Optics, Acoustics, and Stress in a Nearshore Bottom Nepheloid Layer (OASIS)

John H. Trowbridge
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
phone: (508) 289-2296 fax: (508) 457-2194 e-mail: jtrowbridge@whoi.edu

Emmanuel Boss
School of Marine Sciences
5741 Libby Hall
University Of Maine
Orono, ME 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

LONG-TERM GOALS

To quantify and understand the effects of aggregation dynamics on the distribution of particles in the bottom boundary layer, and to understand how the properties of particles (composition, shape, and internal structure) affect their optical and acoustical properties.

OBJECTIVES

- Obtain a set of acoustical and optical measurements that determines the evolution of the particle size distribution.

- Obtain concurrent velocity, temperature and conductivity measurements sufficient to determine the fluid dynamical environment within which the particle size distribution evolves.

- Evaluate and improve a state-of-the-art model of particle dynamics by comparing model calculations with measurements.

1. REPORT DATE **2006**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**	
4. TITLE AND SUBTITLE **Optics, Acoustics, and Stress in a Nearshore Bottom Nepheloid Layer (OASIS)**		5a. CONTRACT NUMBER	
		5b. GRANT NUMBER	
		5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)		5d. PROJECT NUMBER	
		5e. TASK NUMBER	
		5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Woods Hole Oceanographic Institution Woods Hole, MA 02543**		8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)	
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**			
13. SUPPLEMENTARY NOTES **The original document contains color images.**			
14. ABSTRACT			
15. SUBJECT TERMS			

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**5**	

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

WORK COMPLETED

Three sets of measurements have been obtained, the first during August-September 2004, the second during August-September 2005, and the third during August-September 2007. All three sets of measurements occurred at the Martha's Vineyard Coastal Observatory (MVCO), which is operated by the Woods Hole Oceanographic Institution (WHOI). The MVCO, off the southern coast of Martha's Vineyard, Massachusetts, is a cabled observatory consisting of a shore station, a meteorological mast on the beach, a seafloor node at a water depth of 12 m, and an air-sea interaction tower (ASIT) at a water depth of 15 m. Atmospheric measurements are obtained routinely at the meteorological mast and the ASIT. Routine oceanic measurements of temperature, salinity and velocity are obtained at the 12-m node and the ASIT. The 2004 measurements for this study were obtained near the ASIT and the 2005 and 2007 measurements were obtained near the 12-m node. The 2007 program included measurements obtained from a profiler deployed by WetLabs.

RESULTS

Analysis of OASIS measurements has focused on characterization of the near-bottom flow environment in which the suspended particles exist and evolve. The flow characterization includes quantitative estimates of the bottom stress, dissipation rate, and mean shear. The measurements indicate a production-dissipation balance in the turbulent kinetic energy equation and excellent agreement with the Prandtl-Karman law of the wall, as expected in an un-stratified shear flow. A primary result of the analysis is estimates of the stress associated with the hour-averaged current and the standard deviation of the stress produced by surface gravity waves (Figure 1). The analysis indicates good agreement between measured hour-averaged stresses and corresponding stresses estimated from a boundary layer model, and much larger oscillatory stresses produced by surface gravity waves. Work in progress addresses the relationship between the stresses and the characteristics and concentration of the suspended particles.
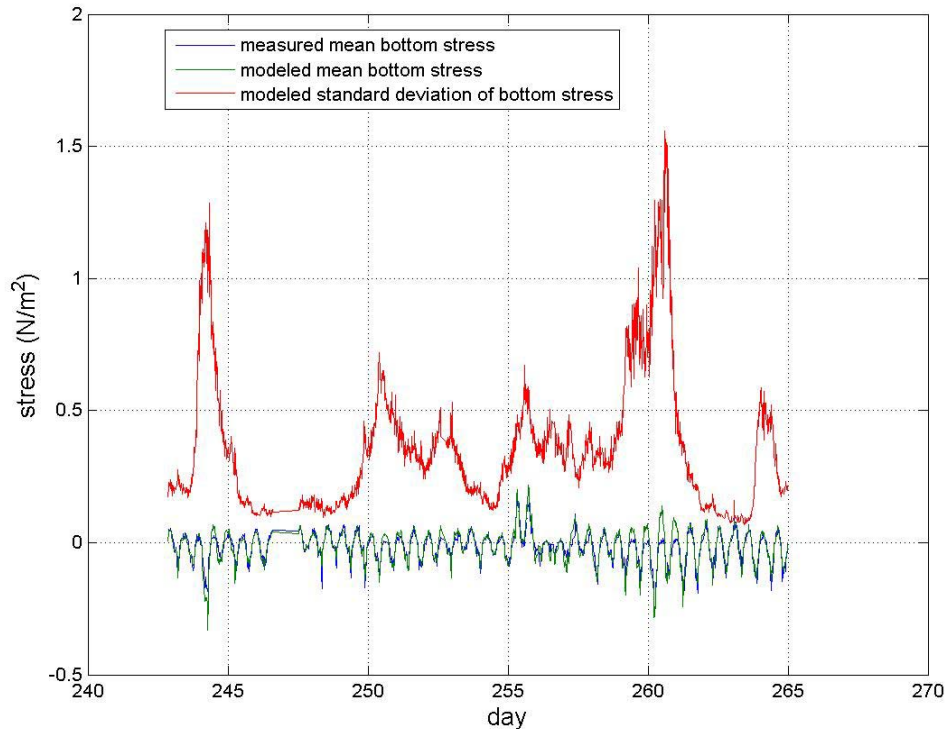

Figure 1. Stresses estimated from the 2005 measurements at the Martha's Vineyard Coastal Observatory. The terms 'mean' and 'standard deviation' refer to statistics of hour-long records. The mean stress is associated with the hour-averaged current, which is forced by tides and winds, and the much larger standard deviation of the stress is produced by oscillatory near-bottom flows produced by surface gravity waves. Particle re-suspension is believed to be controlled by the large wave-induced bottom stress, while upward transport of particles into the water column is controlled by the smaller mean bottom stress. The measured and modeled mean stress agree well. The standard deviation of the stress is inferred from measurements and a model.

3

Additional analysis has focused on the dynamics controlling the particle size distribution. This work has begun with consideration of older LISST measurements obtained during the ONR-funded Coastal Mixing and Optics (CMO) Experiment, conducted over the "mud patch", at a water depth of approximately 60 m on the New England shelf. The analysis indicates favorable agreement between measured particle size distributions and calculations based on a model that assumes a uniformly sized particle source at the sea floor, a balance between upward transport by turbulence and downward transport by settling, and a power-law dependence of settling velocity on particle size (Figure 2). Ongoing work addresses the applicability of the model to the 2005 and 2007 OASIS measurements, as well as the utility of the model for estimating and understanding acoustical and optical signatures of suspended particles.
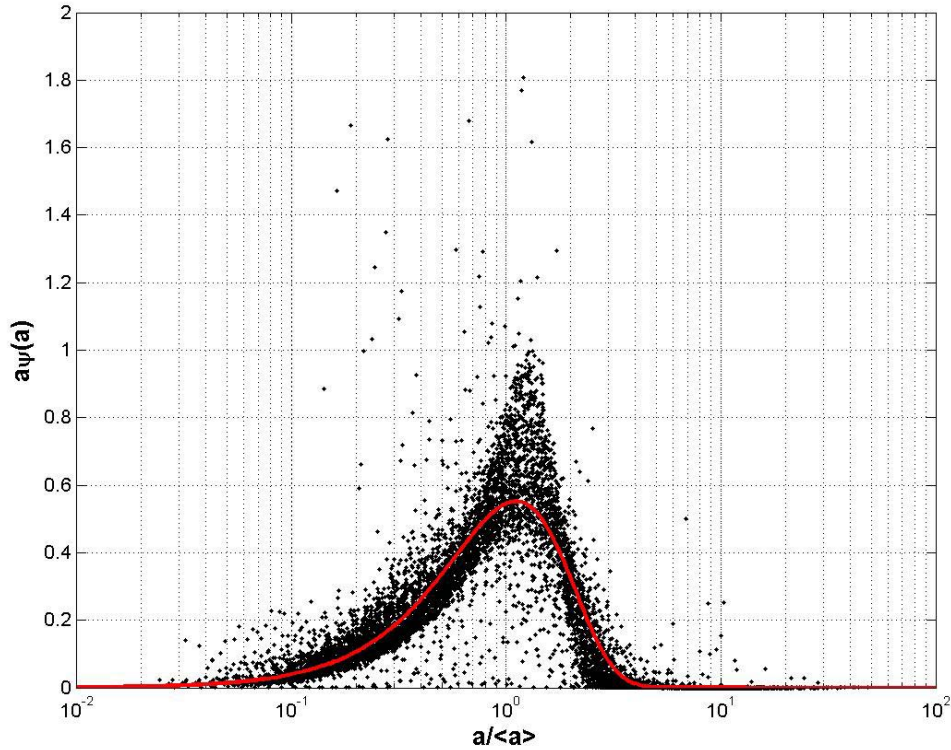

Figure 2. Dimensionless particle size distributions determined from LISST measurements (black dots), compared with a theoretical model (red line). Here a denotes the particle radius; $\psi(a)$ is the particle size distribution, defined so that $\int_0^{+\infty}\psi(a)da$ is the volumetric particle concentration; and $<a>$ is the mean particle radius, defined as the ratio of the first to the zeroth moment of the size distribution. The model is based on the assumptions of a uniformly sized particle source at the sea floor, a balance between upward transport by turbulence and downward transport by settling, and a power-law dependence of settling velocity on particle size.

IMPACT/APPLICATIONS

Operational seagoing systems often depend on optical and acoustical properties of suspended particles in the water column. Understanding the processes that regulate the particle characteristics and

understanding the optical and acoustical signatures of suspended particles are essential in order to predict the performance of these operational systems.

RELATED PROJECTS

Coherent Structures in Estuaries (COHSTREX), an ONR-funded study of surface signatures of turbulence and coherent structures in shallow estuarine environments. This study has been undertaken by A. Horner-Devine (University of Washington), A. Jessup (University of Washington Applied Physics Laboratory), D. Fong (Stanford University) and their colleagues. W. R. Geyer and J. H. Trowbridge (Woods Hole Oceanographic Institution) are participating in a companion project. The focus of Geyer and Trowbridge's work is direct measurement of turbulent fluxes and dissipation rates in stratified and un-stratified estuarine environments, in order to understand the turbulence dynamics and their impact on coherent structures visible on the water surface.

Mechanisms of Fluid-Mud Interactions under Waves, an ONR-funded MURI project aimed at understanding the dissipation of surface gravity waves over muddy seafloors. This combined field, laboratory, numerical, and theoretical study has been undertaken by S. J. Bentley (Memorial University), R. A. Dalrymple (Johns Hopkins University), G. C. Kineke (Boston College), C. C. Mei (Massachusetts Institute of Technology), P. Traykovski (Woods Hole Oceanographic Instituion), J. H. Trowbridge (WHOI), and D. Yue (MIT). Companion field and analysis studies are being carried out by S. Elgar (WHOI), B. Raubenheimer (WHOI), T. Herbers (Naval Postgraduate School), and A. Sheremet (University of Florida). A focus of the WHOI, Boston College, and Memorial University field work is quantitative imaging and interpretation of the near-bottom mud dynamics that control energy dissipation.

REFERENCES

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

Curran, K. J., P. S. Hill, and T. G. Milligan. 2002. The role of particle aggregation on size-dependent deposition of drill mud. *Continental Shelf Research*, 22: 405-416.

Holliday, D. V. 1987. Acoustic Determination of Suspended Particle Size Spectra. Proceedings of a Specialty Conference on Acoustical Measurements.

Shaw, W.J. and J.H. Trowbridge, 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.

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

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