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.

SCIENTIFIC 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

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), LISST-100 and LISST-Floc laser diffraction particle sizers (Agrawal & Pottsmith 2000), a digital floc camera (DFC) (Curran et al. 2002), 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 LISSTs 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 LISSTs; 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.

Boss, Hill, and Milligan collaborate closely on this project. Together they are providing data and models on the flocculated size distribution of suspended sediment and on the optical and acoustical properties of the water column. Boss has responsibility for deployment of optical and acoustical sensors, and he is responsible for the deployment of the LISSTs. Milligan has responsibility for design and construction of the new DFC and components of the tripod. Hill takes responsibility for data interpretation and development of models. Wayne Slade is a graduate student at UMaine. Jim Loftine (UMaine), Brent Law (BIO) and Kristian Curran (Dal) provide support in the lab and field.

We also collaborate with John Trowbridge (WHOI) on this project. He is responsible for characterizing the stress in the bottom boundary layer during the deployments.

WORK COMPLETED

The tripod carrying particle, acoustic, and optic sensors was deployed in September 2004 and recovered in October 2005. The deployment was partially successful, yielding approximately 5 days of data when all sensors were functioning. Fouling degraded the observations after approximately 1 week, and the DFC failed after 5 days. The DFC housing suffered massive corrosion. The switch designed to isolate the contribution of particles to attenuation and absorption did not work properly.

Re-designs of the tripod, the ac-9 switch, and the DFC were completed in 2004-2005.

The re-designed tripod was deployed on September 3, 2005 and recovered on September 22, 2005. Measurements included particulate size distribution (DFC, LISST-100, 2-250μm and LISST-FLOC, 8μm-1mm), spectral attenuation and absorption by particles and dissolved material (ac-9 with a mechanical valve periodically sampling through a filter and with flow monitored with an underwater flow meter), spectral back scattering (bb-9), vertically resolved (128 1cm long bins) multi-frequency (4) acoustical back scattering (AQUAScat), dissolved and chlorophyll fluorescence, CTD and measurements of acoustic backscattering and 3-D velocity with two different acoustic Doppler velocimeters (Nortek and Sontek's ADV).

We were able to turn instruments on and off and download data in real time, and as far as we can tell (based on preliminary QC of the data) the data are of high quality for at least the first two weeks of the deployment. Some minor bio-fouling was observed on the window faces of the LISSTs upon retrieval of the tripod. The filters were replaced twice during the deployment, with the flow rate through them never falling under 1L/min (fresh filter had a flow of 2.5L/min). The DFC functioned properly, gathering 2300 images over the course of the deployment.

A tripod designed to measure aggregate settling velocity was deployed contemporaneously with the other tripod. It gathered four days of data before being tipped over by waves.

RESULTS

Results are preliminary. We have devoted most of our attention to gathering a full data set in the 2005 deployment. Nonetheless, some interesting results have emerged from analysis of the 2004 and 2005 data.

The magnitude and wavelength dependence of the attenuation undergo a regular pattern of evolution in response to stress events. The passage of Hurricane Ophelia illustrates the response of light attenuation (Figure 1). As stress due to tidal currents and waves increases, optical attenuation increases because of erosion and suspension of sediment from the seabed. It also increases due to the destruction of particle aggregates. Aggregates possess an overall smaller scattering cross section than the individual particles within them. Therefore, stress elicits a rapid rise in light attenuation. Under these conditions shorter wavelengths of light are attenuated more strongly than longer wavelengths. When stress relaxes, fine sediment particles re-combine into aggregates that, because of their relatively large size, scatter all wavelengths of light equally. The incorporation of small particles into large aggregates reduces the overall scattering area of the sediment in suspension, causing rapid reduction in the attenuation of light. The aggregates also have large settling velocities, so when stress falls enough to allow deposition of the aggregates, attenuation continues to fall rapidly. Aggregates have settling velocities of order 1 mm s^{-1}, so the bottom 2 m of the water column can clear in approximately 30 minutes. The rapid increase in water clarity following storms is important to naval operations in mixed sand-mud environments.

IMPACT/APPLICATIONS

The high resolution time series of particle, optical, and acoustical properties will enhance understanding of the rates and mechanisms by which the water column clears following storm events.

RELATED PROJECTS

Ongoing studies of the role of floc fraction in the transport of fine-grained sediment are funded by ONR Coastal Geosciences. Work is being carried out in the Gulf of Lions as part of the EuroSTRATAFORM project. (ONR N00014-04-1-0182)

The proposed parameterization of aggregation and disaggregation is being applied successfully to the interpretation of optical measurements gathered at the Coastal Mixing and Optics site by Oregon State University researchers. Collaborator is Emmanuel Boss (U.Maine).

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

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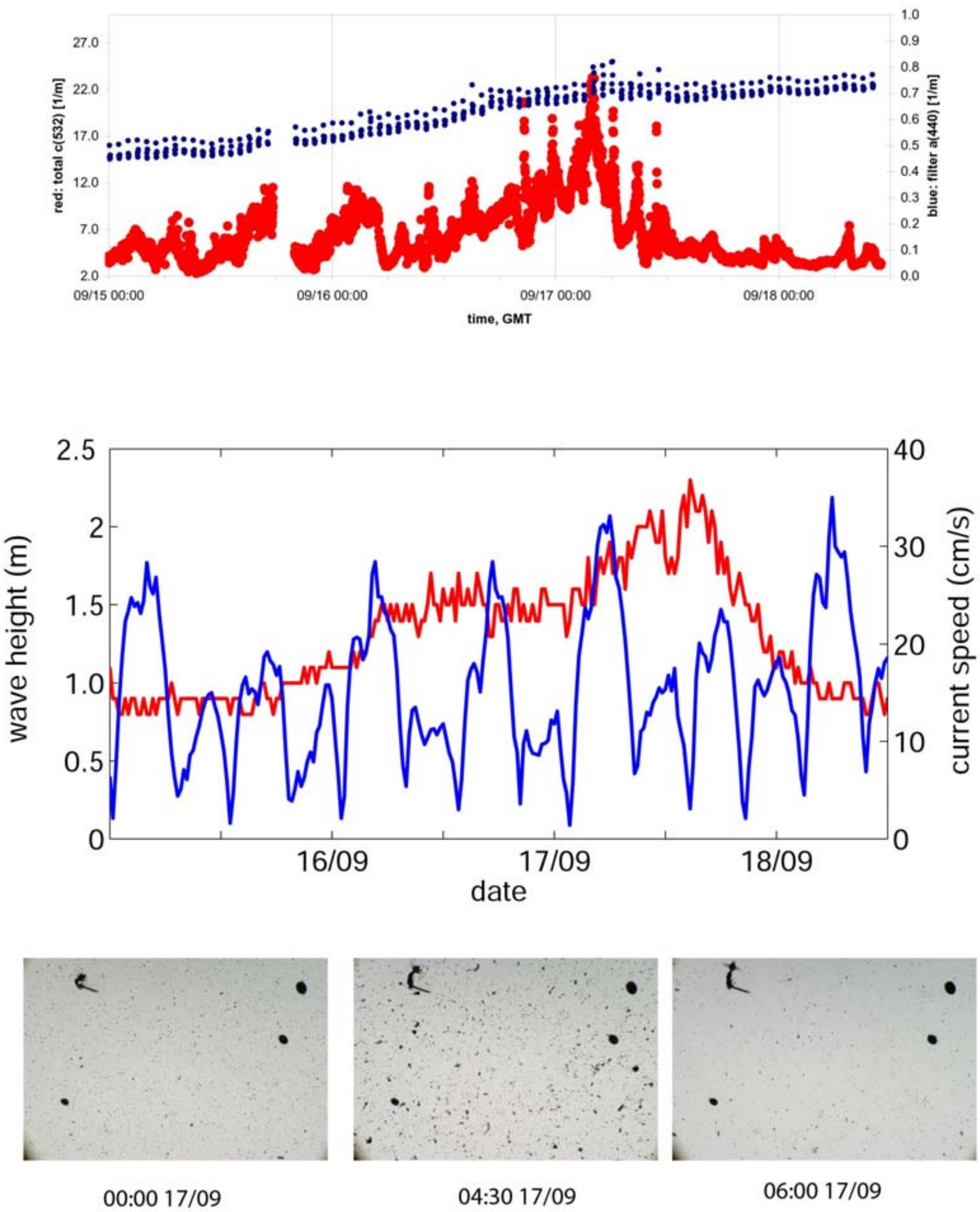

Figure 1. Time series of Particulate + dissolved Beam-attenuation at 532nm and dissolved attenuation at 440nm as function of time during the passage of hurricane Ophelia (9/15-18/2005) as recorded by an ac-9 moored 1.2m above bottom at the 12m node of the Martha's Vineyard Coastal Observatory (MVCO) (top panel), ADCP measurements of wave height and current speed measured at the same time (middle panel), and three digital floc camera images 1.2 m above bottom at the height of the storm. Field of view for images is 4cm x 3cm x 2.5cm deep. [Beam attenuation increases rapidly in the early morning hours of 17/09, when wave and currents are both large. When stress is high, floc size is small. By 04:30, current speed falls enough to allow extensive and rapid formation of large flocs. These flocs sink rapidly to the seabed, so by 06:00, the water column is relatively clear.]