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

Emmanuel Boss
School of Marine Sciences
5741 Libby Hall
University Of Maine
Orono, Maine, USA 04469-5741
phone: (207) 581-4378 fax: (207) 581-4388 email: emmanuel.boss@maine.edu

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

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

Grant Numbers: N000140410278, N000140410233, and N000140410235
http://www.phys.ocean.dal.ca/~phill , http://www.marine.maine.edu/~eboss/

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.

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 includes a 9-wavelength optical attenuation and absorption meter (WetLabs ac-9, with automated regular dissolved measurement for calibration independent particulate measurements), LISST-100 (Type B) 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 ac-9 measurements with and without a filter assure high-quality particulate spectral absorption and attenuation measurements. The LISSTs and DFC together provide particule size distributions from 1.25 μm to 1 cm in diameter. 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 and Elgar, 2001; Shaw and Trowbridge, 2001; Trowbridge and Elgar, 2003).

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 LISST-100 Type B and LISST Floc. Milligan has responsibility for the DFC. 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. Chris Sherwood (USGS) has provided LISST-100 Type C measurements made from a nearby bottom tripod during the deployment period, for comparison to the LISST-100 Type B and LISST Floc measurements.

WORK COMPLETED

The tripod housing particle, acoustic, and optic sensors was first deployed from September to October 2004. The deployment was partially successful, yielding 5 days of data when all sensors were functioning. Fouling degraded the observations after 1 week, and the DFC failed after 5 days. Re-designs of the tripod, the ac-9 switch, and the DFC were completed for re-deployment in September 2005.

The re-designed tripod was deployed on September 3, 2005 and recovered on September 22, 2005. On September 17, 2005, at 1200 GMT, Tropical Storm Ophelia passed 109 km southwest of the field site. The INSSECT (IN situ Size and SEttling Column Tripod) was also deployed on August 29, 2005 and recovered on September 7, 2005. INSSECT is a multi-instrumented tripod designed to measure fine sediment (or floc) properties close to the seabed in coastal environments (Mikkelsen et al., 2004). The deployment of the INSSECT was compromised by the energetic coastal environment and tipped over during a large wave event.

We were able to turn instruments on and off and download data in real time, and 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 ac-9 filters were replaced twice during the deployment, with the flow rate through them never falling below 1 L min^{-1} (fresh filter had a flow rate of 2.5 L min^{-1}). The DFC functioned properly, gathering 2300 images over the course of the deployment.

RESULTS

The angular scattering of light is described by the optical volume scattering function (VSF), defined as the ratio of intensity of scattered light as a function of angle to the incident irradiance per unit volume. Together with absorption, the VSF is crucial in determining the subsurface light field.

The LISST-100 Type B instrument was calibrated in the laboratory using polystyrene microsphere standards (Duke Scientific), giving a set of scaling factors to convert the scattering signal from each ring into a ring-averaged volume scattering function (Slade and Boss, 2006). Calibration of the LISST Floc instrument proved more difficult, as signal levels for beads ~1 - 10 μm in diameter were too low for the most near-forward rings. We combined the measurements of the two instruments by assuming that the response of the LISST Floc was constant for all rings (a reasonable assumption based on our calibration for the LISST-100 Type B), and adjusted the magnitude of the LISST Floc VSF by minimization of the difference between observations in the region of overlapping angles, creating a merged VSF from the two instruments. Disagreement between the LISST-100 Type B and LISST Floc measurements of VSF in the overlapping angular region was observed over the course of the deployment, but the relative difference was on average < 20%. Figure 1 shows examples of the merged VSF from the time series covering an angular range of roughly 0.01 to 15 degrees, an order of magnitude further near-forward than the observations of Petzold (1972), made decades ago.

A simple diffraction-based model of scattering indicates that the slope of the near-forward VSF depends mostly on the slope of the particle size distribution. Preliminary results of modeling the near-forward VSF as a power-law function of angle, $\beta(\psi) = \beta_0 \cdot \psi^{-\eta}$, show a wide range of variability in the slope η (Figure 2), indicative of changes in the particle size distribution resulting from particle dynamic processes such as settling, resuspension, aggregation, and disaggregation.

The DFC images were analyzed and the particle areas in each image were converted to equivalent circular diameters. Particle volumes were estimated assuming spherical geometry. The volume concentrations (mm^3 L^{-1}) were binned into size classes with logarithmically-spaced diameter midpoints between 45 μm – 1 cm, in accordance with the binning geometry of the LISST-100 Type B and Type C, and LISST Floc. Volume concentrations estimated from the DFC were merged with volume concentrations from the different LISST instruments yielding merged volume concentration distributions for all particles in suspension (Figure 3). Merging of the DFC and LISST spectra followed the procedure of Mikkelsen et al. (2006).

The merged volume concentration and area concentration (i.e. cross-sectional area) distributions were apportioned into single grain (<36 μm in diameter), microfloc (36 – 133 μm in diameter), and macrofloc (>133 μm in diameter) fractions (Mikkelsen et al., 2006). For all merged spectra, the suspension composition by volume concentration was dominated by the macrofloc population throughout the deployment (Figure 4). In contrast, the single grain fraction dominated the suspension composition when apportioned by area concentration. Increase in the single grain fraction is observed during the approach of Tropical Storm Ophelia on September 15 (Figure 4). The merged LISST-100 Type C and DFC spectra provide particle size distribution data throughout the passage of Tropical Storm Ophelia.

Change in the suspension composition is more obvious when the time domain is reduced to a few days (Figure 5). For instance, the periods characterized by smaller particles occur at times when the attenuation of light is low and the "slope" of the attenuation spectrum is high. These periods occur when wave height is low and current speed is near zero. 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, 2005, 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 and resuspension caused by increased wave-induced stress on the seabed.

To date, a report summarizing the merged particle size distribution data from the three LISST instruments and DFC has been circulated to co-investigators. The aim is to begin discussion on the coordination and circulation of data among investigators.

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

Studies of the role of floc fraction in the transport of fine-grained sediment were funded by ONR Coastal Geosciences. Work has been carried out in the Gulf of Lions as part of the EuroSTRATAFORM project (ONR Grants: N000140410165 and N000140410182).

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.

REFERENCES

Agrawal, Y. C., Pottsmith, H.C. 2000. Instruments for particle size and settling velocity observations in sediment transport. Marine Geology, 168: 89-114.

Curran, K.J., Hill, P.S, Milligan, T.G. 2002. Fine-grained suspended sediment dynamics in the Eel River flood plume. Continental Shelf Research, 22: 2537-2550.

Hay, A.E., Sheng, J. 1992. Vertical profiles of suspended sand concentration and size from multifrequency acoustic backscatter. Journal of Geophysical Research (Oceans), 97: 15661-1567.

Holliday, D.V. 1987. Acoustic determination of suspended particle size spectra. IN Proceedings of a Specialty Conference on Advances in Understanding of Coastal Sediment Process, Coastal Sediments - 1987, 1: 260-272.

Mikkelsen, O. A., Milligan, T.G., Hill, P.S., Moffat, D. 2004. INSSECT---an instrumented platform for investigating floc properties close to the seabed. Limnology and Oceanography Methods, 2: 226-236.

Mikkelsen, O.A., Hill, P.S., Milligan, T.G. 2006. Single-grain, microfloc and macrofloc volume variations observed with a LISST-100 and digital floc camera. Journal of Sea Research, 55: 87-102.

Petzold, T.J. 1972. Volume scattering functions for selected ocean waters. Contract No. N62269-71-C-0676, USCD, SIO Ref. 72-78.

Shaw, W.J., Trowbridge, J.H. 2001. The direct estimation of near-bottom turbulent fluxes in the presence of energetic wave motions. Journal of Atmospheric and Oceanic Technology, 18: 1540-1557.

Slade, W.H., Boss, E.S. 2006. Calibrated near-forward volume scattering function obtained from the LISST particle sizer. Optics Express, 14: 3602-3615.

Trowbridge, J.H., 1998. On a technique for measurement of turbulent shear stress in the presence of surface waves. Journal of Atmospheric and Oceanic Technology, 15: 290-298.

Trowbridge, J.H., Elgar, S. 2001. Turbulence measurements in the surf zone. Journal of Physical Oceanography, 31: 2403-2417.

Trowbridge, J.H., Elgar, S. 2003. Spatial scales of stress-carrying nearshore turbulence. Journal of Physical Oceanography, 33:1122-1128.

PUBLICATIONS

Slade, W.H., Boss, E.S. 2006. Calibrated near-forward volume scattering function obtained from the LISST particle sizer. Optics Express, 14: 3602-3615. [published, refereed]

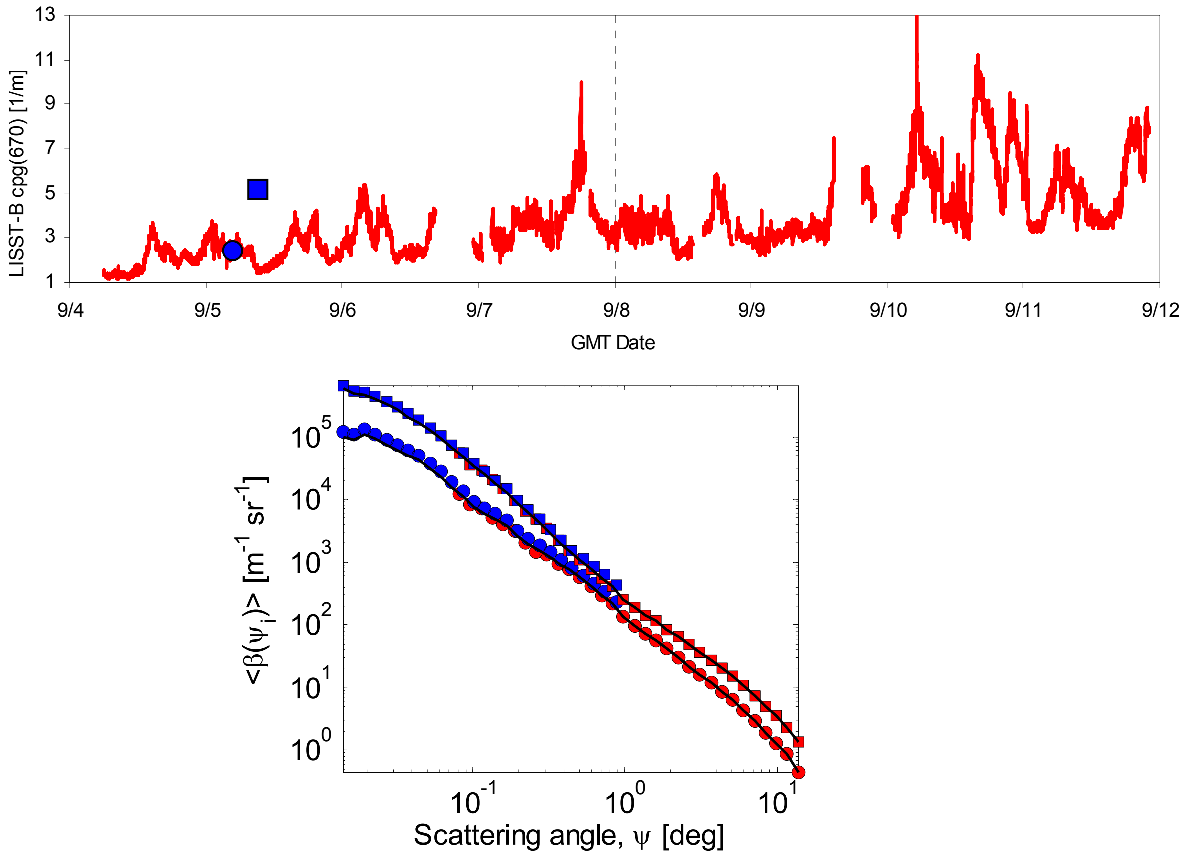

Figure 1. Beam attenuation coefficient is an indicator of changes in particle concentration near the seabed (top panel). The blue symbols denote sample times of the VSF measurements shown in the bottom panel. The red and blue symbols in the bottom panel represent VSF data from the LISST-100 Type B and LISST Floc instruments, respectively, and the black lines denote the "merged" VSF estimated from the adjusted LISST Floc data.

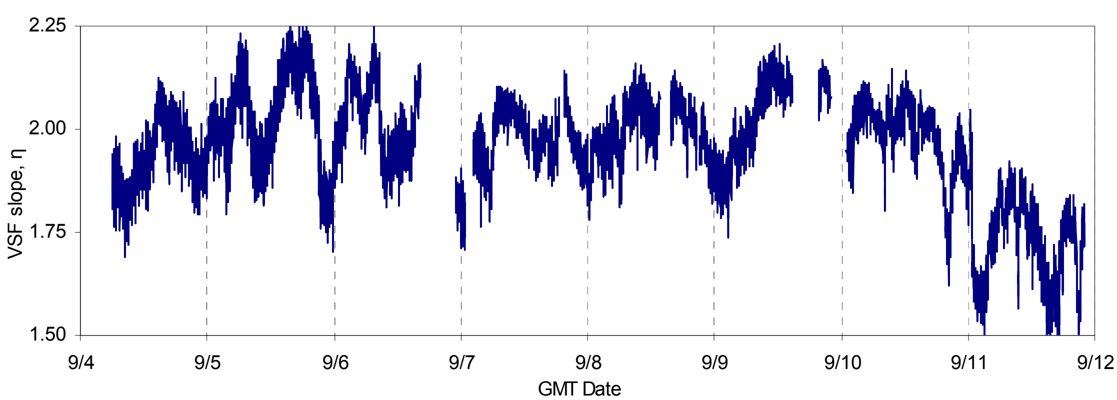

Figure 2. Slope of the near-forward VSF based on the power law fit $\beta(\psi) = \beta_0 \cdot \psi^{-\eta}$, which indicates changes in the particle size distribution of suspended particles.

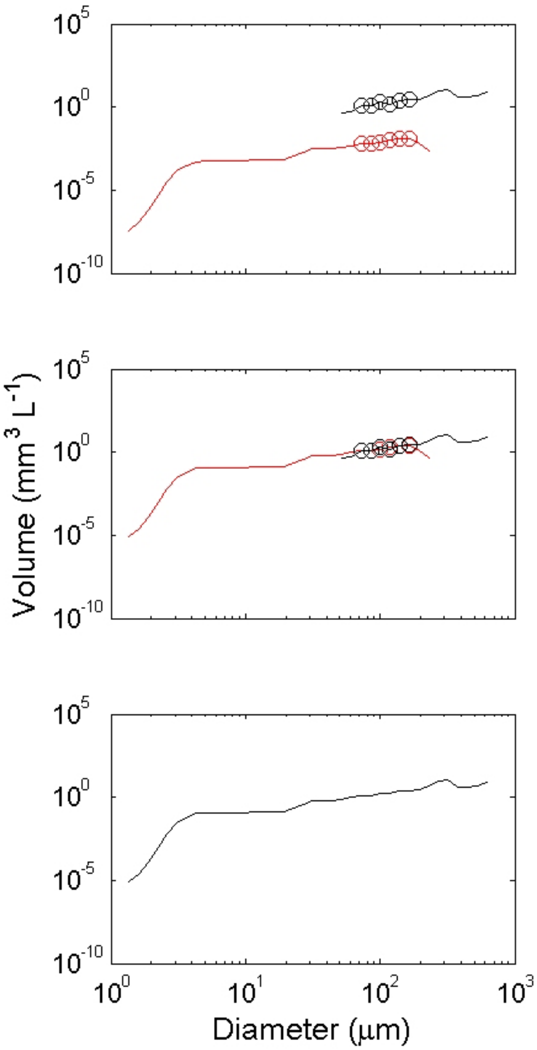

Figure 3. Example of the LISST-100 Type B and DFC size distributions during adjustment that results in a merged size distribution 1.25 µm – 1 cm in diameter. The red line represents the LISST-100 Type B size distribution and black line represents the DFC size distribution. The circles mark the region of overlap used for adjusting both size distributions. The adjustment factor for this data was 212. The data was collected on September 4, 2005, at 0444 GMT.

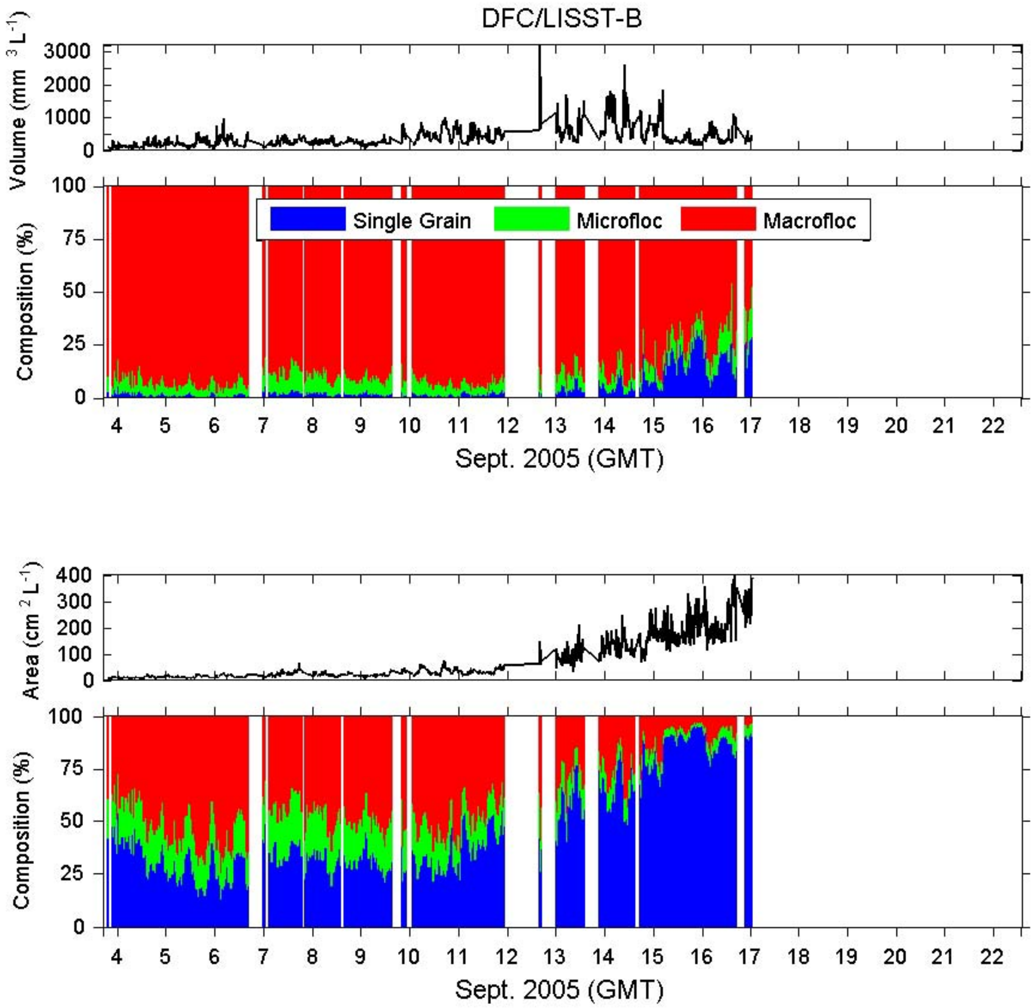

Figure 4. Volume concentration and area concentration (i.e. cross-sectional area) from the merged size distributions using the LISST-100 Type B and DFC apportioned into single grain (<36 µm in diameter), microfloc (36 – 133 µm in diameter), and macrofloc (>133 µm in diameter) fractions.
White regions represent periods of no data.

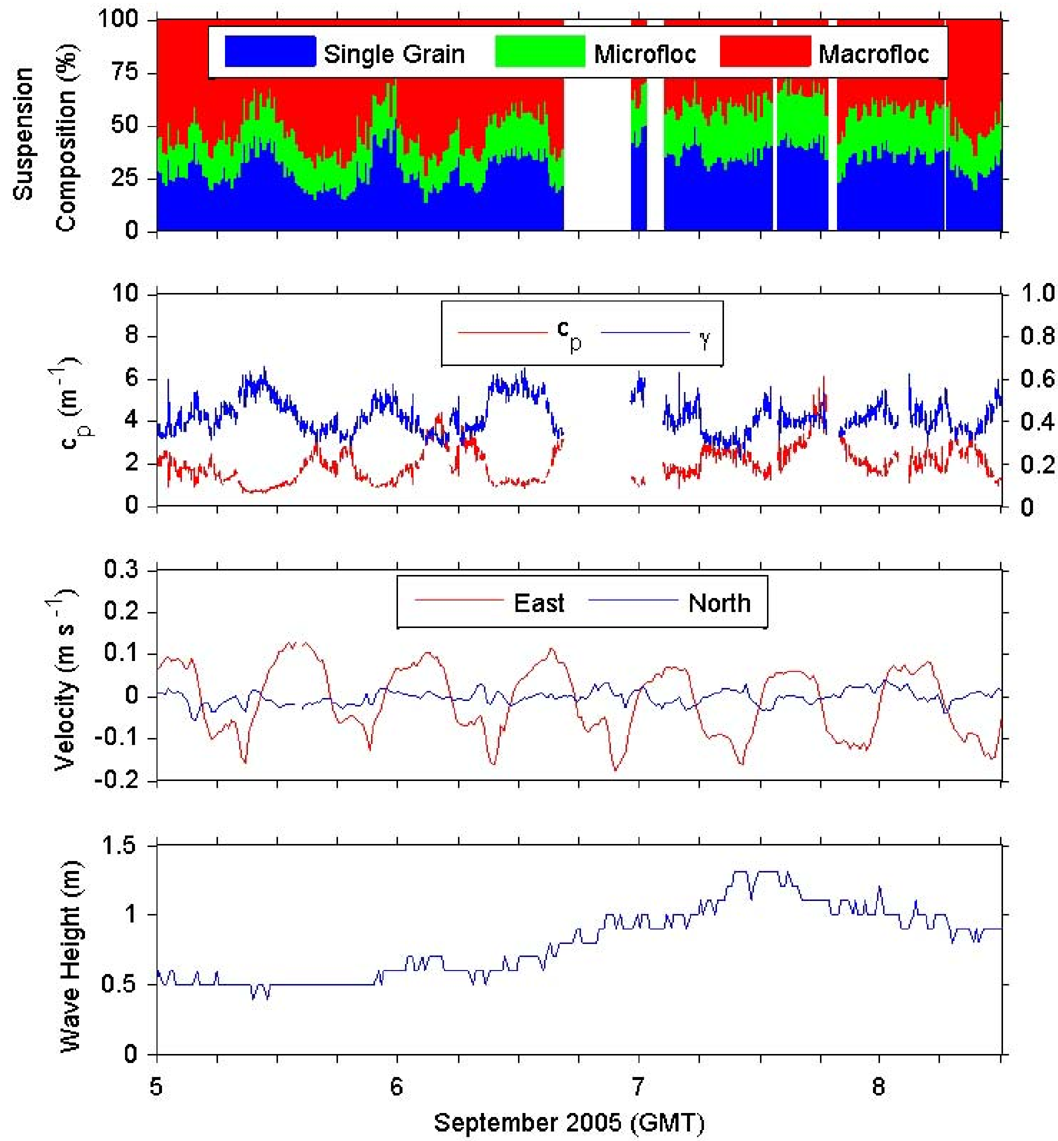

Figure 5. Properties in the boundary layer at MVCO from September 5, 2005, at 0000 GMT to September 8, 2005, at 1200 GMT. The top panel shows the percentage contribution of three nominal size classes to the suspended sediment at 1.2 meters above the bottom using the merged size distributions from the LISST-100 Type B and DFC instruments. The second panel shows beam attenuation (c_p) and the "slope" of the attenuation spectrum (γ) at the same height. The third panel shows currents measured at the 12-m node and the bottom panel shows significant wave height. Early in the record, there are three periods when the proportion of macroflocs decreases. The periods occur when beam attenuation is low, and the spectrum of beam attenuation is steep. These periods are associated with zero velocity and small waves. The data indicate that when bed shear stress is low, macroflocs deposit on the bed, thereby enriching the suspension in more slowly depositing microflocs and single grains. Later in the record, wave height increases, producing a decrease in the proportion of macroflocs, likely due to floc breakup.