

## **Flocculation, Optics and Turbulence in the Community Sediment Transport Model System: Applications of Oasis Results**

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### **LONG-TERM GOALS**

The goal of this research is to develop greater understanding of 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.

### **APPROACH**

The approach is to obtain measurements that permit comparisons of temporal evolution of bottom stress, suspended particle size, and optical and acoustical properties in the bottom boundary layer. The instrumentation is mounted on bottom tripods. Our **Modified IN Situ Size and Settling Column Tripod (MINSSECT)** has been deployed multiple times in four different field years to measure optical beam attenuation, suspended particulate mass and particle size distributions. The MINSSECT is

instrumented with a Sequoia Scientific LISST-100x Type B laser particle sizer and a Digital Flocc Camera (DFC) to measure a range of particle diameters from approximately 2  $\mu\text{m}$  to 4 cm. The LISST also measures the beam attenuation coefficient,  $c_p$ . Size-versus-settling-velocity measurements are made with a digital video camera that images a slab of fluid in a settling column. These measurements are used to estimate particle density as a function of particle size, which in turn allows estimation of suspended particulate mass (SPM) based on particle size distributions measured with the LISST and DFC. MINSSECT has an in situ water filtration system (McLane Research Laboratories, Inc. Phytoplankton Sampler) for direct measurements of SPM concentration. All instruments are mounted so the centers of the measuring volumes are located 1.2 m above the sea bed. Optical and acoustical properties of the water column are measured by Emmanuel Boss' group from University of Maine, and turbulence in the boundary layer is characterized by John Trowbridge at Woods Hole.

The modeling work is focusing on accurate characterization of the sediment mass in three suspended size classes. Single grains are smaller than 30  $\mu\text{m}$  diameter, and at this point are given a settling velocity of zero. The only way for these particles to clear the boundary layer is to become incorporated into microflocs or macroflocs. Microflocs are aggregates with diameters less than 100  $\mu\text{m}$  and a uniform average settling velocity of 0.1  $\text{mm s}^{-1}$ . Macroflocs are large flocs with diameters of greater than 100  $\mu\text{m}$  and a uniform average settling velocity of 1  $\text{mm s}^{-1}$ . Mass moves among size classes at rates determined by suspended sediment concentration and turbulent-kinetic-energy dissipation rate, which is a function of boundary shear stress due to waves and currents.

Hill, Law, and Milligan collaborate closely on this project. Together they are providing data and models on the flocculated size distribution of suspended sediment. Law, Milligan, and Hill have responsibility for the MINSSECT. John Newgard (Dal) and Vanessa Page (BIO) provide support in the lab and field.

As mentioned, we collaborate with Emmanuel Boss (UMaine) and John Trowbridge (WHOI) on this project. Boss is responsible for all optical and acoustical characterization of the water column. He has also conducted laboratory manipulations of the particle size distribution in order to explore the effect on optical attenuation. Boss and Hill have worked together on an optical model of marine aggregates. John Trowbridge is responsible for characterizing the stress in the bottom boundary layer during the deployments. We are working with Chris Sherwood from the USGS in Woods Hole on incorporation of our results into the Community Sediment Transport Modeling System (CSTMS). We are working with Dave Bowers at the University of Bangor in Wales to examine the effect of particle composition on optical properties.

## **WORK COMPLETED**

Work in 2010-2011 focused on four areas. First, we worked on publication of results from past field experiments. Second, we prepared for another field season in September and October of 2011 at the Martha's Vineyard Coastal Observatory. Third, Hill spent time at the University of Bangor in Wales in order to collaborate with Dave Bowers in exploring how component particle composition affects the ratio of particulate beam attenuation to suspended particulate mass in suspension. Finally, we worked on developing a simple model of the distribution of mass among size classes in suspension.

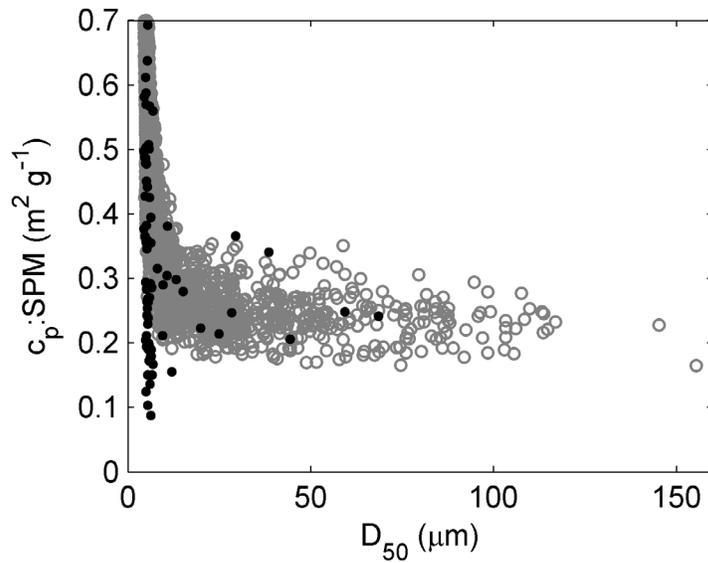
## RESULTS

With our past OASIS support we have gathered three one-month-long time series of observations linking physical forcing, sediment concentration and size distribution, and optical properties. We are collecting a fourth data set in September and October 2011. Over a range of environmental conditions, the conversion from SPM to optical properties is more predictable than the theory that assumes constant-density particles suggests. The broad conclusion that can be drawn from our work is that particle and optical properties are easier to predict when the stress on the seabed is adequate to resuspend particles. When stresses are too low to resuspend sediment, biology and chemistry determine the concentration, composition, and size of particles in suspension, so biology and chemistry also determine optical properties. When stress grows large enough to resuspend particles, however, particle and optical properties are more closely linked to physical forcing, which is fundamentally more predictable. As well, the composition of particles becomes more uniform with increasing stress.

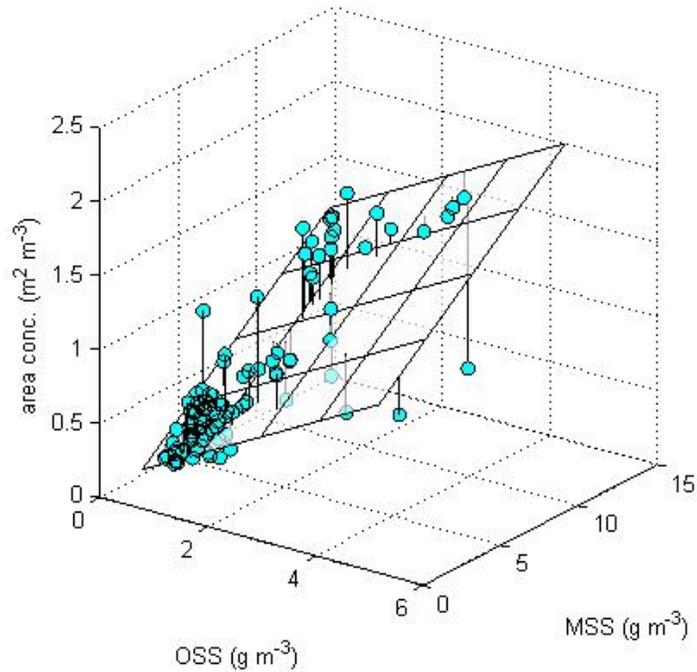
We have used data from OASIS 2007 to examine the lack of sensitivity of particulate beam attenuation to particle size. Estimated *SPM* and measured  $c_p$  from the LISST were linearly correlated throughout the experiment, despite wide variations in particle size. The slope of the line, which is the ratio of  $c_p$  to *SPM*, was 0.22. Individual estimates of  $c_p$ :*SPM* were between 0.2 and 0.4 for volumetric median particle diameters ranging from 10 to 150  $\mu\text{m}$  (Figure 1). The wide range of values in  $c_p$ :*SPM* found in the literature, which has usually been blamed on variable particle size, instead likely results from three factors capable of producing factor-of-two variability in the ratio: particle size, particle composition, and differences among acceptance angles of commercial beam-transmissometers. This work has been published in *JGR Oceans* (Hill et al., 2011).

A corollary of our result that particle size only accounts for a fraction of the observed variability in  $c_p$ :*SPM* is that particle composition must cause this ratio to vary. Unknown, however, is how much variability particle composition is likely to produce. . If composition varies independently from particle packing geometry within aggregates, then a 2x range in variability is expected. Alternatively, if composition affects particle packing geometry, then a greater than 2x range in variability is possible. We did not collect data on compositional variability in this project, but Dave Bowers at University of Bangor routinely measures mineral and organic fractions in SPM. In May, Paul Hill spent two weeks in Wales to explore the effect of particle composition on  $c_p$ :*SPM*. Preliminary results indicate that composition is not correlated with particle packing geometry, so particle composition produces a factor of 2 variability in  $c_p$ :*SPM* (Figure 2).

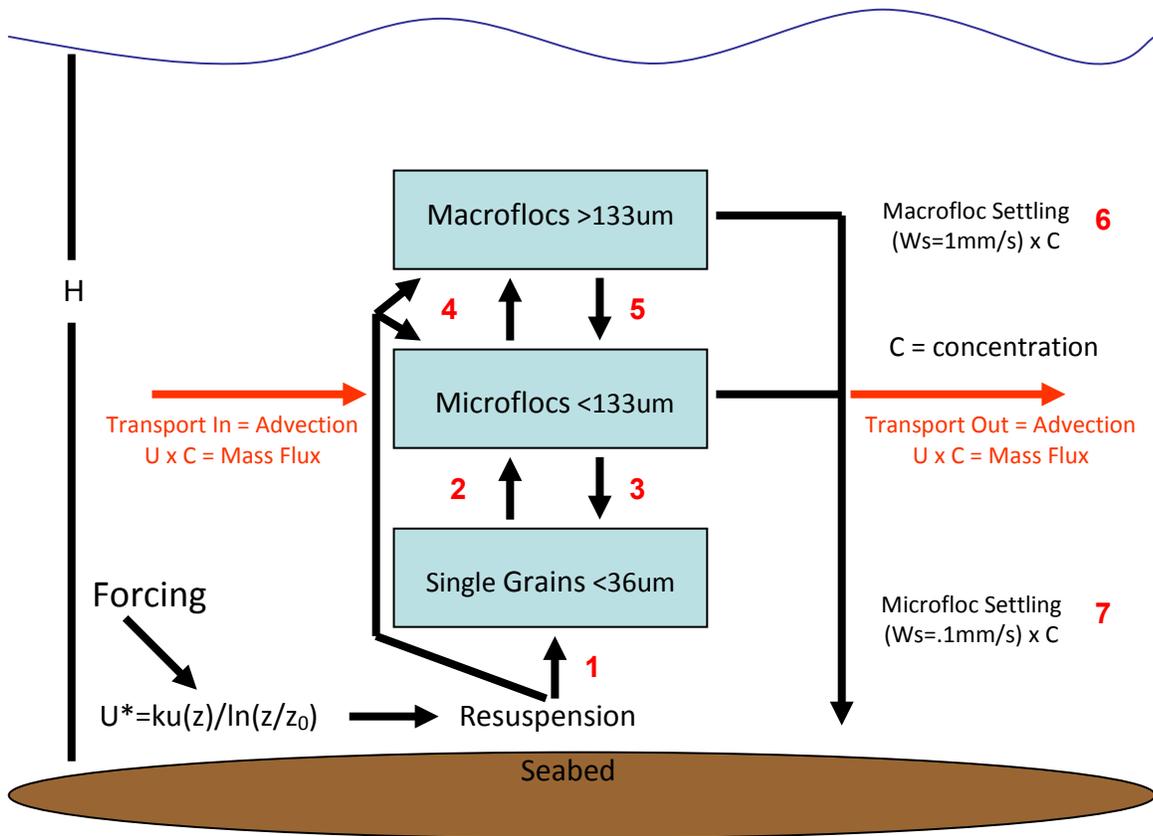
We are now in a position to use our observations of flocculated size distributions and their response to stress to implement and test models that convert predictions of suspended particulate mass into predictions of the optical properties in bottom boundary layers (Figure 3). Brent Law initiated this work as his final project in a modeling class at Dalhousie in the spring. Worked ceased over the summer as we prepared for upcoming field work, but we will return to this effort in late fall, after field work is completed.



**Figure 1.** The ratio  $c_p:SPM$  plotted versus median particle size. Closed black circles are associated with values of SPM measured with the in-situ filtration system. Open gray circles are values associated with SPM estimated every 5 minutes from the merged size spectra and the size-settling velocity data. When median particle size is small,  $c_p:SPM$  is variable, but when median particle size grows larger than  $10 \mu m$ , the value of  $c_p:SPM$  is constrained between 0.2 and 0.4.



**Figure 2.** Area concentration in suspension versus organic suspended sediment concentration (OSS) and mineral suspended sediment concentration (MSS). Data are from Dave Bowers at the University of Bangor in Wales. They were collected in a range of coastal environments. The plane shows the best fit linear regression of area concentration on OSS and MSS. If particle composition is uncorrelated with the packing geometry of flocs, then the ratio of the regression coefficient for OSS to the regression coefficient for MSS should equal the ratio of densities between mineral matter and organic matter. Assuming a mineral density of  $2650 \text{ kg m}^{-3}$  and a bulk organic density of  $1370 \text{ kg m}^{-3}$ , the predicted ratio of coefficients is 1.93. The observed ratio is 2.12 and is not significantly different from 1.93. This result suggests that compositional variability accounts only for a 2x range of variability in the  $c_p$ :SPMratio.



**Figure 3.** *The conceptual floc model in a well mixed bottom boundary layer. Arrows indicate direction of sediment mass movement between boxes and settling ( $W_s$ ). Resuspension brings sediment mass in, settling takes sediment out, advection in and out are deemed equal at this point in our model development. Forcing shown as  $U^*$  is the shear velocity at the bed which causes resuspension, and is generally extrapolated from current meter records from some height above the bed ( $z$ ). At this point forcing is driven by tidal stress and will include waves at a later date.*

## 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. The development of a floc module for CSTMS will enable the implementation of a module that converts sediment to optical properties. The latter advance will provide the sedimentology community with a simple tool to test their model predictions against the most ubiquitous measurement of suspended matter in coastal waters, and it will lead to prediction of in-water optical properties based on predictions of seabed stress.

## **RELATED PROJECTS**

Hill obtained NSERC funding in Canada to purchase of the LISST-100 on the MINSSECT. Hill, Milligan and Law are funded by another Littoral Sciences project to investigate depositional and erosional fluxes on tidal flats. As part of that work, we measured particle size, particle mass, particle settling velocities, optical attenuation, and seabed stress. Law has research into particle transport around aquaculture sites funded by Fisheries and Oceans Canada. This project funded the purchase of another LISST.

## **REFERENCES**

- Boss, E., W. H. Slade, and P. S. Hill. 2009. Effect of particulate aggregation in aquatic environments on the beam attenuation and its utility as a proxy for particulate mass. *Optics Express*, 17, 9410-9420.
- Hill, P. S., E. Boss, J. P. Newgard, B. A. Law, and T. G. Milligan, 2011. Observations of the sensitivity of beam attenuation to particle size in a coastal bottom boundary layer, *J. Geophys. Res.*, 116, C02023, doi:10.1029/2010JC006539.

## **PUBLICATIONS**

- Hill, P. S., E. Boss, J. P. Newgard, B. A. Law, and T. G. Milligan, 2011. Observations of the sensitivity of beam attenuation to particle size in a coastal bottom boundary layer, *J. Geophys. Res.*, 116, C02023, doi:10.1029/2010JC006539, [published, refereed].

## **HONORS/AWARDS/PRIZES**

Kirby Liang Fellowship, University of Bangor Wales, Paul Hill, May, 2011