Ocean Mixing

James N. Moum

College of Oceanic & Atmospheric Sciences
Oregon State University
Corvallis, OR 97331-5503
ph: (541) 737-2553 fx: (541) 737-2064 email: moum@coas.oregonstate.edu

Award #: N00014-96-1-0250
http://www.oce.orst.edu/po/mixing/index.html

LONG-TERM GOALS

The long-term goal of this program is to understand the physics of small-scale oceanic processes including internal waves, hydraulics, turbulence and microstructure that act to perturb the circulation in coastal oceans and, in doing so, affect the propagation of sound and light. Ongoing studies within the **Ocean Mixing Group** at OSU emphasize observations, a continual program of sensor and instrumentation development, and interaction with turbulence modelers.

OBJECTIVES

Our present objectives are directed towards a determination of the influence of both near-surface internal solitary waves of depression and near-bottom internal solitary waves of elevation on mixing of water masses and flow drag over the continental shelf.

APPROACH

We have combined acoustic backscatter measurements with shipboard ADCP and our microstructure profiling measurements (using CHAMELEON), all from the same platform in two separate experiments (September 2001, April 2003). This has permitted an observational view of shoreward-propagating internal solitary waves (both near the surface and near the bottom) not previously achieved. These observations have been supplemented by the deployment of a bottom lander outfitted with an upward looking ADCP (to obtain water column velocity profiles), 2 acoustic Doppler velocimeters (to detect the turbulent component of the velocity signal at 1 m height above the seafloor) as well as a CTD.

WORK COMPLETED

Initial results from the 2001 experiment in which the generation of turbulence in near-surface internal solitary waves of depression is linked to compressive wave straining at the wave crest have been published (Moum et.al. 2003). Work is continuing to define the evolution of the energetics as the waves progress across the shelf. This work is a collaboration with David Farmer (URI) and Bill Smyth (OSU).

A 7-day experiment to investigate the near-bottom internal bore and its evolution into a train of solitary waves was conducted in April 2003.

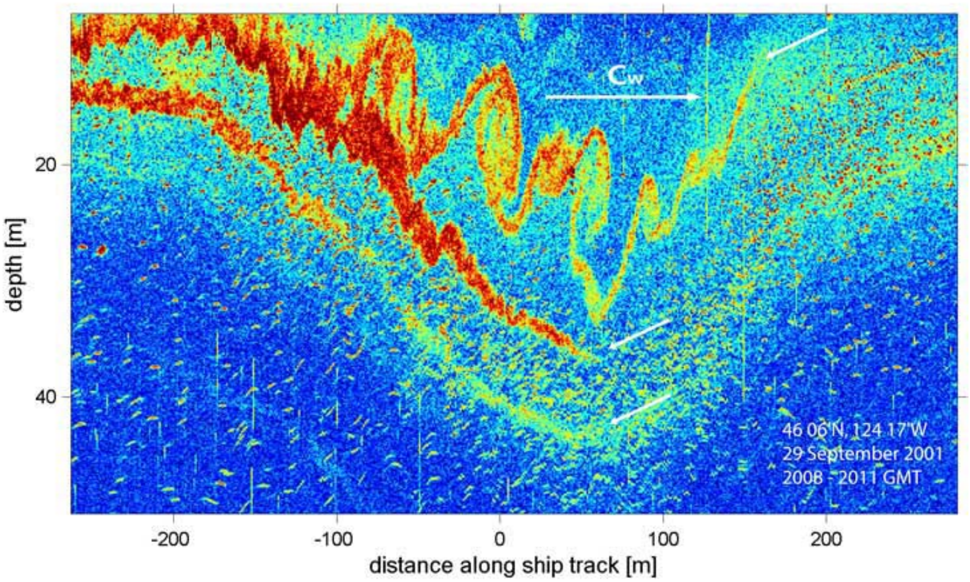

Figure 1 - Example acoustical snapshot of a propagating internal solitary wave within which is embedded a sequence of rollups identical to Kelvin-Helmholtz instabilities observed in the lab and in simulations. Vertical scale of the largest is > 10 m; horizontal scale (in the direction of wave propagation) is ~ 50 m. Toward the wave's trailing edge, rollups are less coherent but contribute greater backscatter signal, suggesting breakdown to turbulence. At greater depth, denoted by arrows, are two more layers of bright backscatter. These are presumably the same phenomenon, but smaller scale. The echosounder resolution does not permit a clear depiction of rollups in these thin interfaces.

RESULTS

Analysis of the data from September 2001 is ongoing. Detailed observations of the structure within internal solitary waves propagating shoreward over Oregon's continental shelf reveal the evolving nature of interfaces as they become unstable and break, thereby creating turbulent flow (Moum et al, 2003). A persistent feature is high acoustic backscatter beginning in the vicinity of the wave trough and through its trailing edge and lee (Figure 1). This is clearly demonstrated to be due to enhanced density microstructure. Increased small-scale compressive strain ahead of the wave trough occurs at select interfaces, thereby locally increasing stratification. This is followed by a sequence of overturning, high density microstructure and turbulence at the interface, which is coincident with high acoustic backscatter.

Density profiles reveal these pre-turbulent interfaces to be O(10 cm) thick, much thinner than can be resolved with shipboard velocity measurements. Consequently, Richardson number estimated from observations is larger than 1/4, leading to the prediction that the interface is stable. By assuming that streamlines parallel isopycnals where turbulence is small ahead of the wave crest, we infer a velocity profile in which the shear is sufficiently high to create explosively-growing, small wavelength shear instabilities (as suggested from linear stability analysis). We argue that this is the generation mechanism for the observed turbulence and the persistent structure of high acoustic backscatter at selected interfaces (Moum et al, 2003).

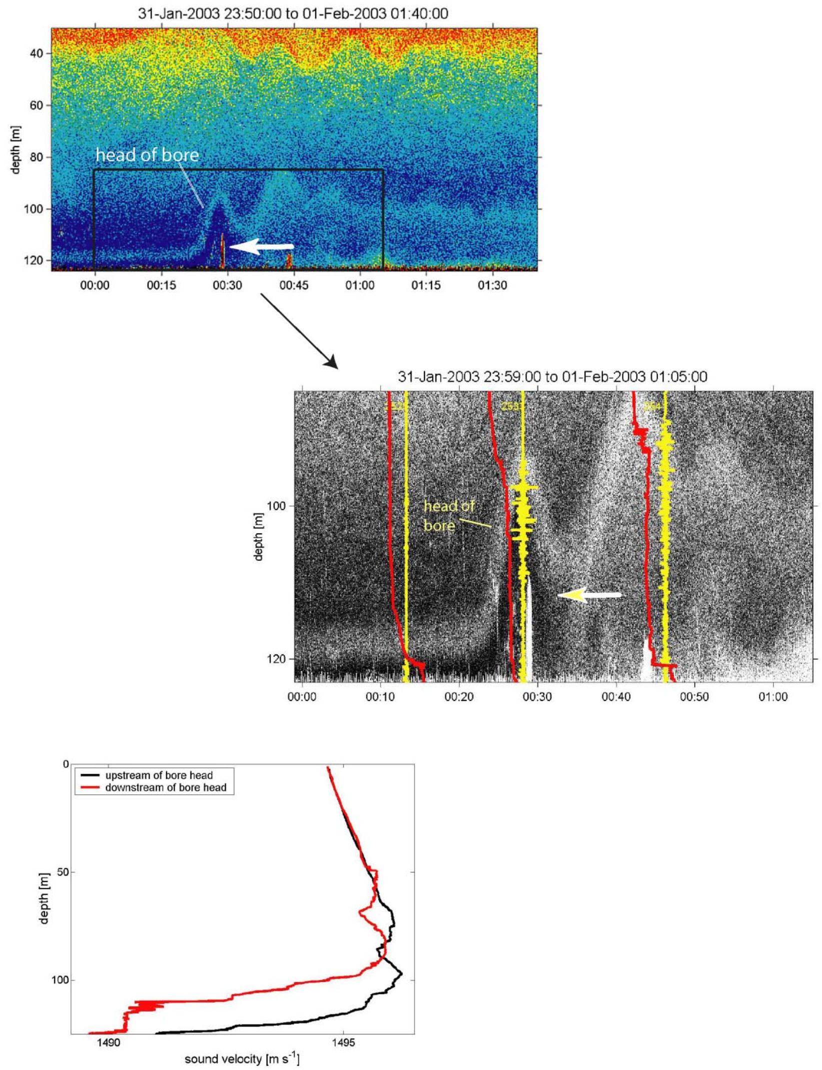

Figure 2 – A highly turbulent and undular bore. Upper plot shows acoustic backscatter image made while maintaining station over a position in 120 m of water depth on the continental shelf. This record is 2 hours long and shows the propagation shoreward of an internal undular bore over the bottom. Beneath this is an expanded plot with CHAMELEON profiles of turbulent shear (yellow) and density (red) through the bore. Sound speed profiles computed across the head of the bore are shown at bottom.

Observations of near-bottom waves of elevation (April 2003) positively identified 8 bores during a 116 h sampling period but unlike solitons observed elsewhere (ASIAEX, for example), these were only loosely phase-locked to the semidiurnal tide (over 2 periods of > 24 h, no bores were detected) . Some properties of near-bottom bores can be seen in Figure 2 which combines results our hull-mounted narrow-beam echosounder (120 kHz) and CHAMELEON profiles. The bore propagates shoreward at about 0.5 m s^{-1}. Its amplitude is 30 m (25% of the water column) and its head represents a sharp boundary, offshore of which is dense, cold, salty water propagating onto the shelf. It is also highly turbulent as depicted by CHAMELEON profiles through the head of the bore (for clarity we show here only every 4th profile). The large change in sound speed profiles across the bore's head is also shown in figure 2.

An internal bore shown from the perspective of our bottom lander is shown in figure 3. At this stage, the bore had progressed from appearing to be turbulent in nature (from Chameleon transects made prior to the lander record shown), to becoming more undular in nature. At the point of observation of the lander, the bore clearly had undulations at the leading edge (as seen especially from the horizontal banding of vertical velocity structure there and the ADV point velocity measurement – 4th panel of figure 3). It was also clearly turbulent, as seen from the highpassed point velocity record. The density jump across the bore front was 0.5 kg m^{-3}; this lagged the velocity core of the front. Perhaps most striking is the large acoustic backscatter in the 500 kHz ADCP extending to 5 m above the bed. The acoustic wavelength of 3 mm is equivalent to a huge grain of sand. Either the bore has brought with it a rarely-observed uniformity of biological scatterers or fairly large particles were resuspended above the sea bed. The latter occurrence would be consistent with the smaller particles resuspended above the bed as seen from 880 nm optical backscatter on Chameleon.

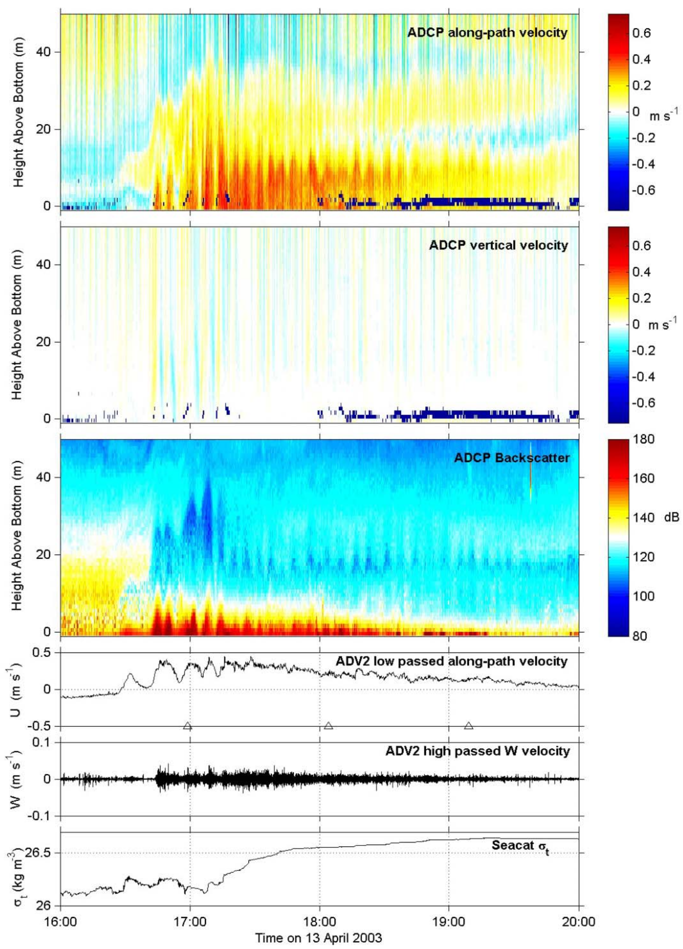

Figure 3 – Time series observations from our bottom lander deployed in 100 m water depth in April 2003. Top panel - shoreward velocity (peak speeds are 0.5 m s^{-1}) as a function of height above bottom; 2nd panel - vertical velocity; 3rd - acoustic backscatter; 4th panel - lowpassed velocity record from an Acoustic Doppler Velocimeter (ADV) 1 m above the bottom; 5th panel - highpassed record from the ADV showing the variability of the turbulence within the bore; bottom panel - density 1 m above bottom;

IMPACT/APPLICATION

I was recently asked by the Essential Fish Habitat coordinator from NOAA's Fisheries Habitat Conservation Division about the viability of dumping Columbia River dredge discharge in 100 m water depth to a height of 5 m above the bottom in a 1 sq.mile patch south of the Columbia R. The concern was whether it would be disturbed and affect the local ecosystem. The answer (as we have recently discovered) is that the pile will most certainly be eroded (and probably quite rapidly) by onshore transport effected by near-bottom internal bores.

The consequences for acoustic propagation over the continental shelf remain to be seen. Recent acoustics experiments designed to determine the effects of near-surface solitary waves of depression have neglected the effects of near-bottom waves of elevation. Yet these appear to be ubiquitous features of the coastal ocean. Because they are difficult to detect (requiring measurements near the bottom) and have no known surface expression, their properties, evolution and importance have yet to be determined.

RELATED PROJECTS

The examination of near-surface solitary waves includes collaborations with David Farmer (IOS), Larry Armi (SIO) and Bill Smyth (OSU).

PUBLICATIONS

Microstructure observations of turbulent salinity flux and the dissipation spectrum of salinity. *J. Phys. Oceanogr.*, 32, 2312-2333. 2002 (J.D. Nash and J.N. Moum).

Waves and instability in an asymmetrically stratified jet, *Dyn. Atmos. Ocean*, 35, 265-294. 2002 (W.D. Smyth and J.N. Moum).

Structure and generation of turbulence at interfaces strained by internal solitary waves propagating shoreward over the continental shelf, *J. Phys. Oceanogr.*, 33, 2093-2112. 2003 (J.N. Moum, D.M. Farmer, W.D. Smyth, L. Armi and S. Vagle).

Form drag and mixing due to tidal flow past a sharp point, in press, *J. Phys. Oceanogr* (K. A. Edwards, P. MacCready, J.N. Moum, G. Pawlak, J. M. Klymak and A. Perlin.

Internal solitary waves of elevation advancing on a sloping shelf, in press *Geophys. Res. Lett*. (J. M. Klymak and J.N. Moum)