Optics, Acoustics and Stress in Situ (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

Peter Traykovski
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
phone: 508-289-2638 fax: 508-457-2194 e-mail: ptraykovski@whoi.edu

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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 direct measurements of the turbulent Reynolds stress within the centimeters-thick wave boundary layer (WBL)
- Obtain concurrent velocity, turbulence and seafloor microtopography (bedforms) measurements to constrain the fluid dynamical environment within which the particle size distribution evolves.
- Improve state-of-the-technology for measuring boundary layer velocity and turbulence profiles (Pulse Coherent Doppler Profiler) and seafloor bedform measurements (Rotary Sidescan and Pencil-beam sonars)

APPROACH

The approach is to obtain direct measurements of the turbulent Reynolds stress within the centimeters-thick wave boundary layer (WBL), which has not been possible in previous field studies. This is motivated by the order-of-magnitude difference between relatively small stresses that have been measured above the WBL and the much larger stresses that have been inferred within the WBL, the discrepancy between measured and modeled stresses above the WBL, which has been attributed to processes within the WBL, and the dominant role inferred by Boss, Hill and Milligan of large stresses within the WBL in controlling particle size and thus strongly influencing particle settling velocities, concentrations, and optical properties (Figure 1).

The measurements will capitalize on multi-frequency pulse-coherent Doppler sonars developed recently at WHOI by Peter Traykovski and Fred Jaffre (2011) based on a high frequency sonar board designed by Gene Terray and Tom Austin and Peter Traykovski. The multi-frequency methodology (Hay an Zedel, 2008) removes the ambiguity associated with conventional pulse-coherent Doppler sonar measurements (Figure 2). The combination of range-gated vertical (transmit-receive) and slanted (receive-only) acoustical beams produces vertically resolved measurements of the horizontal and vertical velocity throughout the wave boundary layer and the lower part of the overlying current boundary layer (Figure 3). The effective sample volume is the product of the beam patterns along the acoustical transmission and reception paths, and is small because of the narrow vertical beam. The new sensors produce high-precision velocity measurements along with order-one-meter range, sub-centimeter spatial resolution, and a sample rate of approximately 18 Hz. With proper configuration, these sensor characteristics are sufficient for measurements of both the oscillatory velocity and the turbulent velocity fluctuations in the WBL at field scales.

WORK COMPLETED

Improvements to our Rotary sonar system were implemented by purchasing two new 881 L rotary sidescan sonars from Imagenex. We worked the manufacturer to develop a downward tilted head fan-beam transducer within an oil filled cap with sufficient vertical beam width to permit imaging of ripples from 1 m horizontal range from the transducer to 7 m based on an mounting height of 1m. The data acquisition system was also upgraded from a Persistor CF2 with only serial communications capabilities to a TS-7260 ARM9 based Linux embedded computer which supports Ethernet, USB and serial communications, while maintaining low power consumption.

The multi-frequency pulse coherent Doppler system first deployed in multi-frequency mode in the Skagit tidal flat program was upgraded to focused beam geometry. Analysis combined with the evaluation of several prototypes was used to determine to optimum geometry to maximize overlapping range of the fan beam with the vertical beam while not sacrificing performance of the horizontal velocity estimates due to a low incidence angle. The circuitry was also upgraded with a more powerful analog front end to increase the SNR of the system. Through extensive laboratory testing we were able to increase output power while ensuring the system did produce excessive non-linearity's resulting in acoustic streaming. At maximum power output, due to non-linear momentum transfer to the water (acoustic streaming), the system produced 5 cm/s mean velocities away from the central transducer. By lowering the output power these were reduced to below 1 mm/s.

RESULTS

Since the instrumentation was deployed just before the submission of this report (Figure 4) results are limited to laboratory testing of the systems. Figure 5 shows data from two prototype 881L tilted head rotary fan-beam sonars in which we tested different transducer heads, one with a wider beamwidth transducer to increase the ability to image under the sonar.

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. The development of instrumentation that can resolve wave boundary layer turbulence has potential to make significant improvements to our understanding of boundary layer and sediment processes.

RELATED PROJECTS

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.

Much of the development work and equipment purchases described in this work was funded by a DURIP proposal entitled “Instrumentation for Measuring Nearshore Morphologic Change and Hydrodynamic Forcing” (00014-10-10768) and instrumentation will also be used in the “Dynamics of sandwaves under combined wave-current forcing and mine burial processes” (N00014-11-10291) and “Multi-Scale (cm to km) Hydrodynamic and Morphologic Interactions in Tidal Inlets” (N00014-10-10376)

FIGURES

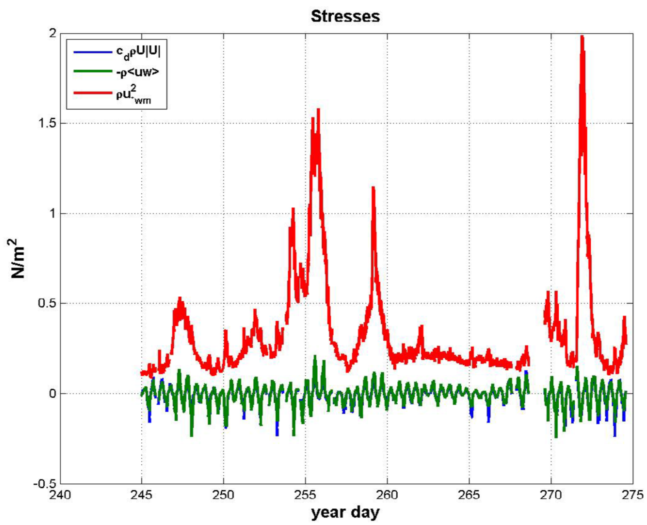

Figure 1. Stresses estimated from the 2007 measurements at the Martha's Vineyard Coastal Observatory. The directly measured hour-averaged Reynolds shear stress $-\rho < uw >$ agrees well with the drag-law estimate $c_d \rho |U| U$ inferred from the measured burst-averaged velocity U by means of an empirically determined drag coefficient c_d . The standard deviation $\rho u_{*wm}{}^2$ of the oscillatory bottom shear stress produced by surface waves is inferred from a wave-current interaction model and is much larger than the hour-averaged stress $-\rho < uw >$, which is associated with wind-driven and tidal currents. The wave-induced stress is primarily responsible for suspending particles and controlling the size of water-borne flocs.

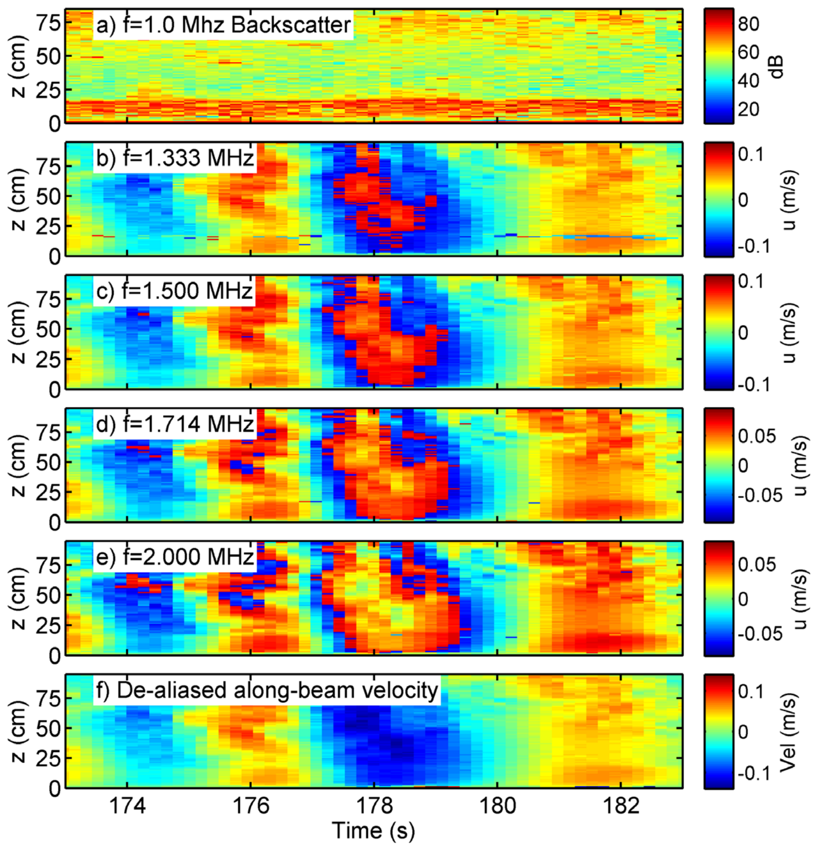

Figure 2. Acoustic backscatter profiles form the 2010 Mud MURI field program showing scattering from suspended sediment (15 to 80 cm), a fluid mud layer (1 to 15 cm) and the stationary seafloor (0 cm). b through e) Along beam velocity profiles for each of the 4 individual frequencies that are used in the multi-frequency inverse showing two cycles of a 5 s period wave. The velocity aliasing can be seen as the sharp transition from blue to red (discontinuity of 0.24 m/s) at t=178 s in panel b, and t = 174, 176 and 178 of the higher frequencies. f) The result of the multi-frequency inverse showing the de-aliased velocity profiles.

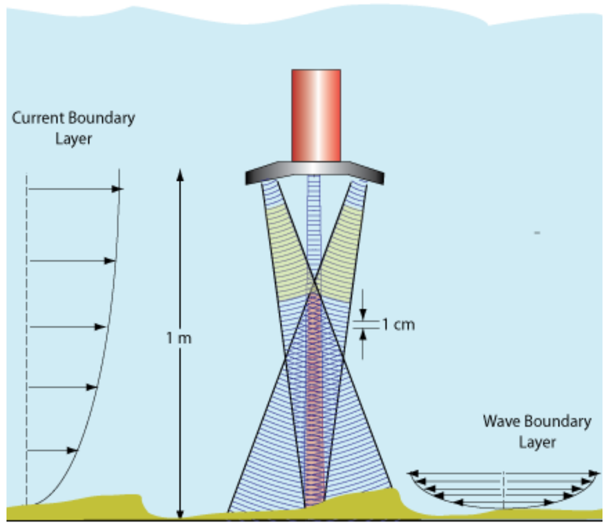

Figure 3. Schematic diagram of the pulse-coherent Doppler sonar system developed at WHOI by Austin, Jaffre, Terray & Trakovski. The red shaded area represents the region that would be profiled at turbulence resoving rates (~10 hz) and the extended yellow region would be profiled at a slower rate (~2 hz). An additional pair of angled transducers is located in the plane perpendicular to the pair shown.

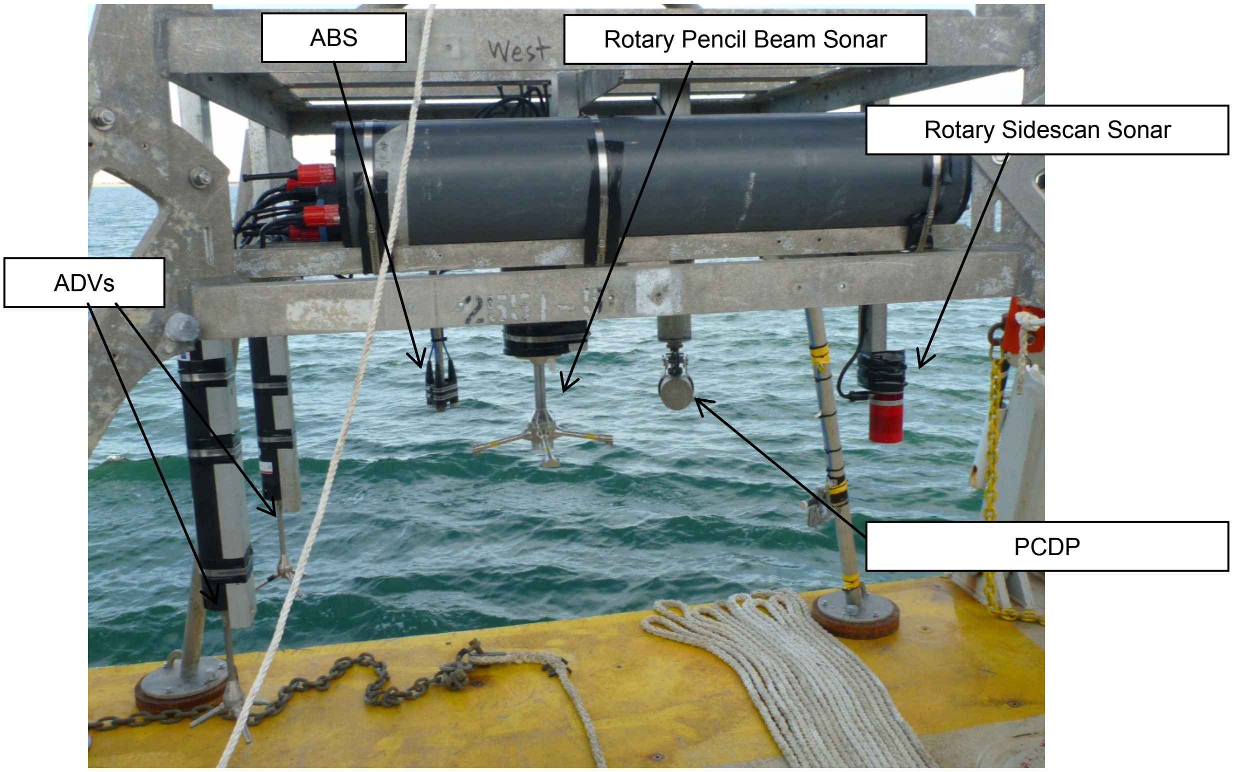

Figure 4. Photograph of instrumentation just before deployment at MVCO in September 2011, showing Pulse Coherent Doppler Profiler (PCDP), Imagenex rotary sidescan sonar, Imagenex 2-axis rotary pencil beam sonar, Aquatec ABS and Nortek Vector ADVs.

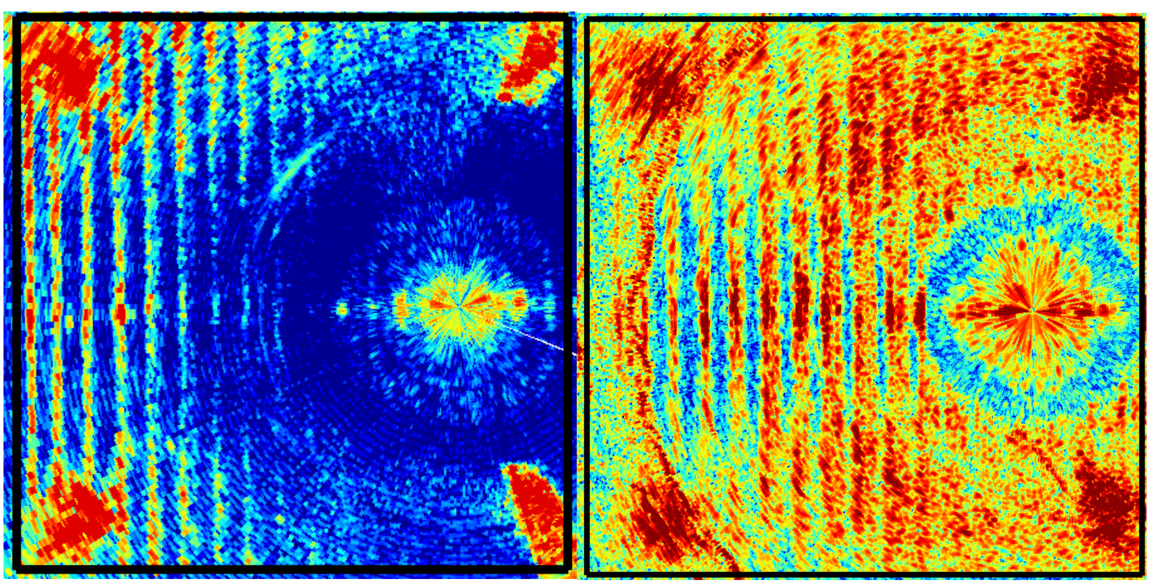

Figure 5. Data from two prototype 881L tilted head rotary fanbeam sonars. The data in the right panel uses a wider beamwidth transducer to increase the ability to image under the sonar. The size of the imaged box is 2.5 m on a side.

REFERENCES

Hay, A. E., L. Zede1, R. Craig and W. Paul (2008), Multi-Frequency, Pulse-to-pulse Coherent Doppler Sonar Profiler, Proceedings of the IEEE/OES/CMTC Ninth Working Conference on Current Measurement Technology, Charleston, SC, March 2008

PUBLICATIONS

Traykovski and Jaffre, Development and Field Measurements with Multi-Frequency, Pulse-Coherent Doppler Systems, The Journal of Ocean Technology, Vol. 6, No. 2, 2011