FROM MICRONS TO MILLIMETERS: THE USE OF OPTICALLY DETERMINED PARTICLE SIZE AND DISTRIBUTION IN UNDERSTANDING COASTAL VERTICAL MIXING PROCESSES

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LONG-TERM GOALS

1) To quantify variations in inherent optical properties (absorption scattering coefficients) as a function of particle size distribution and concentration on the shelf; 2) combine these measurements with hydrographic measurements (including turbulence and mixing as measured by others) to determine the forcing functions and biological processes that cause the temporal and spatial variations in optical properties on the shelf.

SCIENTIFIC OBJECTIVES

1. Determine the relationship between inherent optical properties (attenuation, absorption, scattering) and particle characteristics (mass concentration, size distribution) for the area studied during the ONR Coastal Mixing and Optics (CMO) Advanced Research Initiative (ARI).
2. Determine whether the distribution of inherent optical properties or large aggregates can be used to identify the location and scales of mixing where physical parameters such as temperature or salinity show no variation.
3. Determine how inherent optical properties can remain uniform across depths where there are gradients in conservative parameters such as temperature and salinity.
4. Determine the significance of the presence of large aggregates on the inherent optical properties.

BACKGROUND

The coastal ocean is the region where land meets sea, fresh water meets saltwater, and turbid rivers meet clearer seawater. This region of strong vertical and horizontal mixing is physically forced by wind, surface and internal waves, buoyant plumes and tides. If particles were conservative, it would be relatively straightforward to determine particle mixing processes by measuring the distribution of temperature and salinity to calculate mixing rates, since T and S are easily measured. Particles, however, are not conservative and they are very heterogeneous in their size, composition and optical properties. Particles which enter the coastal ocean or are produced biologically in nutrient-rich waters interact, disaggregate, aggregate and settle out at different rates depending on their size, density, composition, the turbulence field and regional mixing. The transfer of particulate matter from one water mass or hydrographic regime to another is not restricted to mixing, but is also driven by biological activity (production, grazing, etc.) and gravitational sinking. These processes, with the resulting heterogeneity of the particle field, cause variations in the apparent and inherent optical properties of coastal waters. If we can determine the relationship between inherent optical properties of seawater and the properties of the particles present, we will be better able to quantify the role of mixing versus biological activities and gravitational settling. Advection is another important parameter to consider in this analysis.

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APPROACH

Our primary approach was to collect a time-series of synoptic data on particle concentration and size, hydrography, and in-situ inherent optical properties at the central CM&O site on the continental shelf south of Cape Cod, Massachusetts during periods of high (Fall '96) and low (Spring '97) stratification. Our data will be interpreted in the context of measurements made by others over the same time period such as shipboard mixing and turbulence measurements; moored data on currents, bottom shear stresses, optics and aggregates; and SeaSoar measurements at various space scales around the CM&O site to ascertain the roles of mixing, advection, primary particle production, aggregation and resuspension on the relationships between particle and optical properties of the water in that region.

To this end, we constructed a Particle and Optics Profiling System (POPS) that is a frame (1m x 1m x 2.5m) which integrates several different instrument packages. A SeaBird SeaCat CTD provided a synoptic hydrographic context in which to place our particle and optical measurements. Integrated with the CTD was a SeaTech transmissometer (λ=660nm) and SeaTech chlorophyll fluorometer to provide in-situ optical data about the concentrations and particle type in the water. Most of the signal for both of these instruments comes from particles less than 20 µm in size. To further test which sizes of particles are responsible for producing variations in the signals of inherent optical properties (attenuation, absorption and scattering), we simultaneously deployed three absorption/attenuation (ac) meters on the POPS frame. The water passing through one ac meter instrument was unfiltered, another was filtered at 0.2 µm to obtain the particle-free values of a and c and the third ac meter was filtered at 5, 10 or 20 µm to determine the intensity of the signal in the different size ranges.

A Sequoia Scientific LISST 100 was used to measure the in-situ forward volume scattering function (0.5 to 5 degrees) from which the size distribution of particles is derived from 5-500 microns. Between cruises the instrument was upgraded to a LISST 100B to yield particle sizes from 1.25-250 µm. A SeaTech Light Scattering Sensor (LSS) was interfaced with the LISST 100 as a rough back-up measurement of total particle scattering. To measure the size and abundance of large aggregates, we have developed a dual video camera and synched-strobe system that illuminates and video records two separate volumes of water. The close-up, small-volume video is used to discriminate aggregates as small as 300 µm and the larger-volume system images aggregates >500 microns. Thus, on a single platform we have a series of instruments that measure the particle spectrum from a few microns to several millimeters as well as important physical (temperature, salinity, and pressure) and the optical parameters of attenuation, absorption and chlorophyll fluorescence.

The primary reason for making in-situ measurements of particle sizes is that from diving with scuba and from submersibles, we and others have observed that aggregates can fall apart from the slightest disturbances, thus altering the true particle size distribution. Individual phytoplankton are more likely to survive collection with water bottles intact and bulk particle concentrations are less prone to bias. In order to correlate the optical measurements at various wavelengths with particle size distribution, concentration and particle types, we collected samples from the CTD/rosette profiles at discrete depths. Bulk particle measurements were made by passing the water through preweighed 0.4 µm filters to determine concentrations of Particulate Matter (PM), and through precombusted glass fiber filters to determine the concentration of Particulate Organic Carbon (POC). We measured the abundance and size distribution of particles in water samples using a Coulter Multisizer. Comparisons of particle size were made between the water-column particles, surface sediments and settling particles by collecting cores and deploying sediment traps during each cruise. The physical and optical measurements will be integrated to achieve the objectives outlined above.

ACCOMPLISHMENTS AND RESULTS

We participated in an ONR Coastal Mixing and Optics cruise on the continental shelf south of Cape Cod, Massachusetts aboard the R/V Seward Johnson from August 18 to September 7, 1996. The purpose was to monitor conditions during late summer when stratified conditions were expected. Results were described in the FY96 report. To observe conditions after winter mixing, we went to the same location from 23 April-9 May, 1997 on the R/V Knorr. During that cruise we made 82 daytime profiles with the POPS instruments described above. Nighttime measurements of physical mixing were made by Dr. M. Gregg (UW) during the cruise. A total of 111 CTD/rosette profiles were taken and PM and POC samples were taken from many of them. Dr. Collin Roesler (U.Conn.) determined the pigment concentration for the same samples using fluorometric techniques. Particle size distributions from 1-25 µm were measured from bottle samples using a Coulter Multisizer. Attenuation and absorption were measured in the ship's in-line clean-seawater system using an WET Labs ac3 instrument in the lab. A short-term sediment trap mooring using cylindrical sediment traps recorded mass flux during the first 2 weeks of the cruise and gravity cores provided samples of surface sediment.

POPS and CTD/rosette casts were made routinely 3-12 times a day during the occupation of the 70 m deep central station at 40.5 deg. N, 70.5 deg. W. Beam attenuation and fluorescence or chlorophyll-related optics were recorded on both CTD and POPS casts. Upon our arrival, the water column was nearly mixed due to winter storms, but was still a distinct 2-layer system which further stratified during the cruise to a 3-layer system due to solar heating even though several nor'easters passed through the area (Fig. 1). Particle concentrations were substantially lower in the spring than the fall, but bottom concentrations increased during the spring cruise either from resuspension or advection. Chlorophyll fluorescence was higher in the spring.

SCIENTIFIC IMPACT AND TRANSITIONS ACCOMPLISHED

The two cruises provided excellent time series observations of stratified summer conditions (stirred dramatically by the passage of Hurricane Edouard at the end of the cruise) for comparison with low-stratified spring conditions. To our knowledge, the data sets collected during these cruises represent the first time that full-water column profiles have been collected over such a wide particle spectrum - microns to millimeters - in even a single profile, let alone the excellent time-series and cross-shelf sections we obtained. The ADCP data showed periods of strong horizontal shear as internal waves or solitons generated at the shelf break passed the site in the late summer, but these waves were not clearly observed in the spring. These events may be important for the generation and/or re-distribution of aggregates and the resultant impact on inherent optical properties of the water column. The passage of a hurricane represented the ultimate short-term mixing event for a stratified system and we were fortunate to be there before and after it occurred. The passage of several strong storms in the spring provided us with the opportunity to observe and quantify optical conditions during a wide range of coastal mixing conditions.

Figure 1. Profiles of A) density, B) beam attenuation coefficient, and C) chlorophyll fluorometer voltage from CTD casts before the passage of Hurricane Edouard in the fall of 1996 and at the beginning and end of the cruise in the spring of 1997.