Optics, Acoustics and Stress in Situ (OASIS): Effects of Aggregation, Vertical Structure, and Relation to Physical Forcing.

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TITLE:	**Optics, Acoustics and Stress in Situ (OASIS): Effects of Aggregation, Vertical Structure, and Relation to Physical Forcing.**
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PROPOSAL SUBMITTED IN COLLABORATION WITH DRS PAUL HILL (DALHOUSIE), JOHN TROWBRIDGE (WHOI) AND TIM MILLIGAN (BIO).

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Abstract

Nearbed optical and acoustical properties in coastal waters are determined by particle concentration, composition, and size distribution, all of which can change in response to erosion, deposition, advection, and particle aggregation and disaggregation. Aggregation and disaggregation rates depend on sediment concentration and turbulence in the water column, which in turn are functions of wave- and current-generated shear stresses, distance from the bottom, and stratification. The overarching goal of this research is to use in situ observations to evaluate and improve models of the mechanistic links between physical forcing, particle concentration, particle size distribution, particle composition and optical and acoustical properties near the seabed. Over the past three years, we have gathered and analyzed a comprehensive time series of these varaibles at the Martha's Vineyard Coastal Observatory (MVCO). These data so far have revealed rapid changes in particle size distribution mediated by aggregation, disaggregation, and particle settling. The particle size distribution plays an important role in determining the wavelength dependence of optical beam attenuation as well as affecting the magnitude of error associated with the confusion of light scattered in the near forward direction with transmitted light.

In this round of research we propose two field deployments at MVCO during which we will gather the same data as in the first round of research. In addition we propose to characterize particle sinking with in situ observations, to collect water samples to ground-truth optical and acoustical estimates of sediment concentration and to monitor compositional variability in suspension, and to gather vertical profiles of optical and particulate properties.

The proposed research will be carried out collaboratively by Emmanuel Boss from the University of Maine, Paul Hill from Dalhousie University, Tim Milligan from the Bedford Institute of Oceanography, and John Trowbridge from the Woods Hole Oceanographic Institution. The four principal investigators are submitting companion proposals with nearly identical text but different budgets.

Scientific Plan

Rationale

Naval operations in the nearshore environment are complicated by bottom nepheloid layers, which are nearbed layers of enhanced sediment concentration generated by resuspension of particles from the seabed forced by waves and currents. The enhanced sediment concentration increases optical and acoustical attenuation, which compromises underwater navigation, communication, and object detection and recognition.

Background

Optical and acoustical attenuation in nepheloid layers depends on sediment concentration, composition, and size distribution (e.g. Boss et al., 2001). Dependence on particle size distribution proves particularly problematic to prediction of water column properties, because size distributions in nearshore waters are affected by aggregation and disaggregation (Mikkelsen et al., 2006).

Aggregation and disaggregation rates are controlled by sediment concentration and turbulence. When turbulence intensity is weak to moderate, concentration controls the degree of aggregation, with high concentrations associated with a high degree of packaging within flocs (Curran et al., 2002). Eventually, however, increasing turbulence causes disaggregation rate to increase to the point where it overwhelms the aggregation rate, and floc sizes fall (Hill et al., 2001; Agrawal and Traykovski, 2001). Because turbulence levels vary with depth in bottom boundary layers, the rates of aggregation and disaggregation do as well. Resultant changes in floc packaging affect fundamentally the optical and acoustical properties of the water column.

Observations of physical forcing, sediment properties, and optical and acoustical properties are scarce. The scarcity of data leaves elements of any model linking physical forcing, particle size, and water column properties essentially uncalibrated. The goal of the OASIS (**O**ptics, **A**coustics, and **S**tress **I**n **S**itu) program is to gather time series of vertically distributed, co-located observations of shear stress, stratification, dissipation, sediment concentration, sediment size distribution, sediment composition, and multi-spectral optical and acoustical properties in a nearshore bottom boundary layer. These observations will be used to evaluate and improve models of the characteristics of the suspended particles and their effect on optics and acoustics.

In the first phase of OASIS, equipment was deployed in 2004 and 2005. The 2005 deployment was successful, and the data from it reveal rapid changes in the particle size distribution that are accompanied by distinct changes in the optical properties. For example, from September 5-7 there are three periods when the relative abundance of single grains and mircoflocs rises while the proportion of macroflocs falls (Figure 1). “Single grain” is a catchall term for particles with diameters smaller than 36 μm, “microfloc” describes particles with diameters between 36 and 133 μm, and “macrofloc” refers to particles with diameters greater than 133 μm (Mikkelsen et al., 2006). Conceptually, single grains combine to form microflocs, which can then combine to form macroflocs. Macroflocs can break to form microflocs, which themselves resist disruption by fluid forces. The periods characterized by smaller particles occur at times when the attenuation of light is low and the “slope” of the attenuation spectrum (cf. Boss et al., 2001) is high (Figure 1). These periods occur when wave height is low and current speed is near zero (Figure 1). One explanation for these correlations is that at slack water, large flocs settle out of suspension, leaving the boundary layer relatively enriched in slowly sinking microflocs and single grains. The loss of large flocs to deposition drives beam attenuation down and the slope of the attenuation spectrum up. Large flocs have a flat attenuation spectrum while small single grains attenuate decreasing amounts of light with increasing wavelength. After September 7 wave height increases, and the increase is accompanied by an overall increase in the proportion of single grains and microflocs in suspension. The change in the size distribution likely arises due to increased disaggregation caused by increased wave-induced stress on the seabed.

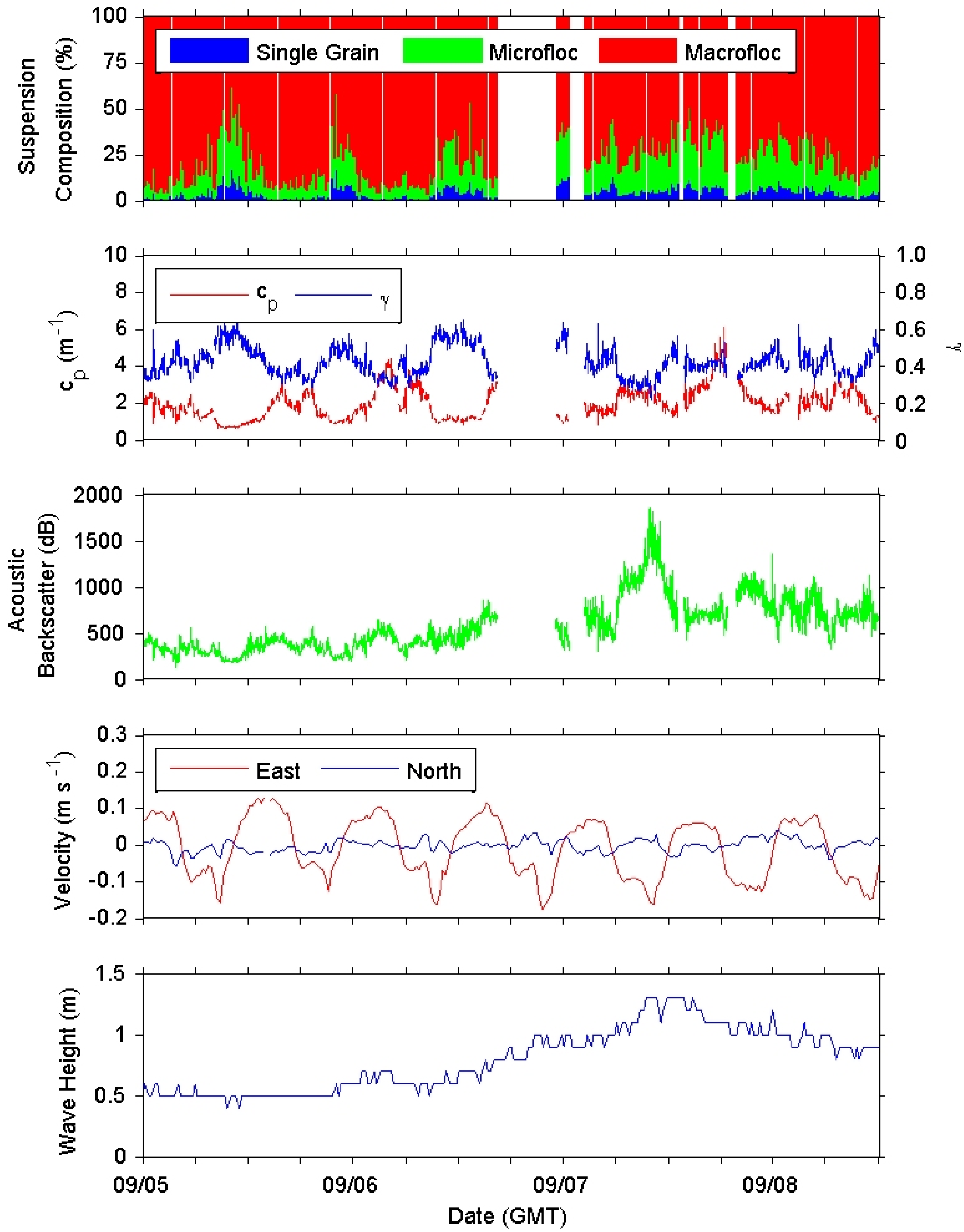

Figure 1. Properties in the boundary layer at MVCO during September 2005. The top panel shows the fractional contribution of three nominal size classes to the suspended sediment at 1.2 meters above the bottom. The next panl shows beam attenuation and the "slope" (Boss et al., 2001) of the attenuation spectrum at the same height. The third panel displays acoustic backscatter as measured by an ADV, and the fourth shows currents measured at the 12-m node. The bottom panel shows significant wave height. Early in the record, there are three periods when the proportion of macroflocs falls. These periods occur when beam attenuation is low, and the spectrum of beam

attenuation is steep. The periods are associated with zero velocity and low waves. These data indicate that when bed shear stress is low, macroflocs deposit on the bed, thereby enriching the suspension in fine. Later in the record, wave height increases, producing a decrese in the proportion of macroflocs, likely from floc breakup. The acoustical properties of the water column respond differently than the optical properties, likely due to differential response of optical and acoustical devices to flocs.

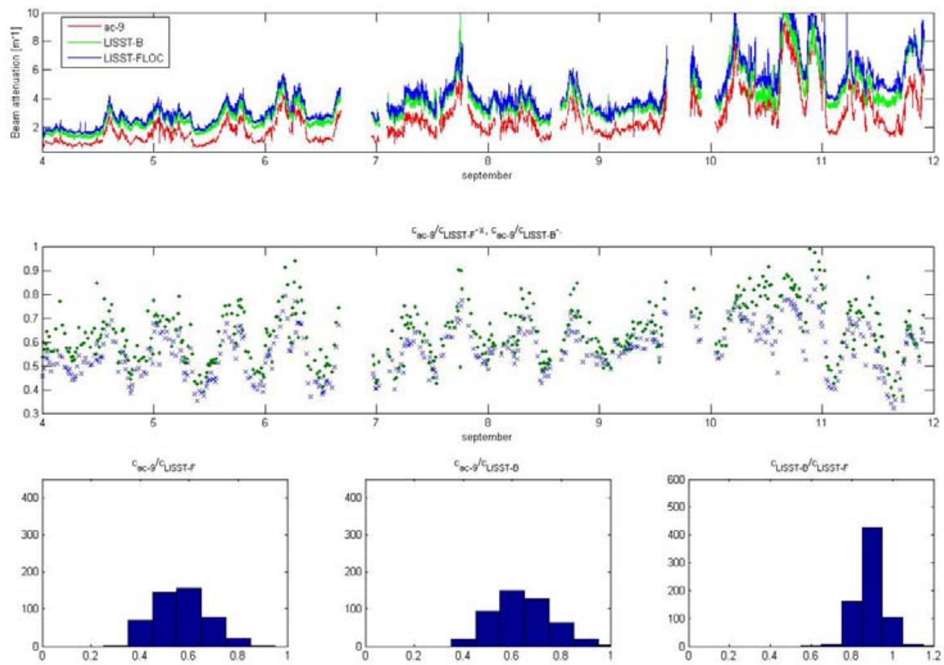

Figure 2. Time series of beam attenuations from different tranmissometers (top panel), of the ratios between the beam attenuation coefficients from the different instruments (middle panel) and probability densities of the different ratios (bottom panels). The ac-9 and the two LISSTs all measure transmitted light, yet they each have a different acceptance angle for defining how much light is transmitted versus scattered in the near forward direction. When the size distribution is rich in macroflocs (see Figure 1), estimates of beam attenuation converge, because all instruments characterize the near forward scatter from large flocs as transmitted light. When the suspension becomes richer in microflocs, estimates of beam attenuation diverge. Instruments with a wider acceptance angle (ac-9 > LISST-B > LISST-F) treat more of the light scattered in the near forward direction by microflocs as tranmitted, so they have a lower beam attenuation coefficient.

The 2005 OASIS data show in general the linkages among physical forcing, particle concentration and size, and optical properties. They also expose some unexplained sources of variability. For example, beam attenuation increases, presumably due to resuspension, when currents flow eastward. Yet when currents flow westward with similar intensities, beam attenuation does not increase (Figure 1). Not all changes in beam attenuation, therefore, are forced by local resuspension and deposition. Apparently, advection also plays a role.

Also, acoustical properties of the water column respond differently to changes in particle properties than do optical properties (Figure 1). Acoustic backscatter remains low during September 5-7, when optical attenuation is variable. A peak in acoustic backscatter appears on the 7th, but it is not accompanied by a large peak in the beam attenuation coefficient. Understanding of such differential responses among sensors requires better knowledge of particle density and composition.

The deployment of several different transmissometers during OASIS has revealed that the response of transmissometers to changes in particle size is affected by sensor geometry (Figure 2). Macroflocs are large relative to the wavelength of light, so they scatter much of the light incident upon them in the extreme near forward direction. All tranmissometers have a wide enough acceptance angle to characterize this near-forward scattered light as transmitted. Microflocs, because they are smaller, scatter light over a wider range of near forward angles than macroflocs. As a result, a transmissometer with a wide acceptance angle characterizes a greater fraction of this scattered light as transmitted light than does a transmissometer with a narrow acceptance angle. When a suspension is rich in microflocs, an instrument with a wide acceptance angle will produce lower estimates of the beam attenuation coefficient than an instrument with a narrow acceptance angle. When a suspension is richer in macroflocs, estimated beam attenuations from instruments with different acceptance angles converge.

These preliminary results from the first phase of OASIS show clearly that particle concentration and size distribution change in response to resuspension, deposition, aggregation, disaggregation, and advection. These changes produced marked responses in the optical and acoustical properties of the water. They also affect sensor-dependent relationships between estimated and actual water column properties. With the 2005 data, however, it is difficult to identify unambiguously which physical processes drive changes in the water column properties.

During a February 2006 workshop, the 2005 data were discussed. Based on these discussions, plans for the next phase of OASIS were developed. In particular, important additional measurements were identified. First, a need to ground-truth estimates of particle concentration was identified. Second, constraint needs to be placed on particle composition. Third, particle sinking time scales need to be characterized. Fourth, vertical profiles of water column optical and particle properties need to be measured in order to examine the effects of advection and water-column stratification. Finally, a lab-based, instrument calibration facility was identified as desirable. In this facility, particle size distribution would be measured at the same time as optical and acoustical properties.

Technical Approach

Site Description

We propose to make measurements at the Martha's Vineyard Coastal Observatory (MVCO), maintained by the Woods Hole Oceanographic Institution (WHOI; http://www.whoi.edu/mvco/description/description2.html). The MVCO includes a small shore lab located between the hangars at Katama Air Park, a 10-m meteorological mast near the South Beach Donnelly House, a subsurface node mounted in 12-m water depth approximately 1.5 km south of Edgartown Great Pond, and an air-sea interaction tower (ASIT) equipped with a top-side node to allow access to air-side or underwater instrumentation at the 15-m isobath. The meteorological and subsea instrumentation are connected directly to the shore lab via a buried electro-optic power cable. The core set of instruments at the meteorological mast measure wind speed and direction, temperature, humidity, precipitation, CO2, solar and IR radiation, momentum, heat, and moisture fluxes. The core oceanographic sensors at the 12-m offshore node measure current profiles, waves, temperature, salinity, and near-bottom wave-orbital and low frequency currents. In addition to the core set of instruments, the offshore nodes and the meteorological mast act as “extension cords” into the coastal environment, allowing connection of a wide range of instruments for prolonged deployments.

Our 2005 data come from the 12-m node. We propose to re-occupy this site in the second phase of OASIS.

Proposed Measurements

We propose two field seasons, during which the instruments deployed in 2005 will be used again and several new sets of measurements will be made. A bottom tripod will be deployed at the 12-m node. It will be instrumented with a 9-wavelength optical attenuation and absorption meter (WetLabs ac-9, with automated regular dissolved measurement for calibration independent particulate measurements), a LISST-100b and LISST-100floc laser diffraction particle sizers (Agrawal and Pottsmith, 2000), a digital floc camera (DFC) (Curran et al., 2002b), an Aquatec four frequency acoustic device (Aquascat), a Tracor Acoustic Profiling System (TAPS, Holliday, 1987, through a collaboration with P. Jumars of U. Maine), and an array of three SonTek/YSI acoustic Doppler velocimeters (ADVs) that operate at 5, 10, and 16 MHz respectively. We plan to modify the DFC to allow us to take an image every 15-30 seconds. This high temporal resolution will allow us to resolve changes in the size distribution due to settling and resuspension. Near-simultaneous measurements with and without a filter will assure high-quality particulate spectral absorption and attenuation measurements with the ac-9. The LISST-100s and floc camera together will provide particulate size distributions from 1.25 micrometers to 1 centimeter. The Aquascat obtains range-gated, vertical profiles of acoustical backscatter intensity at four frequencies between 1.0 and 5.0 MHz. The TAPS obtains range-gated, vertical profiles of acoustical backscatter intensity at a range of six frequencies between 0.3 and 3.0 MHz. The TAPS, Aquascat and ADVs will produce acoustical measurements over a wide range of frequencies that can be used to generate particle size distributions (Holliday, 1987; Hay and Sheng, 1992). These measurements will provide a comprehensive description of the suspended particles and optical and acoustical properties near the seabed. Nearbed hydrodynamics will be characterized with a combination of ADCP and ADV data collected at the 12-m node and the nearby ASIT site.

To quantify particle settling and composition, we propose to deploy a modified version of the INSSECT tripod (**I**n **S**itu **S**ize and **SE**ttling **C**olumn **T**ripod, Mikkelsen et al., 2004). The INSSECT will carry a digital floc camera, a LISST-100 (recently funded by Canada’s Natural Sciences and Engineering Research Council), a settling column modified to operate effectively in the relatively energetic waters of the MVCO, and an automated water sampling system. A McLane water sampling system available at Bedford Institute of Oceanography will be mounted onto INSSECT. This system has a

25-filter capacity. Half of the filters will be used to quantify total organics, and the other half will be used to measure the component grain size of inorganic particles in suspension.

Vertical profiles of particulate and optical properties will be gathered in three ways. First, Scott Gallagher's profiling mooring will be instrumented with an ac-9 and a LISST-100. This general plan has been cleared with Gallagher and is included in John Trowbridge's budget. Second, periodic shipboard profiling with a floc camera, LISST-100, and ac-9 is proposed. Third, we understand that a proposal to deploy a WetLabs profiling mooring equipped with various optical sensors has been submitted by Mike Twardowski and Andrew Barnard of WETLabs.

During the 2007 and 2008 field years, 2 back-to-back tripod deployments are planned. The large "OASIS" tripod would go into the water near September 1, and it would be recovered approximately 10 days later. After a several day turnaround, the equipment would be re-deployed. Recovery would again be approximately 10 days later. Based on our experience in 2005, the deployment duration is set to be as long as possible without significant optical fouling. This schedule will produce observations that span the transition from stably stratified, relatively quiescent conditions, typical of summer, to variably stratified conditions with strong, intermittent wind forcing, typical of fall. This range of forcing conditions will produce a wide range of particle concentrations and sizes, with corresponding variability of acoustical and optical properties of the water column. We propose that the initial deployment and recovery and the second deployment occur from the deck of the *R/V Connecticut*. The second recovery would use the *R/V Tioga*.

The INSSECT would be used in a series of 1- or 2-day deployments throughout the first sampling period. These short deployments would permit characterization of tidal variability in particle size, settling velocity and composition. Evolution of these properties over the course of the 10-day sampling period would help to characterize longer term variability. During the second sampling period, the INSSECT would be left in the water for the entire time, gathering a longer time series with reduced temporal resolution.

During the first tripod deployment we propose to have a ship in the area that could be used for shipboard profiling. Ideally, the *R/V Connecticut* could be employed on a shared basis with researchers in the ONR Ripples DRI, which may have a 2007 field season planned for the same area at the same time. Hourly casts would be taken near the 12-m node.

Instruments will be deployed on the Gallagher profiling mooring for the entire study period. Instruments would be serviced midway through that period.

A laboratory study of the effect of aggregation on acoustics and optics will be conducted at the U. of Maine. A "flocatron" will be assembled where aggregates can be generated, manipulated, sampled and measured with acoustical and optical sensors. There is currently no model for the effect of aggregation on mass specific optical and acoustical properties. We have some theoretical expectations that can be explored most fully in a controlled environment.

Proposed Analysis

The analysis will capitalize on ongoing oceanic and atmospheric measurements of temperature, density, and velocity at the MVCO, which will determine the wind stress and bottom stress (Trowbridge, 1998; Shaw and Trowbridge, 2001) and the shear and stratification throughout the water column. These measurements will characterize the fluid throughout the water column, which in turn will permit evaluation and improvement of models of coupled particle and fluid dynamics.

The analysis will focus on estimating Reynolds stresses, dissipation rates, and effective vertical diffusivities for mass, heat, and momentum from the fluid mechanical measurements; estimating particle size distribution and concentration from the DFC and LISST-100; and estimating the optical and acoustical properties of the water column from analysis of the ac-9, TAPS, and ADV data. The analysis will evaluate and improve a one-dimensional (vertical), time-dependent model of the particle size and concentration fields and the accompanying optical and acoustical properties. The model will include 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. Model evaluation and calibration will integrate data both from the bottom tripod and from the vertical profiles.

Division of Labor

The proposed research involves close collaboration among 4 principal investigators: Emmanuel Boss from the University of Maine, Paul Hill from Dalhousie University, Tim Milligan from Bedford Institute of Oceanography, and John Trowbridge from Woods Hole Oceanographic Institution. Boss is responsible for characterization of water column optical and acoustical properties. Hill and Milligan are responsible for measuring particle concentration, size distribution, composition, and settling velocity. Trowbridge is responsible for boundary layer hydrodynamics.

Ship Time

We propose to employ the *R/V Connecticut* for the first half of the sampling period in September 2007 and 2008. From this vessel we would deploy the OASIS tripod, recover it 10 days later and redeploy it two days after that. We would deploy the INSSECT for several 1- to 2-day periods. We would also use the vessel to conduct vertical profiling. In total, up to two weeks of *Connecticut* time is requested. This request could be reduced by sharing time with researchers from ONR's Ripples DRI, which may have field work scheduled for the MVCO at the same time in 2007. We request 2 days of R/V Tioga time for recovery the OASIS tripod and recovery of the INSSECT at the end of the experiment.

Summary and Expected Significance

We propose to extend and enhance an observational study designed to provide a critical evaluation of existing conceptions of the dynamics of suspended particles and their effects on the optical and acoustical characteristics of the water column. The proposed observations will be carried out at the Martha's Vineyard Coastal Observatory, and they will capitalize on routinely gathered fluid dynamical measurements at that site. The routine measurements will be complemented by an array of bottom-mounted and profiling acoustical and optical instrumentation designed to determine the particle concentration and size distribution and the effect of particles on optics and acoustics. The measurements will be used to evaluate a state-of-the-art model of particle dynamics, and will lead ultimately to model improvements and enhanced capabilities for predictions and interpretations of suspended sediments and the associated acoustical and optical fields. Laboratory experiments will provide inputs necessary to model how aggregation affects optics and acoustics.

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Curriculum Vitae of Emmanuel S. Boss

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Education

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Experience

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