number
9. Sponsoring/Monitoring Agency Name(s) and Address(es) ONR, Code 322 Ballston Centre Tower One 800 N. Quincy Street Arlington, VA 22217-5660			10. Sponsoring/Monitoring Agency Report Number
11. Supplementary Notes			
12a. Distribution/Availability Statement a			12b. Distribution Code
13. Abstract Spatial and temporal variability in particulate and dissolved material is a major source of optical variability in the upper ocean. This research was designed to examine the interaction between physical processes and the properties, abundance, and optical importance of different particle types in coastal ocean waters. We have substantially refined individual particle measurement methods and developed new approaches to use individual particle results for interpretation of both inherent and apparent bulk optical properties. The project comprised a combination of instrument development and field studies in coastal waters of the eastern U.S. continental shelf. Work to interpret our field observations has included a combination of laboratory studies, modeling based on Mie theory, and radiative transfer modeling. Our results have emphasized the importance of particles, especially phytoplankton, in determining vertical and temporal optical variability on the continental shelf. Several publications have arisen from this research, and we anticipate 3-4 more during the next year (in conjunction with the completion of a Ph.D. dissertation). In addition, as part of this program, we have submitted our observations to national databases.			
14. Subject Terms			15. Number of Pages 16. Price Code
17. Security Classification of Report	18. Security Classification of this Page	19. Security Classification of Abstract	20. Limitation of Abstract

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)