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@oce.orst.edu

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

LONG-TERM GOALS

The long-term goal of this program is to understand the processes of instability that generate turbulent mixing and drag, especially in the coastal ocean. Our ongoing studies of both the kinematics and dynamics of turbulence and small-scale physical phenomena in the ocean leading to turbulence emphasize observations, a program of continued sensor and instrumentation development, and interaction with turbulence modelers.

OBJECTIVES

Our objectives are to:

- determine the influence of solitons on mixing of water masses and flow drag over the continental shelf. Specifically, from an ensemble of wave train observations we hope to determine:
  - generation sites of internal solitary waves observed in COPE and by us in June 2000
  - evolution of dissipation as waves progress across the shelf from site of generation
  - bottom boundary layer signature of the waves
  - net contribution to mixing of stratified fluid in mid-water column
  - distribution of wave mixing across the shelf
  - distribution of wave-induced bottom stress across the shelf.
- make the 1st systematic estimates of the turbulent diffusivity for salt
- determine the influence of small topographic features on mixing and flow drag over the shelf. Specifically, to complete analyses of and publish results from extended studies of hydraulically-controlled flow over Stonewall Bank.

APPROACH

We have developed and partially tested an experimental plan to observe internal solitary waves on the Oregon shelf. In a pilot experiment conducted in June 2000, we combined acoustic backscatter measurements (Farmer) with shipboard ADCP and our microstructure profiling measurements (using CHAMELEON), all from the same platform. This permitted an observational view of shoreward-propagating internal solitary waves not previously achieved. Some of the difficulties in making these observations became apparent in the pilot experiment and in post-analysis of the data. First of all, it is very difficult to detect the generation site from a ship alone because of the limited field of view from a ship. Secondly, we discovered that another wave train crossed the path of the original as we approached shore, making the identification of the original wave train ambiguous. Thirdly, we believe that the bottom velocity due to the wave passage is an important quantity in determining both the wave dissipation (via bottom boundary layer (BBL) turbulence) and to the local current (via bottom stress) – this is impossible to measure from shipboard ADCP.

To remedy these shortcomings, we plan several additions for our September 2001 field experiment:

1) to improve local scale detection of the wave trains, we will sample the ship's X-band radar. We will set up a web camera and log the radar screen photographically. We expect this will tell us the position of a particular wave in the wave train and help to resolve ambiguity due to crossing wave trains. (Moum)
2) to improve large scale detection of the wave trains, we will photograph the sea surface from aircraft. (Armi)
3) to detect bottom currents, we will place a bottom mooring with upward-looking ADCP, point ADV measurement and SeaBird T/C pair. (Moum)
4) to better sample the upper 5 m (above the depth at which shipboard transducers are mounted) a small boat outfitted with echosounder and ADCP will be periodically deployed during CHAMELEON operations. (Farmer)

WORK COMPLETED

At this writing, we are preparing to embark on a 20-day experiment to investigate internal solitary waves on the continental shelf.

Two papers were published in which the salient features of hydraulic flow around Stonewall Bank are identified, and drag and mixing due to the bank quantified. A comprehensive analysis of the dissipation spectrum of salinity and resultant fluxes has led to an evaluation of differential diffusion in weakly turbulent flows – a paper is in press on this topic.

RESULTS

Analysis of data obtained in our June 2000 solitary wave pilot experiment is ongoing. By using the ship to make repeated passes through the wave train, we have been able to examine the evolution and dissipation occurring in these internal solitary waves as they move shoreward on the shelf. At the wave's leading edge instabilities on the sheared interface appear similar to those found in laboratory studies. These are revealed in higher resolution acoustic backscatter not shown here. The result is very intense turbulence above the interface (Figure 1). In fact, our observations indicate that the kinetic energy dissipated by turbulence in the wave is sufficient to account for the total kinetic energy lost during the time we were able to observe the leading wave of this wave train (Figure 2).

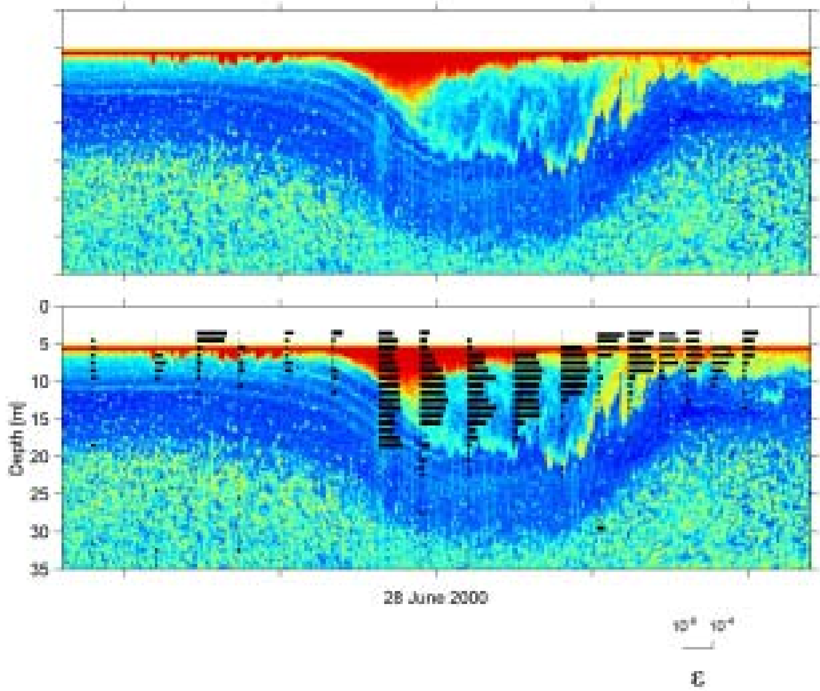

Figure 1 – CHAMELEON profiles indicate strong turbulence within the wave structure, which is clearly outlined by acoustic backscatter. These were made with the ship drifting and the wave propagating shoreward (right to left) past the ship. Profiles do not line up exactly with the acoustic image due to relative motion of ship and CHAMELEON during the profile.

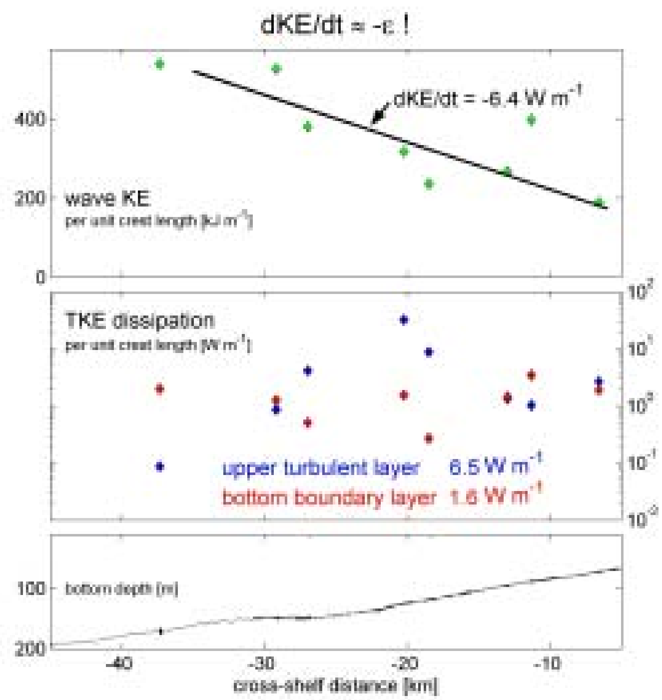

Figure 2 – Evolution of the observed wave as it propagated 30 km onshore during a 12 h period (mean phase speed, 0.7 m/s). The wave kinetic energy (top panel) decreased by a factor of 5, or at the rate –6.4 W per unit crest length. This is nearly equal to the mean value of the turbulent dissipation rate measured in the wave during the 8 profiling transects (2nd panel, blue).

In June 2000, we also conducted a more intensive experiment to investigate the flow over Stonewall Bank. We made a series of 28 transects across the bank. These revealed the following flow states:

- crest-controlled, strong downslope, lower layer flow from NE→SW over the bank. This is similar to what we have observed previously (Moum & Nash, 2000; Nash & Moum, 2001);
- crest-controlled, strong downslope, lower layer flow from SW→NE over the bank – that is, the flow can be controlled in the opposite direction;
- a thinning, accelerated upper layer from NE→SW over the bank. This raises the issue of whether the upper layer can become supercritical – further analysis is needed to identify potential control.

Each of these states is associated with highly turbulent fluid in the BBL, the sheared interfaces and in the downstream hydraulic jump region.

Another important new aspect of the flow over Stonewall Bank is the identification of the downstream wake (Figure 3). We observed a quasiperiodic train of co-rotating vortices with separation several hundred meters and 25 m vertical isopycnal displacements downstream of the bank. In the upwelled BBL at the base of these waves were high levels of turbulence. We hypothesize that this is a remote effect of the hydraulic flow over the bank on the surrounding shelf circulation, either in the form of a vortex street or released lee waves.

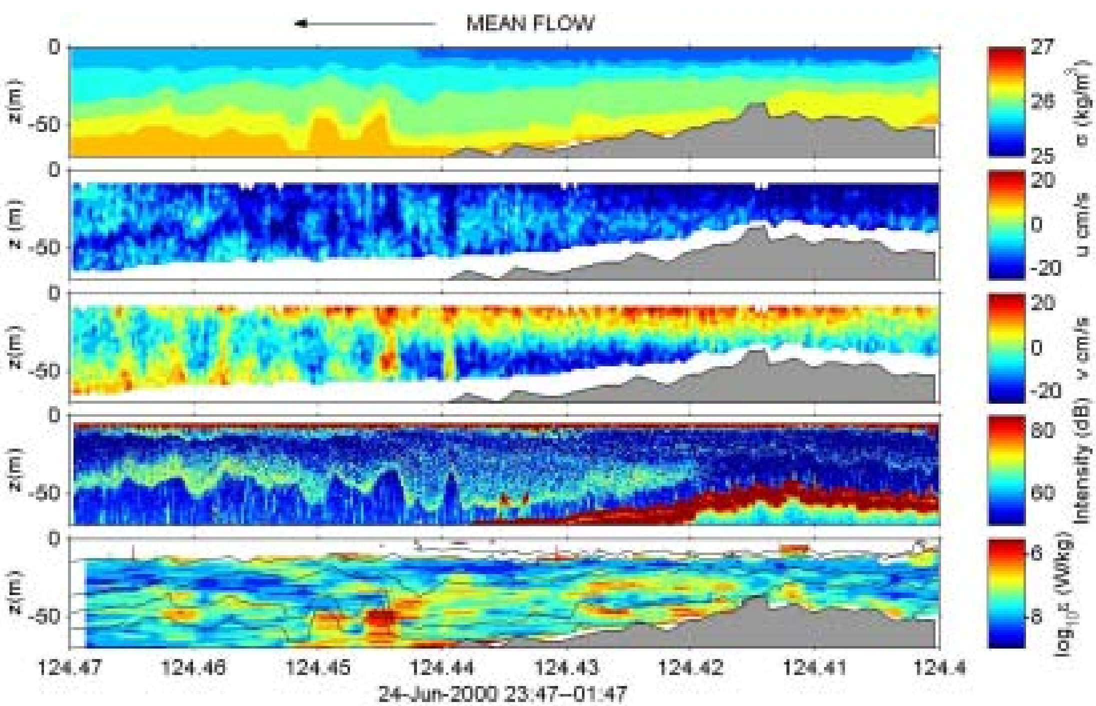

Figure 3 – One of 28 transects across Stonewall Bank in June 2000. The top panel shows density as determined from CHAMELEON, the 2nd panel is the cross-bank current and the 3rd panel is the along-bank current. The 4th panel is the acoustic backscatter from a high frequency echosounder mounted in the hull of the ship (Farmer) and the bottom panel is the turbulent dissipation rate with density contours. The total length of this transect is 8 km. Bottom is shaded gray in all panels except the echosounder intensity in which the bottom is indicated by the high backscattering strength (red). The downstream wake includes large amplitude waves west (to the left of) 124.44 W.

IMPACT/APPLICATION

The disturbances to the coastal circulation due to flow over banks which may occupy a small portion of the continental shelf, and internal solitary waves which occur relatively infrequently, can exercise a disproportionate influence on coastal circulation arising from enhanced drag and mixing. As yet, such effects are not incorporated in larger scale coastal circulation models. Improved representation of these effects requires that we adequately characterize the small-scale dynamics, allowing accurate incorporation in the larger scale models. The present work is intended to lead to this result.

RELATED PROJECTS

This project represents a close collaboration with David Farmer (IOS) and Larry Armi (SIO).

PUBLICATIONS

Moum, J.N. & J.D. Nash, 2000: Topographically-induced drag and mixing at a small bank on the continental shelf. ***J. Phys. Oceanogr***., 30, 2049-2054.

Moum, J.N. & W.D. Smyth, 2001: Upper ocean mixing. in press, *Encyclopedia of Ocean Sciences*. Academic Press.

Nash, J.D. & J.N. Moum, 2001: Microstructure estimates of turbulent salinity flux and the dissipation spectrum of salinity. ***J. Phys. Oceanogr***, in press.

Nash, J.D. & J.N. Moum, 2001 Internal hydraulic flows on the continental shelf: high drag states over a small bank. ***J. Geophys. Res***., 106, 4593-4611

Smyth, W.D. & J.N. Moum, 2000a: Evolution of turbulence in stably stratified mixing layers. Part 1: Length scales. ***Phys. Fluids***, 12, 1327-1342.

Smyth, W.D. & J.N. Moum, 2000b: Evolution of turbulence in stably stratified mixing layers. Part 2: Anisotropy. ***Phys. Fluids***, 12, 1343-1362.

Smyth, W.D. & Moum, J.N. 2001: 3D Turbulence. in press, *Encyclopedia of Ocean Sciences*. Academic Press.