Optics, Acoustics, and Stress in a Nearshore Bottom Nepheloid Layer

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LONG-TERM GOALS

The goal of this research is to develop greater understanding of the how the flocculation of fine-grained sediment responds to turbulent stresses and how this packaging of sediment affects optical and acoustical properties in the water column.

OBJECTIVES

1. Quantify the effects of aggregation dynamics on the size distribution of particles in the bottom boundary layer;
2. Quantify how changes in particle packaging affect the optical and acoustical properties of the water column.
3. Develop models describing the associations between particle aggregation, stress, and the acoustical and optical fields.

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APPROACH

The approach is to obtain measurements that will permit comparisons of the optical and acoustical signatures of suspended particles and inferences of the particle size distribution and its temporal evolution, concurrently with fluid dynamical measurements that determine the flow field within which the particles evolve. The instrumentation is mounted on bottom tripods and includes a 9-wavelength optical attenuation and absorption meter (WetLabs ac-9, with automated regular dissolved measurement for calibration independent particulate measurements), a LISST-100 laser diffraction particle sizer (Agrawal & Pottsmith 2000), a digital floc camera (DFC) (Curran et al. 2002b), a Tracor Acoustic Profiling System (TAPS, Holliday 1987), and an array of SonTek/YSI acoustic Doppler velocimeters (ADVs). Near-simultaneous measurements with and without a filter assure high-quality particulate spectral absorption and attenuation measurements with the ac-9. The LISST-100 and floc camera together provide particulate size distributions from 2.5 micrometers to 1 centimeter. The TAPS obtains range-gated, vertical profiles of acoustical backscatter intensity at a range of frequencies between 0.3 and 3.0 MHz. The TAPS and ADVs produce acoustical measurements over a wide range of frequencies that can be used to generate particle size distributions (Holliday, 1987; Hay and Sheng, 1992). The combined optical and acoustical measurements will provide a comprehensive description of the suspended particles near the seabed. The velocity measurements obtained from the ADVs will provide direct-covariance estimates of Reynolds stress and inertial-range estimates of the dissipation rate for turbulent kinetic energy (Trowbridge 1998, Trowbridge & Elgar 2001, Shaw & Trowbridge 2001, Trowbridge & Elgar 2003).

The analysis includes estimation of Reynolds stress, dissipation rate, and eddy diffusivity; estimation of particle size distribution and concentration from the DFC and LISST-100; and estimation the optical and acoustical properties of the water column from analysis of the ac-9, TAPS, and ADV data. The analysis focuses on evaluation and improvement of a one-dimensional (vertical), time-dependent model of the particle size and concentration fields and the accompanying optical and acoustical properties. The model includes the effects of sediment resuspension by bottom shear stresses produced by waves and currents, vertical transport of suspended particles by turbulence, gravitational settling of particles, and particle aggregation and disaggregation.

WORK COMPLETED

Three sets of measurements have been obtained, the first during August-September 2004, the second during August-September 2005, and the third during August-September 2007. All three sets of measurements occurred at the Martha's Vineyard Coastal Observatory (MVCO), which is operated by the Woods Hole Oceanographic Institution (WHOI). The MVCO, off the southern coast of Martha's Vineyard, Massachusetts, is a cabled observatory consisting of a shore station, a meteorological mast on the beach, a seafloor node at a water depth of 12 m, and an air-sea interaction tower (ASIT) at a water depth of 15 m. Atmospheric measurements are obtained routinely at the meteorological mast and the ASIT. Routine oceanic measurements of temperature, salinity and velocity are obtained at the 12-m node and the ASIT. The 2004 measurements for this study were obtained near the ASIT and the 2005 and 2007 measurements were obtained near the 12-m node and included, in addition to the tripod, measurements with a small autonomous sampling platform. The 2007 program included measurements obtained from a profiler deployed by WetLabs (Fig. 1).

Modeling of the optical properties of oceanic aggregates has been accomplished using an approached pioneered by Latimer, 1985, and using new results linking aggregate size to their fractal dimension (Khelifa and Hill, 2006, Maggi, 2007). Results of this modeling will be presented in several presentations at the Ocean Optics XIX conference in October. To our knowledge this is the first attempt to model the optical properties of marine aggregates (aggregates in the atmosphere and space are much smaller than marine one, having size comparable and smaller than the wavelength of light).

Lab experiments were conducted on two fronts: 1. devising an absolute calibration for commercial acoustical backscattering. 2. Control aggregation experiments where clay aggregates were formed in the lab and their optical and acoustical properties tracked as they grew.

RESULTS

We find the single and population models of aggregates to reproduce the observation that the beam-attenuation/mass ratio is very stable (varying from 0.2-0.6m^2/gr) in measurements done in many environments and conditions (Fig 2 & 3). The underlying physical explanation is that material in aggregates maintains a large cross sectional area and thus has a larger optical cross-section than solid material. Since for large particles the beam attenuation is proportional to the optical cross-section, for aggregates the beam attenuation to mass ratio is nearly constant (as opposed to decreasing as 1/size as for solid particles).

Aggregation experiments showcase several important results (Fig. 4 & 5): 1. Mass normalized beam attenuation and backscattering stay very constant while particle (aggregate) size changes a factor of 10. This is contrary to Mie theory which suggests that specific beam attenuation should fall by a factor of 10 and with the notion that large particles do not affect backscattering (e.g. Stramski et al., 2004). 2. Acceptance angle has an important effect on the measured beam attenuation; the ratio of beam attenuation of the LISST-B to that of the ac-9 varies from 1.05 to 1.4 as particle size increases.

IMPACT/APPLICATIONS

The high resolution time series of particle, optical, and acoustical properties enhances understanding of the rates and mechanisms by which the water column clears following storm events. Development of 1-D model include the development of a module which converts sediment to optical properties. This advance will provide the sedimentology community a simple tool to test their model predictions against the most ubiquitous measurement of suspended matter in coastal waters, the beam attenuation.

Our results helped explain the success of optical methods in predicting mass, an observation that to this date lacked the theory to support it.

RELATED PROJECTS

Hill has a project funded by NSERC (Canada) that investigates the effect of in situ particle size distribution on the interaction of oil and sediment in suspension. This project funded the purchase of the LISST-100 on the MINSSECT.

DURIP grant to E. Boss (N000140410235) provides instrumentation used in the present project.

Boss had a project with Agrawal (N00014-04-1-0710) to study optical scattering from natural (e.g. non-spherical) particles and develop a new scattering sensor which we deployed on the OASIS tripod during our last field work and whose result will be presented in Ocean Optics XIX.

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PUBLICATIONS

Slade, W.H., Boss, E.S. 2006. Calibrated near-forward volume scattering function obtained from the LISST particle sizer. Optics Express, 14: 3602-3615. [published, refereed]

Jumars, P. A., J. H. Trowbridge, E. Boss and L. Karp-Boss. Turbulence-plankton interactions: a new cartoon. Accepted for publication in *Marine Ecology*. [unpublished, refereed]

HONORS/AWARDS/PRIZES

Ocean Optics XVIII, 2006, honorable mentions for student paper by Wayne Slade for: Slade, W. and E. Boss, 2006. Volume Scattering Function Variability in a Nearshore Bottom Nepheloid Layer. Ocean Optics Conference 2006, Montreal, Quebec.

Ocean Sciences Meeting, 2008 Student paper award to Clementina Russo for: Measuring Suspended Sediment Concentration Using High Resolution Current Meters. 2008 Ocean Sciences Meeting, Orlando, FL.

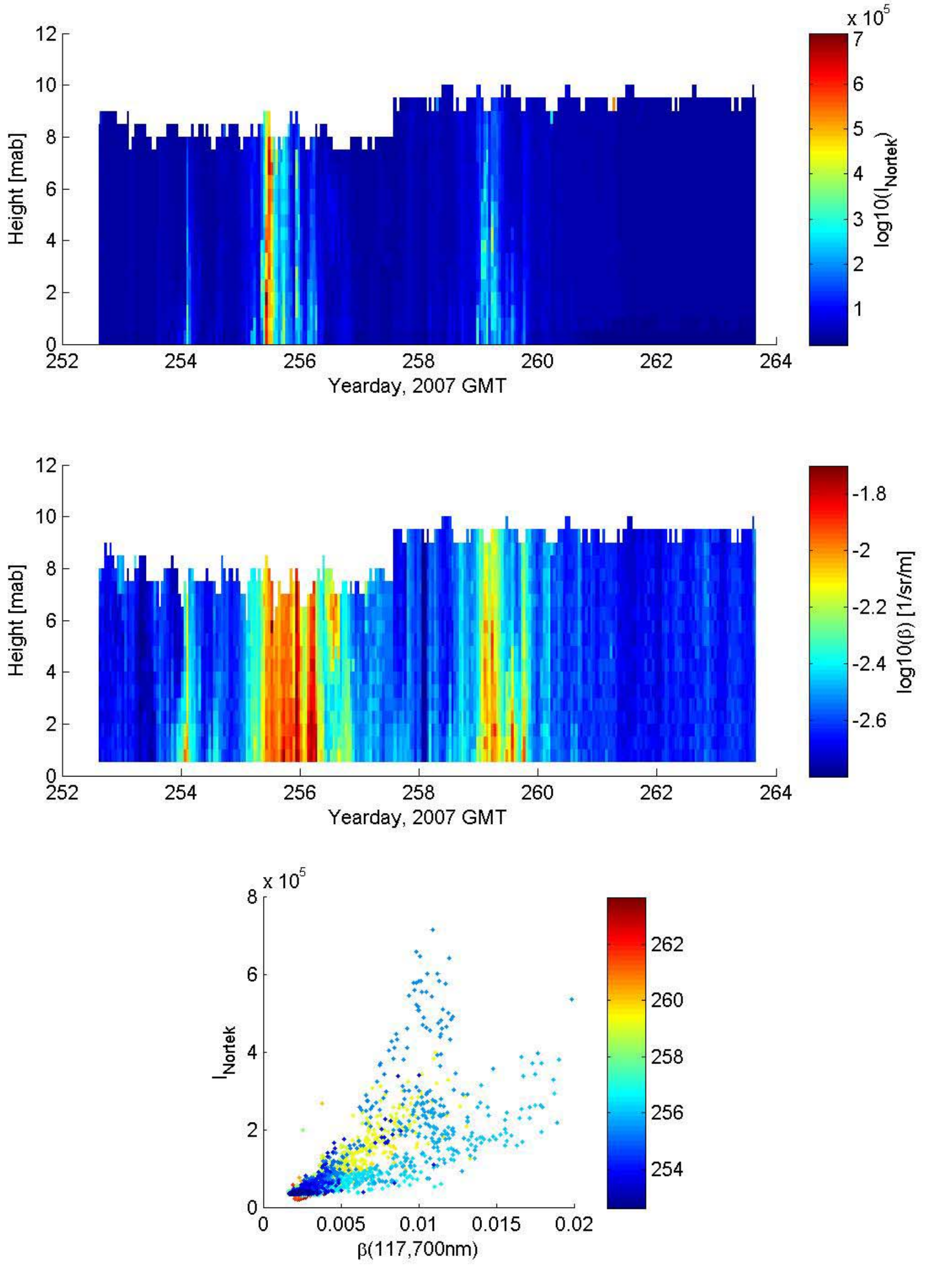

Figure 1. Time series of acoustical (top) and optical (middle) backscattering intensities as function of depth at MVCO in 2007 from the WET Labs profiler. Scatter plot of acoustic backscattering intensity vs optical backscattering intensity with color denoting year day. Correlation R=0.8. Similar correlations are obtained from the tripod time series.

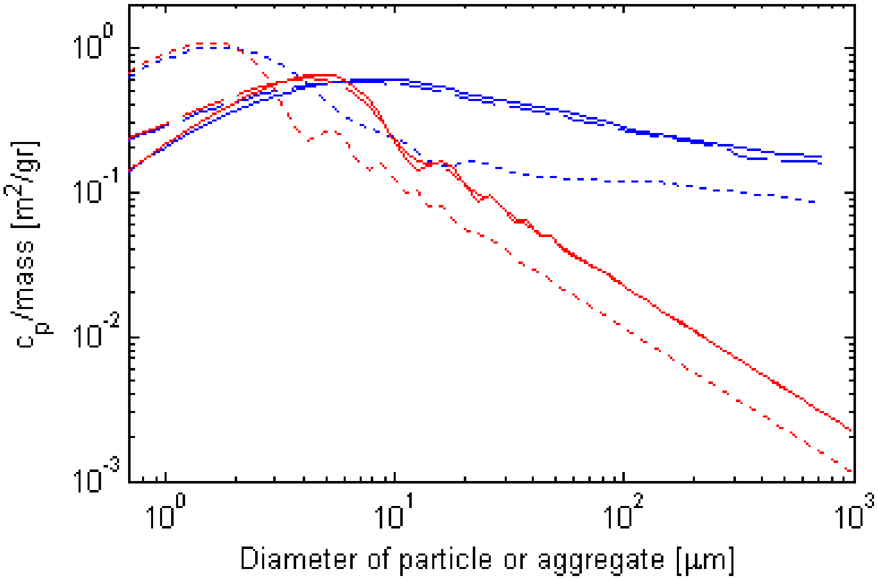

Figure 2. Mass normalized beam attenuation for aggregates assuming a relationship between fractal dimension and size as in Khelifa and Hill, 2006 (blue lines) and solid particles (red lines). Solid lines denote particles with n=1.05+i0.0001, dashed lines n=1.05+0.005 and dotted lines n=1.15+0.0001. Each data point represent a population of particle all of a single size.

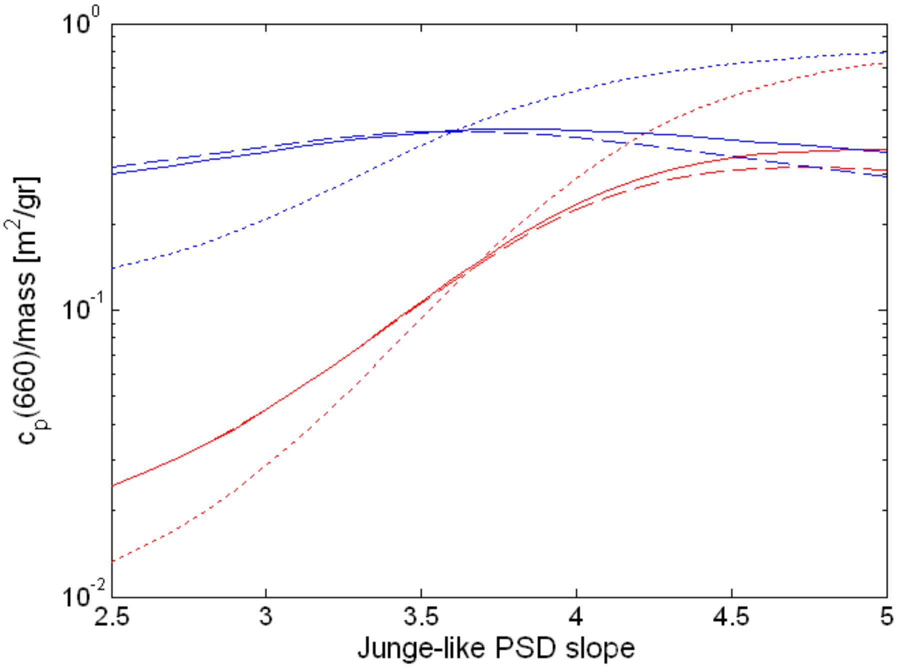

Figure 3. Mass normalized beam attenuation for populations of aggregates assuming a relationship between fractal dimension and size as in Khelifa and Hill, 2006 (blue lines) and populations of solid particles (red lines) both as function of power-law exponent of the disaggregated particle populations. Solid lines denote particles with n=1.05+i0.0001, dashed lines n=1.05+0.005 and dotted lines n=1.15+0.0001.

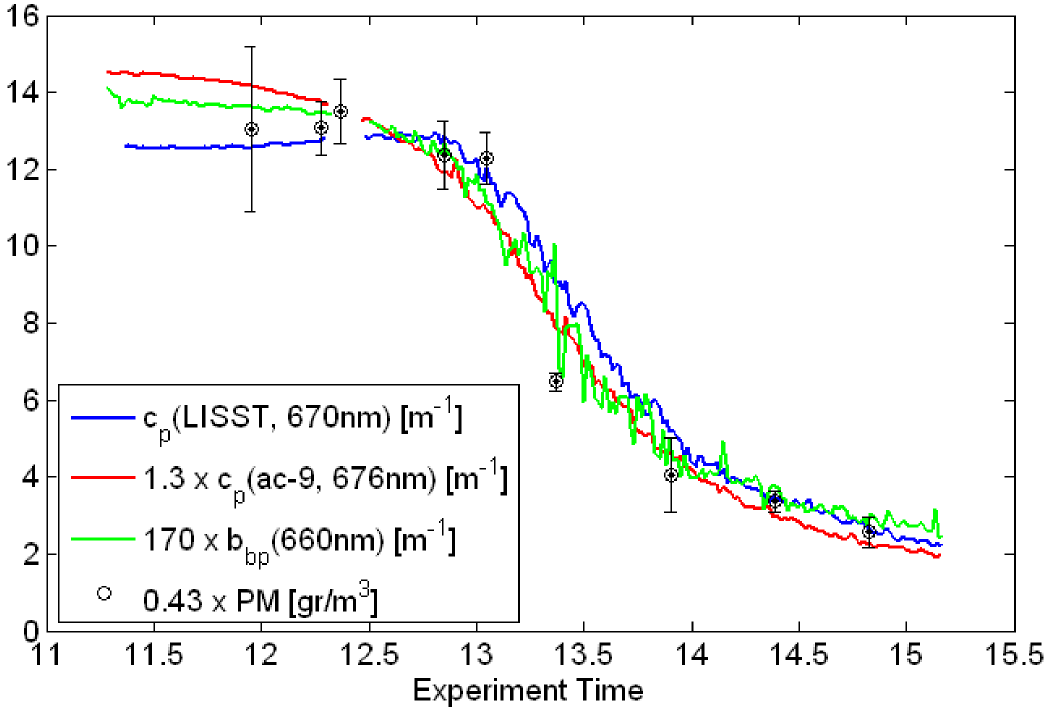

Figure 4. Time series of mass (symbols), beam attenuation measured by the LISST-B, beam attenuation measured by the ac-9 and backscattering coefficient during an aggregation experiment conducted in the summer of 2007. Notice the effect of settling after 12:30pm,

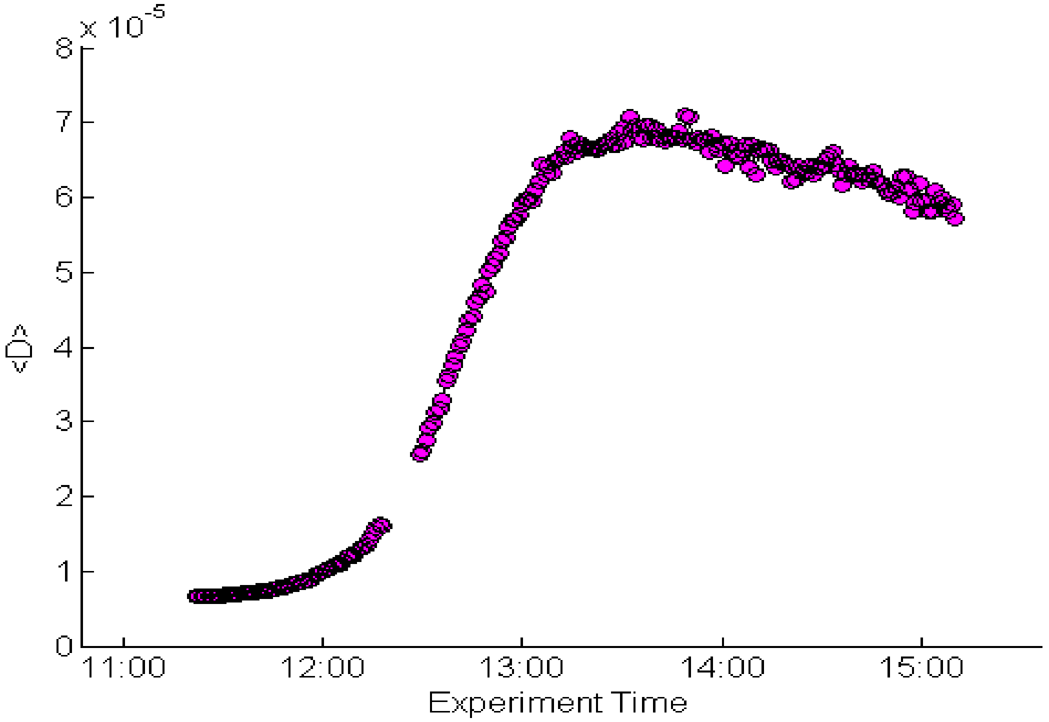

Figure 5. Time series of the mean diameter of aggregates as measured by the LISST-B and inverted from its scattering measurements during an aggregation experiment conducted in the summer of 2007. Independent confirmation from microscopy is available but not shown.