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

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LONG-TERM GOALS

In this Final Report on this Office of Naval Research contract, we demonstrate the successful completion of all proposed tasks. We have participated in a series of observational studies at the Woods Hole Martha's Vineyard Coastal Observatory where we collected high-quality physical, acoustical and optical data. The data has been processed demonstrating the close link between resuspension dynamics, particle aggregation and settling. Results indicate that contrary to existing models and interpretation, and based on theoretical, lab and field measurements, optical properties can predict suspended mass quite accurately due to the process of aggregation. Contrary to optical data, we find high frequency acoustics backscattering to be sensitive to aggregation suggesting that the ratio of acoustical to optical backscattering could provide a sensitive proxy to the degree of packaging of the suspended mass. Insight from this work will be applied shortly into an aggregation module in the community sediment transport model.

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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.

APPROACH

Our approach designed to achieve the above objectives consisted of several components:

1. Deployment of instrumented arrays at the 12m node of the Woods Hole Martha’s Vineyard Coastal Observatory (MVCO).

2. Laboratory experiments using suspension of known materials.

3. Numerical modeling of light interaction with idealized aggregates.

4. Analysis of our own and historical data sets.

WORK COMPLETED

The major thrust of our work involved the deployments at MVCO (in 2004, 2005, 2007 and 2009). MVCO 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.

The aim was to obtain (in collaboration with Hill, Milligan and Trowbridge) measurements that will permit comparisons of the optical and acoustical signatures of suspended particles, measurements of particle size distribution and its temporal evolution, concurrently with fluid dynamical measurements that determine the flow field within which the particles evolve.

Four sets of field measurements have been obtained, the first during August-September 2004, the second during August-September 2005, the third during August-September 2007 and the forth in September-October of 2009. The MVCO, off the southern coast of Martha's Vineyard, Massachusetts, 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, 2007 and 2009 measurements have been 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.

RESULTS

We have published several articles summarizing our results to date.

I. Effect of acceptance angle on optical beam-attenuation:
First we analyzed an extensive data set from OASIS using a variety of beam transmissometers (boss et al., 2009a). We found a strong sensitivity of beam attenuation to the acceptance angle (up to 40% difference between LISST and ac-9) that is variable in time in coastal ocean but rather constant in open ocean environment. In fact, we show that the acceptance angle acts as a filter on size distribution rendering the measurement interpretation size dependent. In areas where size varies a lot, as in coastal areas, this issue deserves attention, for example for visibility models that are based on the beam attenuation. These models could be improved if the size of the object and its distance (that is the spatial angle the object occupies within the field of view) were taken into account (currently they are not).

II. The use of optical measurements to assess particulate mass:
We have analyzed an extensive data set of optical properties and particulate matter collected as part of the Alliance of Coastal Technology from a variety of coastal sites in the US. This data set is unique in that it spans a large number of coastal sites (resolving tidal forcing) and with particulate mass (PM) samples measured by a single group hence minimizing technical variability. We find that beam attenuation at 660nm, side scattering at 880nm and backscattering at 700nm all predict PM within 50% or better for 95% of the sample with backscattering providing the best predictor (Boss et al., 2009b). These results are inconsistent with Mie theory which suggests that size will cause larger scatter between optical measurements and PM. We believe that aggregation, the process of focus of our project, is the cause of the relative consistency of PM-optical properties. This is good news as it suggest optical variable could provide a good constrain to sediment transport models (one of the goals in the continuation of our effort).

III. Effect of aggregation on optical properties:
Modeling of the optical properties of oceanic aggregates has been accomplished using an approach 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 were published (Boss et al., 2009c). 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). This model has been used by Milligan and Hill to provide optical output to a particle dynamics model that is forced with OASIS data.

We have conducted several lab experiments for two purposes: 1. devising an absolute calibration for commercial acoustical backscattering for PM. 2. Control aggregation experiments where clay aggregates were formed in the lab and their optical and acoustical properties tracked as they grew (see Fig1, 2 and 3). Mass normalized optical and acoustical properties change by less than 30% as size changes by a factor of 10(!). These experiments provide unique opportunities to isolate processes that dominate particle dynamics in the field (Fig. 4). We are currently trying to isolate their signature in field data.

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 result on acceptance angle could (and should) improve beam attenuation based diver-visibility algorithm.

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

RELATED PROJECTS

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

Another graduate student (Clementina Russo) is funded to study the link between acoustical and optical properties during OASIS (N000140910577 to E. Boss).

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HONORS/AWARDS/PRIZES

Ocean Optics XIX, 2008, best student paper by Wayne Slade for: Slade W. and E. Boss: Significance of particle aggregation on optical properties, Ocean Optics Conference, Barga, Italy.

PATENTS

None.

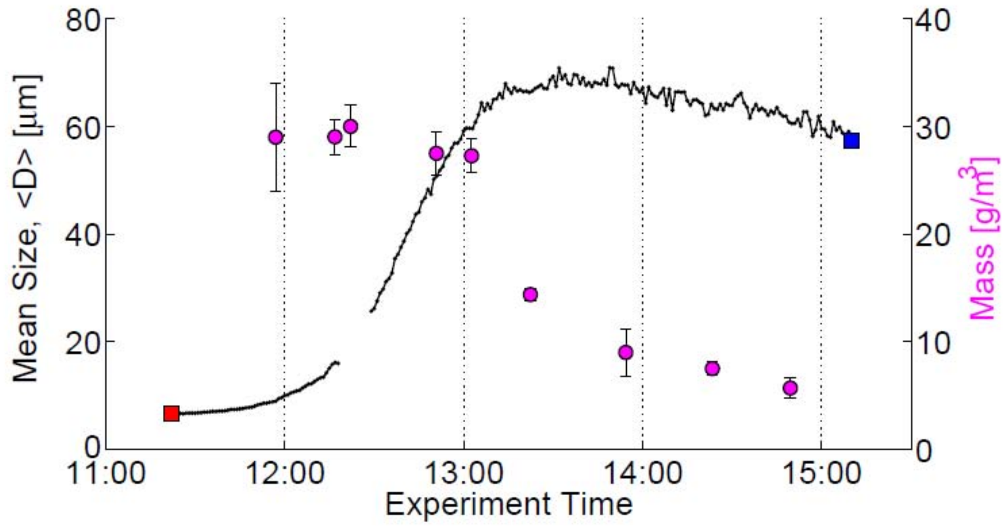

Figure 1. Time series of mass (blue spheres) and mean aggregate size (solid line). Squares represent microscopy derived mean particle size.

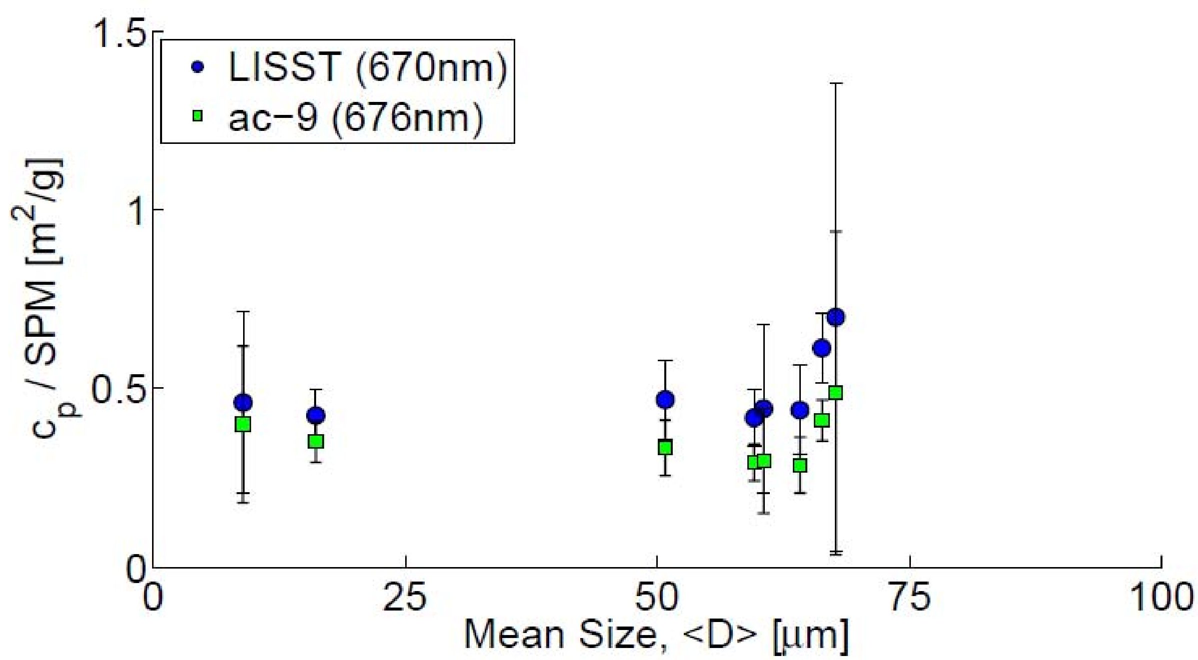

Figure 2. Time series of mass normaized beam attenuation measured by the LISST-B (blue) and ac-9 (yellow squares).

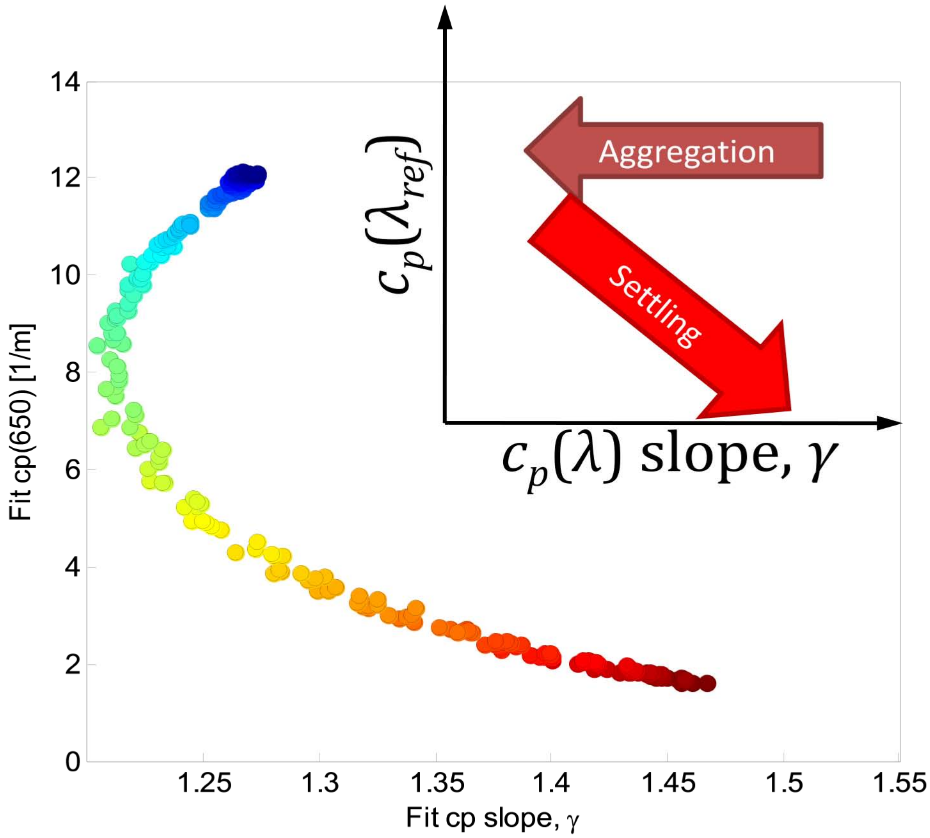

Figure 3. Aggregation settling dynamics during the laboratory experiment as observed in the c_p-γ phase space.

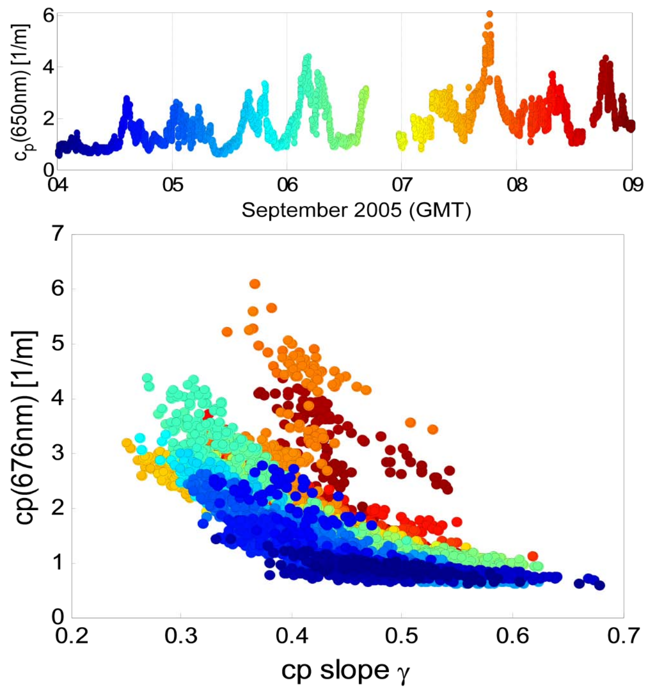

Figure 4. c_p-γ phase space of data collected during the 2005 OASIS deployment.