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

Paul S. Hill
Department of Oceanography
Dalhousie University
Halifax, Nova Scotia, CANADA B3H 4J1
phone: (902) 494-2266 fax: (902) 494-3877 email: paul.hill@dal.ca

Award Number: N00014-10-1-0081
http://www.phys.ocean.dal.ca/~phill

Brent Law and Timothy G. Milligan
Fisheries and Oceans Canada
Bedford Institute of Oceanography
1 Challenger Drive
Dartmouth, Nova Scotia, CANADA B2Y 4A2
phone: (902) 426-3273 fax: (902) 426-6695 email: milligant@mar.dfo-mpo.gc.ca

Award Number: N00014-10-1-0366

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 will 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 and an I-beam frame. Our **M**odified **IN** Situ **S**ize and

Settling **C**olumn **T**ripod (MINSSECT) was deployed to measure optical beam attenuation, suspended particulate mass and particle size distributions. The MINSSECT was instrumented with a Sequoia Scientific LISST-100x Type B laser particle sizer and a Digital Floc Camera (DFC) to measure a range of particle diameters from approximately 2 μm 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 were mounted so the centers of the measuring volumes were located 1.2 m above the sea bed. Another tripod was deployed by Emmanuel Boss' group from the University of Maine. It measured acoustical and optical properties of the water column at multiple frequencies. John Trowbridge's group from Woods Hole Oceanographic Institution deployed an I-beam array near the MINSSECT that carries 4 SonTek/YSI acoustic Doppler velocimeters (ADVs) mounted vertically ~ 0.25 m above the bottom.

The combined optical and acoustical measurements provide a comprehensive description of the suspended particles near the seabed. The velocity measurements obtained from the I-beam-mounted ADVs provide direct-covariance estimates of Reynolds stress and inertial-range estimates of the dissipation rate for turbulent kinetic energy.

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) provides 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 have also collaborated with Oscar Schofield (Rutgers) who deployed gliders in the study area during our September 2007 deployment. A group from WetLabs deployed a profiling mooring during part of our September 2007 deployment. Yogi Agrawal (Sequoia Scientific) placed a prototype "LISST Back" on MINSSECT for part of our September 2007 deployment. 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).

WORK COMPLETED

Work in 2010 focused on four areas. First, we worked on publication of results from past field experiments. Second, we collected and analyzed another data set from Martha's Vineyard Coastal Observatory in September and October 2009. Third, we continued to investigate methods for merging LISST and DFC data to produce full size distributions. Finally, we continued discussions with Chris Sherwood regarding development of a new simple model for floc fraction and how to incorporate this model into CSTMS.

RESULTS

With our past OASIS support we have gathered two one-month-long time series of observations linking physical forcing, sediment concentration and size distribution, and optical properties. These data indicate, that 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 μm (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 accepted for publication in *JGR Oceans* (Hill et al., accepted, 2010).

Reduced sensitivity of the mass-normalized particulate attenuation coefficient at higher stresses is also linked to reduced variability in flocculated particle properties. Our OASIS data show that floc size and floc fraction are variable and difficult to predict at low stresses, but that these properties become more uniform and more predictable at higher stresses (Figure 2). In brief, floc size and floc fraction are variable when turbulence is weak to moderate. Eventually, however, increasing turbulence causes a systematic decrease in floc size and floc fraction. A manuscript describing these data is in preparation.

We have continued to investigate methods for merging LISST and DFC data to produce particle size distributions that extend from diameters of approximately 2 μm to over 1 cm. The merging methodology is an issue because the LISST and DFC apparently "see" large, porous flocs differently. LISST distributions fall off at the upper end of the size distribution, where DFC size distributions continue to increase (Figure 3). We hypothesize that the LISST recognizes microflocs within large porous flocs as distinct particles, whereas the DFC images these components as inclusions in a larger floc. We have been examining the results produced by various merge strategies. The various strategies do not produce widely different results.

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. Chris Sherwood of USGS in Woods Hole is taking the lead on this work.

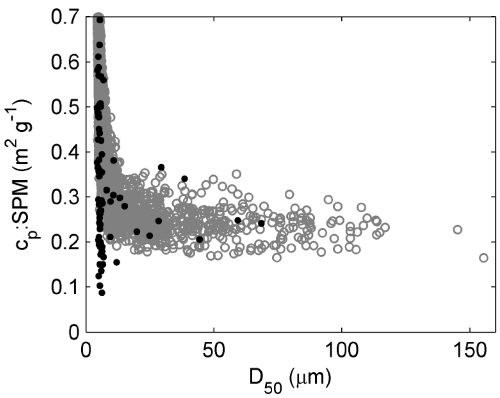

Figure 1. The ratio c_p:SPM plotted versus median particle size. Closed black circles are associated with values of SPM measured with the in-situ filtration system. Open gray circles are values associated with SPM estimated every 5 minutes from the merged size spectra and the size-settling velocity data.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

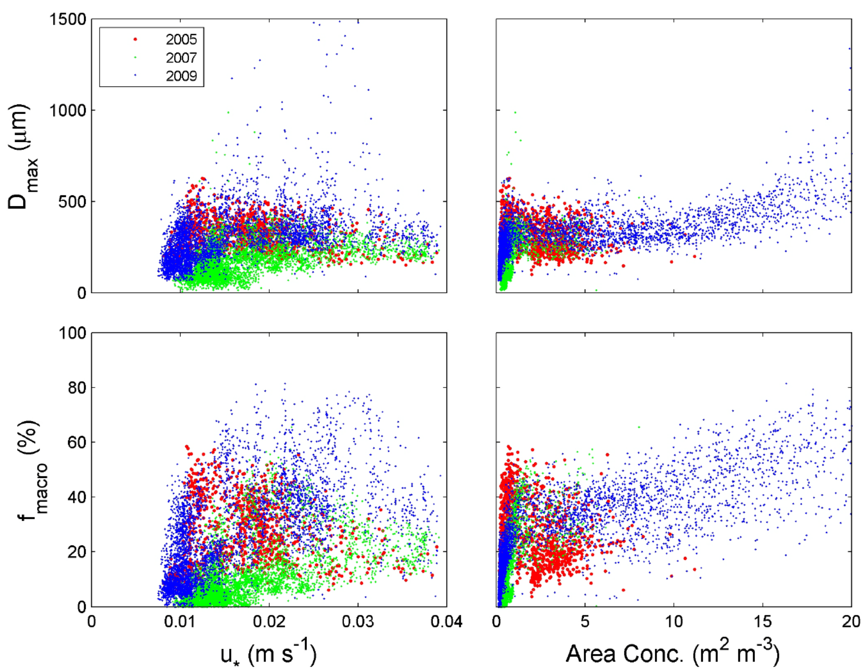

Figure 2. Scatter plots of maximal floc size and macrofloc fraction (diameter > 133 □m) versus shear velocity and area concentration, which scales approximately with suspended sediment mass (e.g. Boss et al., 2009, Hill et al., accepted). Data from the 2005 OASIS field deployment are shown in red, data from 2007 are shown in green, and data from 2009 are shown in blue. When shear velocity is small, floc size and floc fraction are variable, but as stress grows, the values of these two variables decrease and stabilize. These trends reflect the increasing control exerted by turbulence on the properties of suspended flocs, and they help to explain why variability in mass-normalized particulate attenuation coefficients decreases as stress increases.

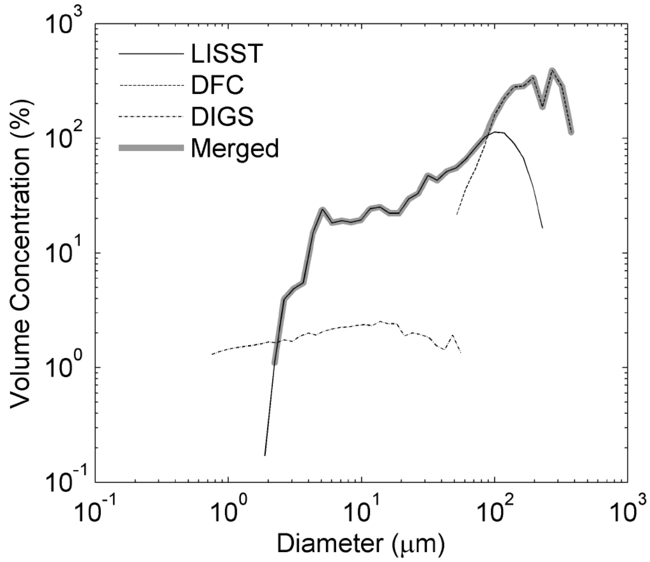

Figure 3. Example of merging of LISST size distribution with DFC size distribution. Merged size distributions were estimated by combining data from the LISST and DFC. On a sample-by-sample basis, an overlap size bin was selected as the "merge bin" at which the two size distributions were joined. Bins less than or equal to the merge bin were assigned concentrations from the LISST. Bins greater than the merge bin were assigned concentrations from the DFC. The merge bin was selected to minimize the difference between the beam attenuation measured by the LISST and two times the total particle area concentration of the resultant merged spectrum. This strategy assumes that the majority of particles were much larger than the wavelength of light, so they had attenuation efficiencies equal to 2. Also shown is the disaggregated inorganic grain size (DIGS) distribution of suspended sediment caught on in situ filtered samples from the McLane water transfer system. DIGS concentrations are lower than LISST concentrations because the DIGS distribution does not include organic matter. DIGS distributions have small particles that LISST does not detect, suggesting that, in situ, the smallest particle sizes are contained in microflocs. This result has important implications for optical models of the water column and should be investigated further.

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 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. Hill, Milligan and Law are funded by ONR Coastal Geosciences to investigate depositional and erosional fluxes on tidal flats. As part of that work, we are measuring 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, 2010. Observations of the sensitivity of beam attenuation to particle size in a coastal bottom boundary layer. Journal of Geophysical Research, Oceans, accepted with revision, 2010.

PUBLICATIONS

Hill, P. S., E. Boss, J. P. Newgard, B. A. Law, and T. G. Milligan, 2010. Observations of the sensitivity of beam attenuation to particle size in a coastal bottom boundary layer. Journal of Geophysical Research, Oceans, [submitted, refereed].