RESPONSE OF PARTICULATE OPTICAL PROPERTIES TO COASTAL MIXING PROCESSES

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Award #: N000149510333

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 significant source of optical variability in the upper ocean. The primary objective of the present work is to examine the interaction between physical processes and the properties, abundance, and optical significance of different particle types in coastal ocean waters. Specific project objectives are to refine individual particle measurement methods and develop approaches to using individual particle results for interpretation of both inherent and apparent bulk optical properties (IOP/AOP). 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 ship-board 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. Our goal is to conduct 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 continues to allow more detailed characterization of optically-active seawater constituents. We have employed 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 COMPLETED

With the completion of the Coastal Mixing and Optics field experiment, effort during the last year has been focused on processing and interpretation of the observations collected in summer 1996 (R/V Seward Johnson cruise 9610) and spring 1997 (R/V Knorr cruise 150). Our primary emphasis has been on characterization of optically active particles, assessment of absorption and scattering properties of particulate and dissolved material (including size dependence for particles), and examination of apparent optical properties. We have completed description of the general differences between the summer and spring periods (Sosik et al. 1998) from both a hydrographic and optical perspective. These results have been presented in a variety of forums and we are proceeding with manuscript preparation for peer-reviewed publication.

In addition, we have been continuing to work on particle characterization, based primarily on flow cytometric measurements. During the past year, we have refined our estimates of particle size distributions and reprocessed our entire data set from CM&O. This complete reprocessing included estimation of non-phytoplankton particle concentration and size. Our efforts have also encompassed investigation of theoretical and empirical considerations for interpreting individual particle light scattering and chlorophyll fluorescence.

RESULTS

Analysis of inherent and apparent optical properties observed during the CM&O experiment has revealed that particles played a dominant role in determining water column optical properties. This is shown clearly by comparison of variations in diffuse attenuation (K_d) with absorption coefficients (Green et al. 1998, Figs. 1 and 2). Absorption by dissolved material (a_s) exceeded that of particles (a_p) at ultraviolet wavelengths; at visible wavelengths, however, a_s was usually lower and much less variable with depth and time than a_p. Interestingly, a_s was somewhat more variable under the stratified conditions present in late summer (Fig. 2) when values were consistently lower in the surface mixed layer compared to the rest of the water column (Sosik et al. 1998).

Based on flow cytometric analysis, it is possible to examine the optical role of different types of particles in greater detail (DuRand et al 1998). We have extended conventional flow cytometric measurements of marine particles, which has focused exclusively on phytoplankton, to include quantitative examination of other particles. This broad class of "non-phytoplankton" material presumably includes particles of organic detritus and of mineral origin, as well as heterotrophic organisms. We have enumerated and estimated optical properties of three types of particles: 1) picophytoplankton of the genus *Synechococcus*, 2) eukaryotic phytoplankton (~2-30 μm) and 3) other particles in the ~1-30 μm size range.

Results of flow cytometric analysis show that non-phytoplankton particles dominated numerically in both late summer and spring and were less variable in space and time than the phytoplankton. In late summer before hurricane Eduoard, *Synechococcus* abundances were very high with a strong subsurface maximum present ($> 10^5$ cells ml^{-1}), while in spring these cells were 10-fold less abundant (DuRand et al. 1998, Sosik et al. 1998). Eukaryotic phytoplankton did not differ in abundance between the two seasons, until the bloom at the end of the spring sampling period when concentrations increased 3-4 fold (Fig. 3).

Particles were found to have substantial differences in their particle specific optical properties that affected the overall contribution to bulk water column optical properties. This is evident when relative contributions to light scattering are considered; the significance of both

Synechococcus and the non-phytoplankton particles decreases relative to their numerical abundance (compare Figs. 3 and 4, Fig. 5). In the spring, in particular, the importance of eukaryotic phytoplankton often exceeded the other particles in surface waters, but decreased rapidly with depth.

Current work on these topics is focused on deriving absolute (rather than relative) estimates of particle scattering cross-sections and estimating backscattering contributions. Preliminary results investigating differences in spatial and temporal variability between diffuse attenuation and spectral reflectance suggest that changes in the particle size distribution and associated scattering effects are important in regulating apparent optical properties of the water column.

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 are being 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 A. 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.

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 to explore the effects of changes in particle properties on ocean color. In addition, Olson is independently funded (DOE, NSF) to develop the in situ flow cytometer. The interpretation of flow cytometric light scattering and fluorescence distributions is also being supported by a NSF JGOFS project for work in the Arabian Sea (Olson). 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 are underway 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).

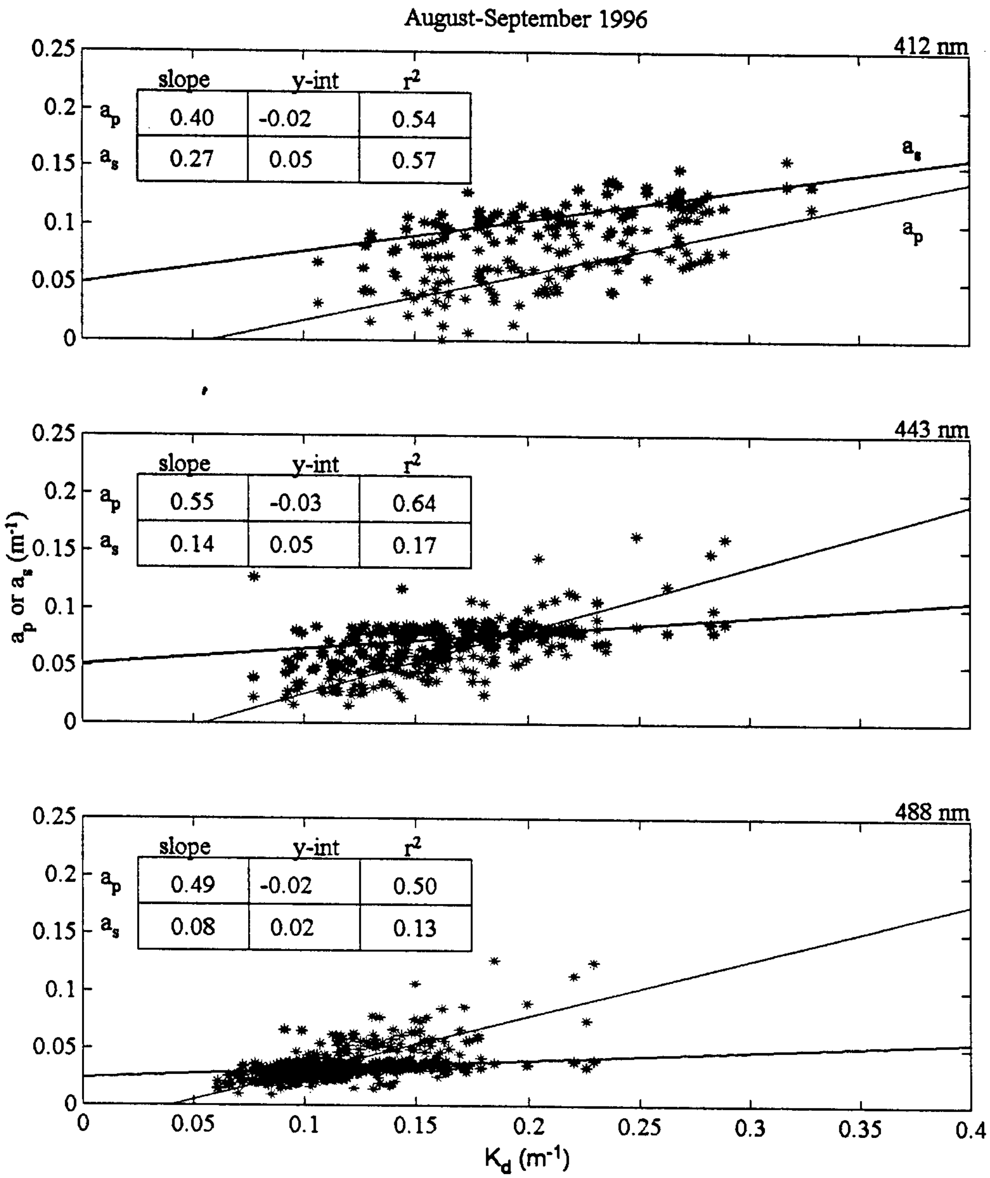

Figure 1. Relationships between diffuse attenuation for downwelling irradiance (K_d) and absorption coefficients for dissolved (a_s) and particulate (a_p) material at three wavelengths during August-September 1996. K_d estimates were derived from irradiance measurements collected with a tethered free-fall profiler (Satlantic SPMR) and the absorption data was collected using ac-9 sensors (WetLabs) mounted on the OSU Slowdrop profiling package. Data were averaged in 10-m bins and K_d and absorption profiles collected within two-hour windows were used. Linear regression results show the importance of dissolved material at 412 nm and the strong dependence of K_d variations on a_p at 443 and 488 nm.

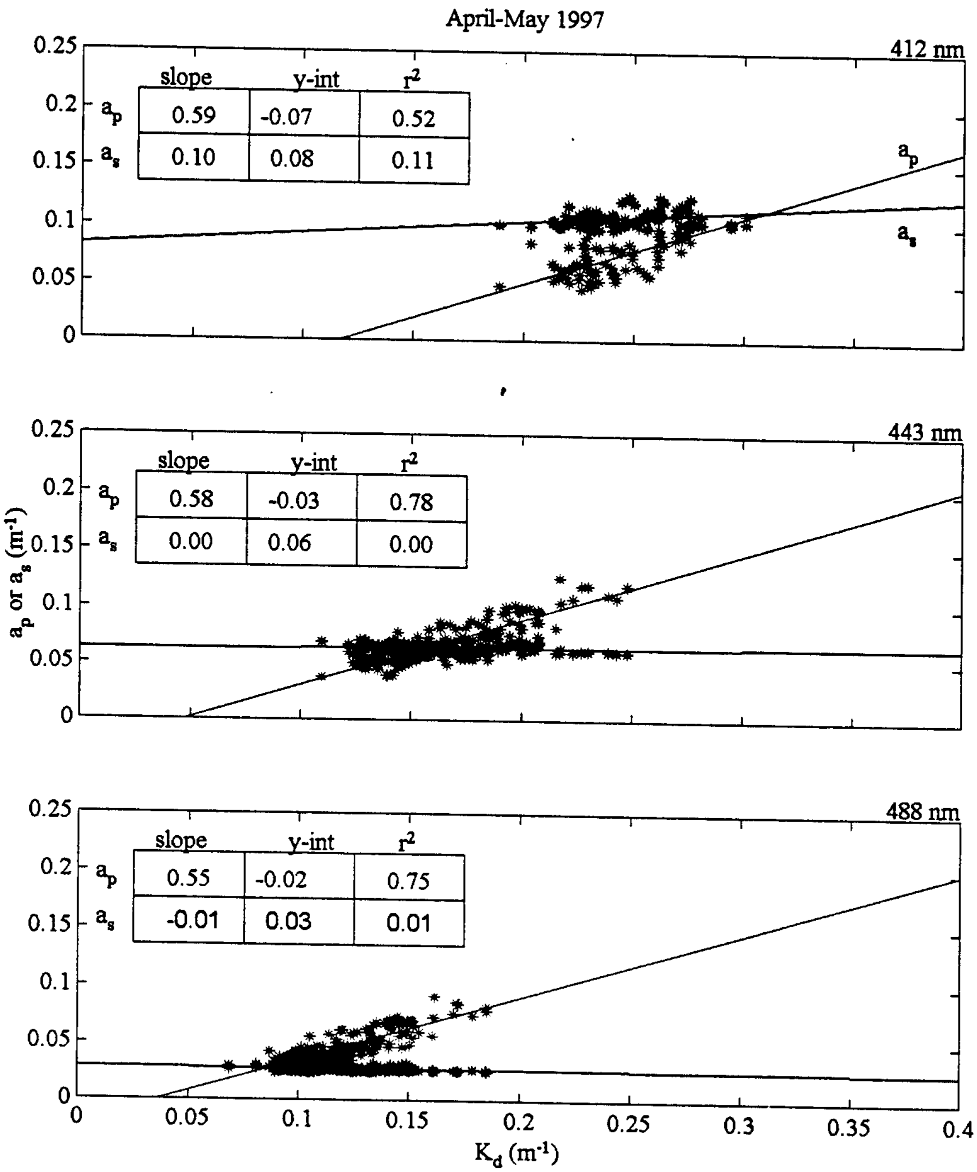

Figure 2. Relationships between diffuse attenuation for downwelling irradiance (K_d) and absorption coefficients for dissolved (a_s) and particulate (a_p) material at three wavelengths during April-May 1997. Data were collected and processed as described for Fig. 1. Linear regression results show strong dependence of K_d variations on a_p, with even less contribution of dissolved material than observed under conditions of greater stratification in late summer the previous year (Fig. 1).

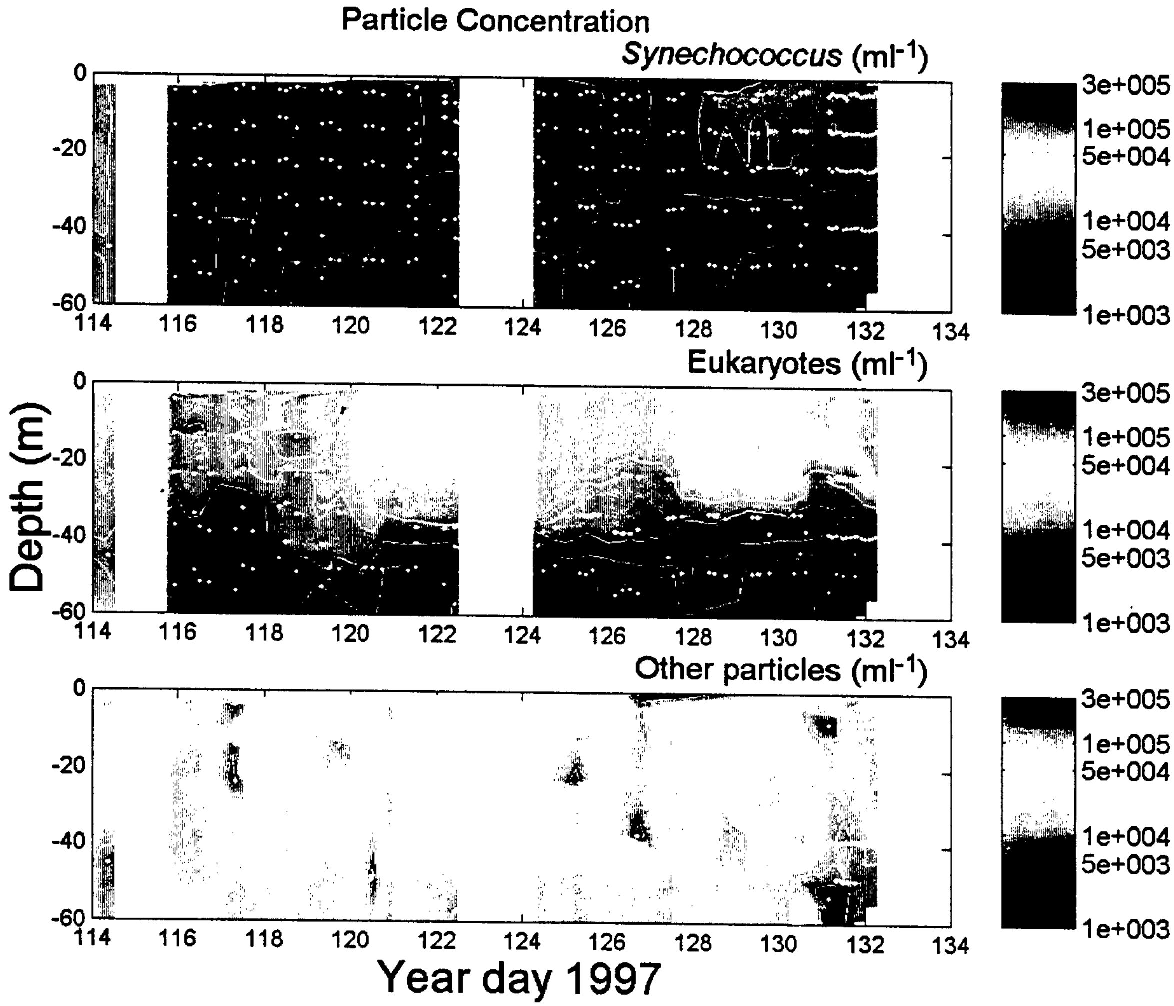

Figure 3. Time series of particle concentration observed during vertical sampling in spring 1997. Results for three general particle classes are shown, Synechococcus (top panel), eukaryotic phytoplankton (middle panel), and other particles in the same size range (bottom panel).

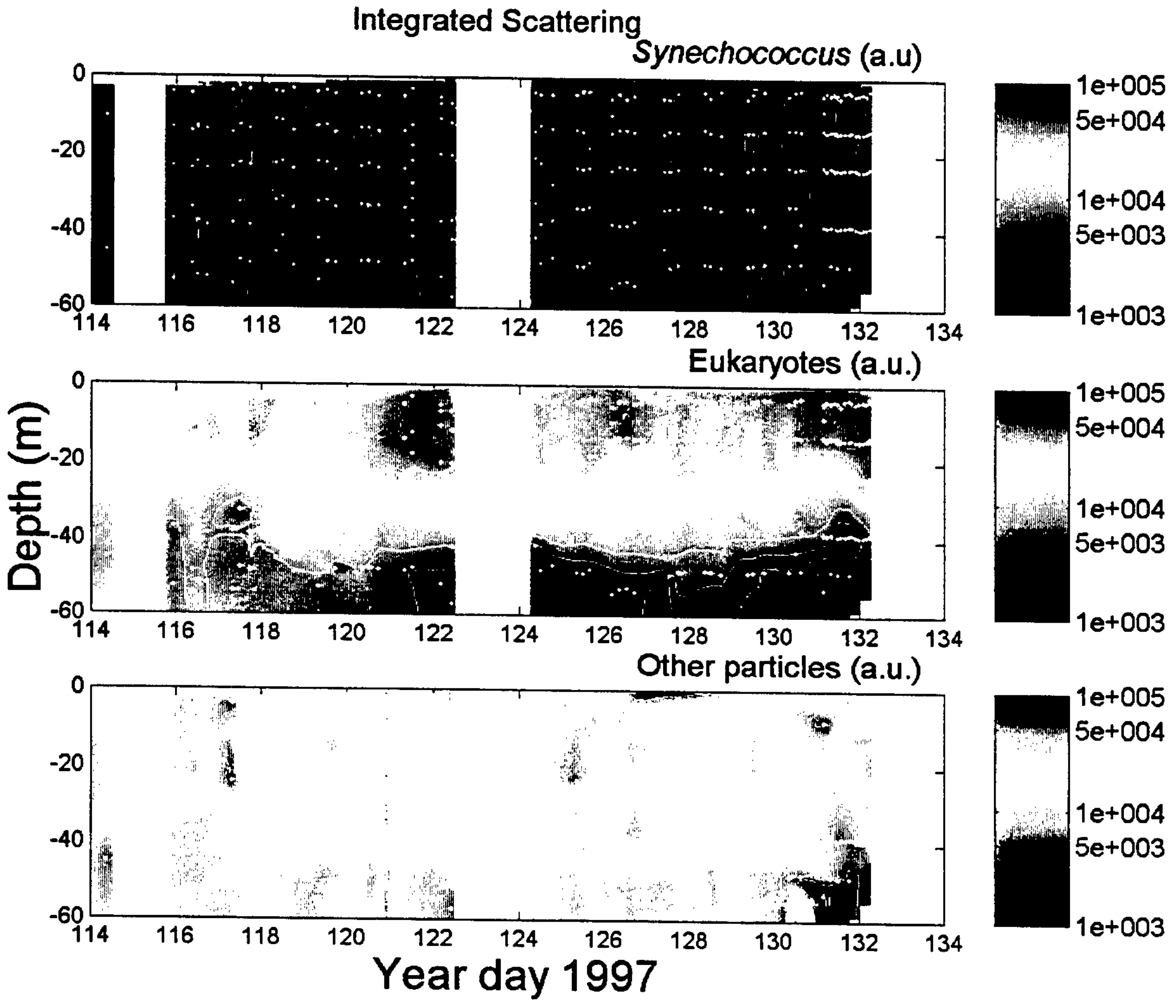

Figure 4. Time series of relative contributions of different particles to forward light scattering observed during vertical sampling in spring 1997. Results for three general particle classes are shown, Synechococcus (top panel), eukaryotic phytoplankton (middle panel), and other particles in the same size range (bottom panel).

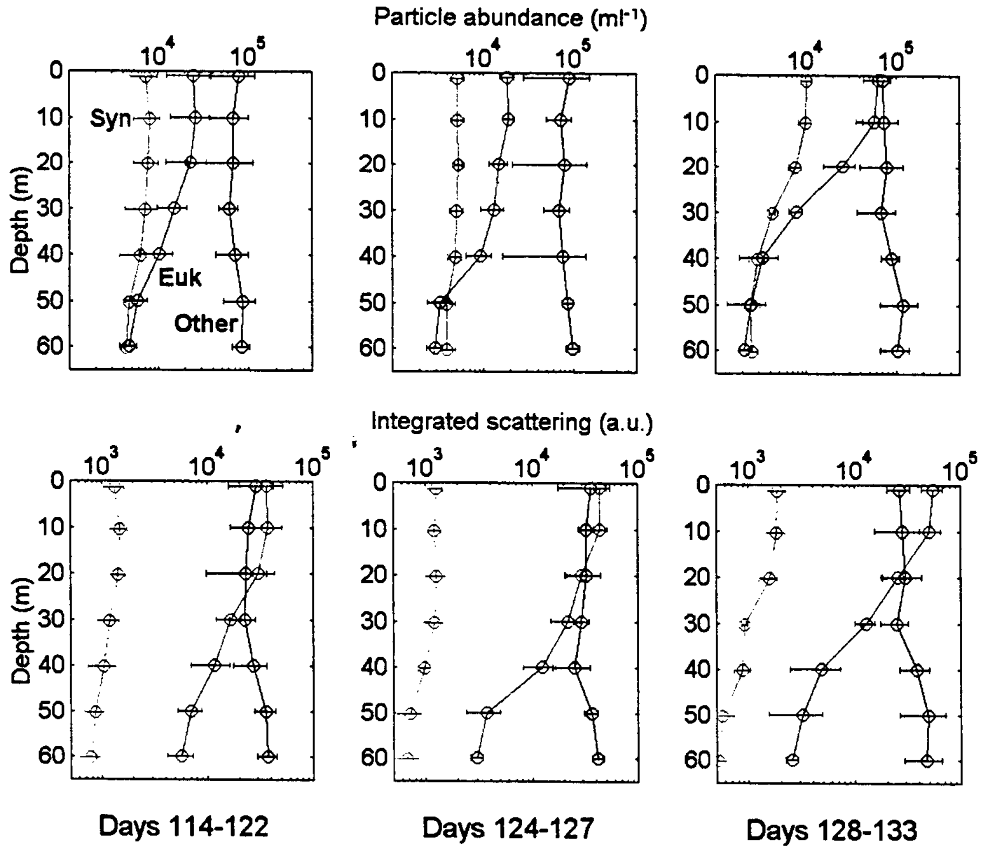

Figure 5. Summary of abundance and integrated forward light scattering for different types of particles sampled by flow cytometry in spring 1997. Mean +/- standard deviation is shown for three time periods and three particle types: *Synechococcus* (red), eukaryotic phytoplankton (green) and other particles in the same size range (black).

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Web sites:

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

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. Agency Use Only	2. Report Date 7 January 1999	3. Report Type and Dates Covered Progress Report 2/1/98 - 1/31/99

4. Title and Subtitle: Response of Particulate Optical Properties to Coastal Mixing Processes

5. Funding Numbers

Grant N00014-95-1-0333

6. Author(s) Heidi M. Sosik and Robert J. Olson

7. Performing Organization Name(s) and Address(es)

Woods Hole Oceanographic Institution
Woods Hole, MA 02543

8. Performing Organization Report Number
WHOI Proposal No. 2241

9. Sponsoring/Monitoring Agency Name(s) and Address(es)
Code 322
Office of Naval Research
Ballston Tower One
800 North Quincy Street
Arlington, VA 22217-5660

10. Sponsoring/Monitoring Agency Report Number

11. Supplementary Notes

12a. Distribution/Availability Statement

12b. Distribution Code

13. Abstract

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14. Subject Terms
optics, mixing, particulates, flow cytometry, phytoplankton

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)