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

Our long-term goals are 1) to determine how changes in particle size distribution, composition and concentration on the shelf affect inherent optical properties (attenuation, absorption and scattering) and 2) correlate these measurements with hydrographic measurements (including wave and current shear stress 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.

OBJECTIVES

1. Determine the relationship between inherent optical and particle characteristics (composition, mass concentration, and size distribution) for the area studied during the Coastal Mixing and Optics (CMO) Advanced Research Initiative (ARI).
2. Determine how the above relationships vary between periods of high stratification (late summer) and low stratification (early spring) conditions.
3. Determine the significance of the presence of large aggregates on the inherent optical properties.

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APPROACH

We collected time-series data on particle concentration, composition and size, hydrography, and in-situ optical properties at the central CMO site on the continental shelf south of Cape Cod, Massachusetts during periods of high (Fall '96) and low (Spring '97) stratification. We must interpret our optical and particle data in the context of measurements made by others such as currents, bottom shear stresses and SeaSoar measurements at various space scales around the CMO 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.

Our Particle and Optics Profiling System (POPS) integrated several different instrument packages. A SeaBird SeaCat CTD provided synoptic hydrographic data. Integrated with the CTD was a SeaTech transmissometer (λ=660nm) to provide in-situ optical data about the concentrations and particle types in the water. Most of the attenuation signal comes from particles < 20 µm in size. To determine the dissolved and particulate contributions to inherent optical properties, we measured both filtered (0.2 µm) and unfiltered absorption and attenuation during the spring cruise. A Sequoia Scientific LISST 100 was used to estimate the size distribution of particles from 5-500 µm in summer and 1.25-250 µm in spring. To measure the size and abundance of large aggregates, we used 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 hydrographic (temperature, salinity, and pressure) and optical parameters.

Optical measurements were correlated with particle size distribution, concentration and particle types, by collecting samples from the CTD/rosette profiles at discrete depths. Samples were analyzed to determine concentrations of total particulate matter (PM) and 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. Physical and optical measurements are being integrated to achieve the objectives outlined above.

WORK COMPLETED

We participated on a cruise to the CMO site (the continental shelf south of Cape Cod, Massachusetts) during late summer (August 18 to September 7, 1996) stratified conditions, and a second cruise after winter mixing (23 April-9 May, 1997) as stratification began. CTD profiles were made just during the day, but we combined nighttime temperature and salinity data from Dr. M. Gregg’s (UW) profiling system to create time-series hydrography-transmissometer-fluorometer sections (Fig. 1). We filtered bottle samples for particulate matter (PM) and particulate organic carbon (POC) to make correlations with other discrete and optical parameters. Dr. Collin Roesler (U.Conn.) determined the pigment concentration for the bottle samples using fluorometric techniques. Particle sizes from 1-25 µm were measured from bottle samples using a Coulter Multisizer. 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 °N, 70.5 °W. Transects were made across the shelf from about 40 m to 1000 m to determine regional variability.

RESULTS

The two cruises provided excellent time series observations of stratified summer conditions for comparison with low-stratified spring conditions. Fast-moving solitons perturbed the water column briefly in the summer, but no storms perturbed the system until the end of the cruise when large surface swells from Hurricane Edouard intensified and thickened the nepheloid layer. Hurricane Edouard created a two-layer system (surface to bottom density difference = 0.8 kg m^{-3}), which started restratifying quickly after Edouard's passage. Sediments were resuspended to within 20 m of the surface, but quickly settled out or, more likely, were replaced by clearer water; subsurface chlorophyll increased slightly.

Upon arrival in the spring, the water column was nearly mixed due to winter storms, but was still a distinct 2-layer system (surface to bottom density difference = 0.05 after our first storm) which further stratified during the cruise to a 3-layer system due to solar heating, even though several nor'easters passed through the area (surface to bottom density difference = 0.5 kg m^{-3} at cruise end). Surface-water particle concentrations were 20-25% higher in the spring than in the summer, and pre-hurricane bottom water particle concentrations were about 60% greater in the summer. Particle fluxes measured with sediment traps at 25 and 65 m in the spring were respectively about 10 times and 4 times greater than in the summer at the same depths. We presume that greater springtime biological activity (substantially higher chlorophyll fluorescence) contributed to greater fluxes. Aggregate concentrations showed no systemic difference between the two cruises. Day to day variability in total aggregate abundance was as large as the inter-cruise variability.

Correlations between bulk particle properties (PM and POC concentrations) and optical properties were poor during highly stratified periods because stratification created numerous small layers of particles with different particle characteristics (composition, size, shape). Correlations were very different for near-surface versus near-bottom waters. After the passage of Hurricane Edouard the water column was mixed to a two-layer system in which correlations were very good, though different, in the two layers. The mean size of particles <20 μm decreased in bottom waters after the hurricane, decreasing the beam attenuation to PM ratio by 50%. The above correlations were much better during the spring when there was a 2-3 layer system, but the correlations were still different in each water mass, suggesting different particle types.

Generally, the aggregate distribution reflected the two or three layer water column, with the near surface layer being characterized by increasing aggregate concentrations from the surface to the pycnocline along with an increase in the relative abundance of the largest aggregates. Intermediate aggregate nepheloid layers were frequently found above the benthic boundary layer, indicative of aggregate rebound at an upstream location and subsequent advection to the site. These features were often found without a corresponding increase in beam attenuation, and sometimes were associated with a decrease in beam attenuation. Within the benthic boundary layer aggregate abundance was observed to increase with increasing beam attenuation. Often, but not always, the aggregate size distribution in the benthic boundary layer was skewed towards the smaller sizes suggesting that turbulent shear stresses may limit the size of aggregates and disrupt the larger aggregates settling out of the mid-water column.

IMPACT/APPLICATIONS

It is more difficult to predict the optical properties of a stratified column of water than a well-mixed body of water given the bulk composition and concentration of particles within the water because of the uniformity of particle properties induced by mixing. During strongly stratified periods, events of hurricane force were required to cause significant vertical mixing, although the passage of solitons had an effect in the upper water column. When the water was only weakly stratified in the spring, nor'easters (with winds over 30 kt) caused primarily surface mixing. Stratification increased as surface waters were heated during a two-week period despite frequent storms. Although particles in the upper water column may increase (primary production), remineralize, aggregate or settle to the lower water column, even minor stratification prevents mixing of particles from the lower layers to the upper layers, though wintertime mixing probably extends throughout the water column.

TRANSITIONS

Our profiling instruments and software (partially developed under NSF and DOE funding) were used in the JGOFS Southern Ocean biogeochemical process studies. They were also used in a study of the Mississippi Canyon in the Gulf of Mexico.

RELATED PROJECTS

1 – The same optical and particle measurements made in CMO were made in the upper water column of the Southern Ocean and are being correlated with hydrography, stratification and biogeochemical measurements to quantify carbon production, distribution and loss.

2 – Similar particle and optical measurements were made in May 1998 at the head of the Mississippi Canyon to study shelf-slope-canyon transport by Gardner and Richardson and Vernon Asper (USM).

3 – Measurements of particles and optics are being made in studies that extend from the inner shelf to 1000 m in the northeastern Gulf of Mexico in work funded by MMS (NEGOM).

4 – Gardner visited scientists (Christos Anagnostou and Aristomenis Karageorgis) at the National Center for Marine Research in Athens, Greece to help them analyze similar particle and optics data collected in the Aegean Sea.

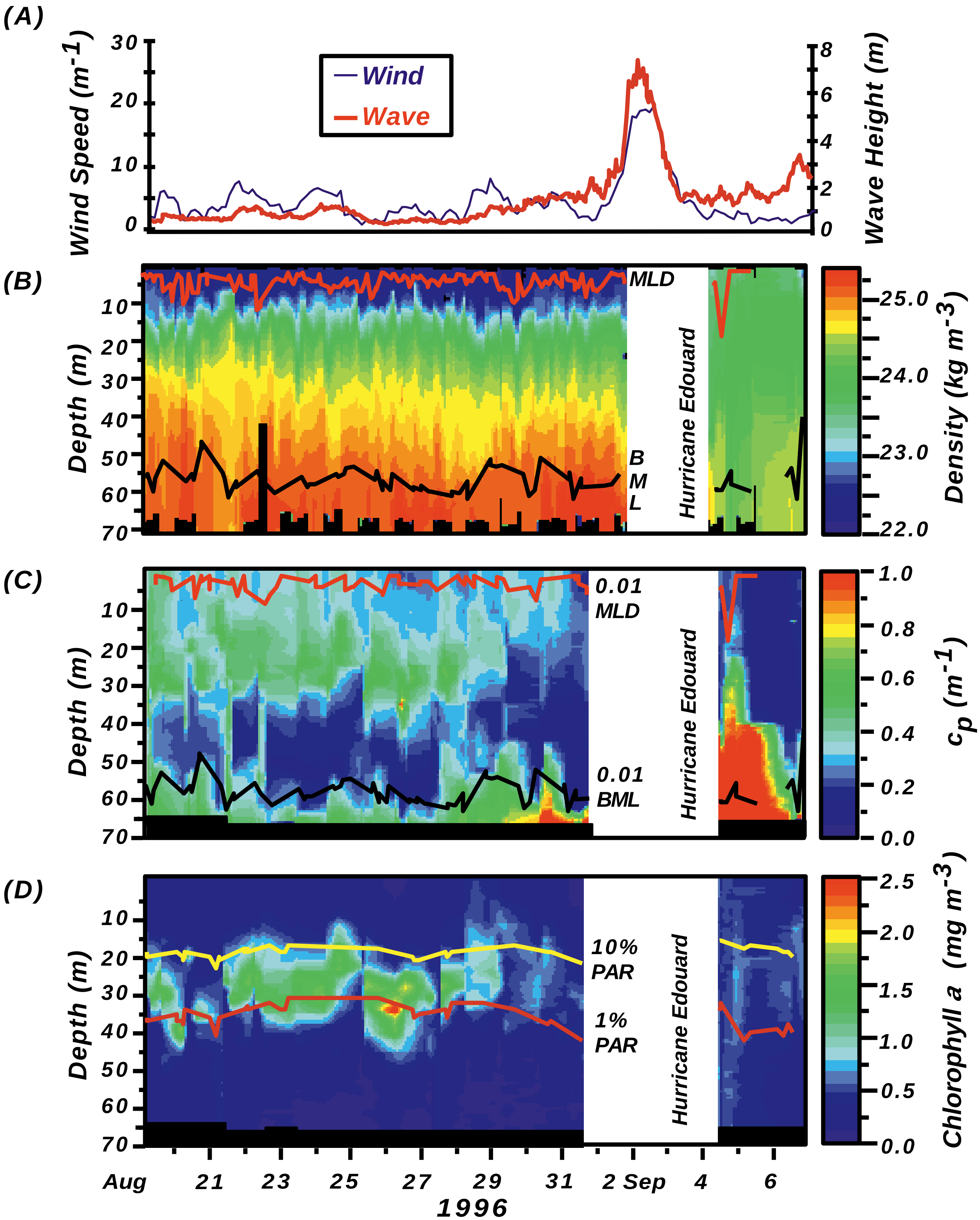

Figure 1. Time-series sections of (A) wind speed and wave height (data from Lentz and Plueddemann), (B) density, (C) beam attenuation and (D) chlorophyll a for the summer 1996 cruise under stratified conditions. The 0.01 $\Delta\sigma_\theta$ MLD (red line) and 0.01 $\Delta\sigma_\theta$ BML (black line) are plotted on B and C. The 10% light level (yellow line) and 1% light level (red line) are plotted on D.

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