Turbulence Fluxes

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LONG-TERM GOALS

The long-term goal of this program is to understand the processes by which heat and mass are transported vertically by turbulent processes in the ocean in order to estimate the rates of these transports. 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 small topographic features and solitons on mixing of water masses and flow drag over the continental shelf
- make the 1st systematic estimates of the turbulent diffusivity for salt
- complete analyses of and publish results from pilot studies of hydraulically-controlled flow over Stonewall Bank.

APPROACH

An experiment was conducted in June 2000 to further investigate the nature of hydraulic flows we have previously observed on the continental shelf and to make a preliminary investigation of internal solitary waves on the Oregon shelf. This was done in collaboration with David Farmer (IOS) and Larry Armi (SIO) and employed Farmer's acoustic imaging techniques to identify the fine scales of the flow and our turbulence profiler *CHAMELEON* to obtain vertical profiles of turbulent dissipation and density, permitting quantitative assessments of flow states. A schematic of the sampling scheme is shown in Figure 1. A similar collaboration and instrumentation will be used to study the evolution of internal solitary waves propagating on to the Oregon shelf in summer 2001.

WORK COMPLETED

Detailed acoustic and *in situ* measurements were acquired of flow over Stonewall Bank in June 2000. Farmer's instrumentation worked well and excellent acoustic images were acquired simultaneous with our microstructure profiles. The addition of an optical backscatter probe on *CHAMELEON* provided a

clean measure of scattering interfaces. Extensive ADCP observations were acquired throughout the cruise. Data processing was partly carried out on the cruise; further analysis is underway.

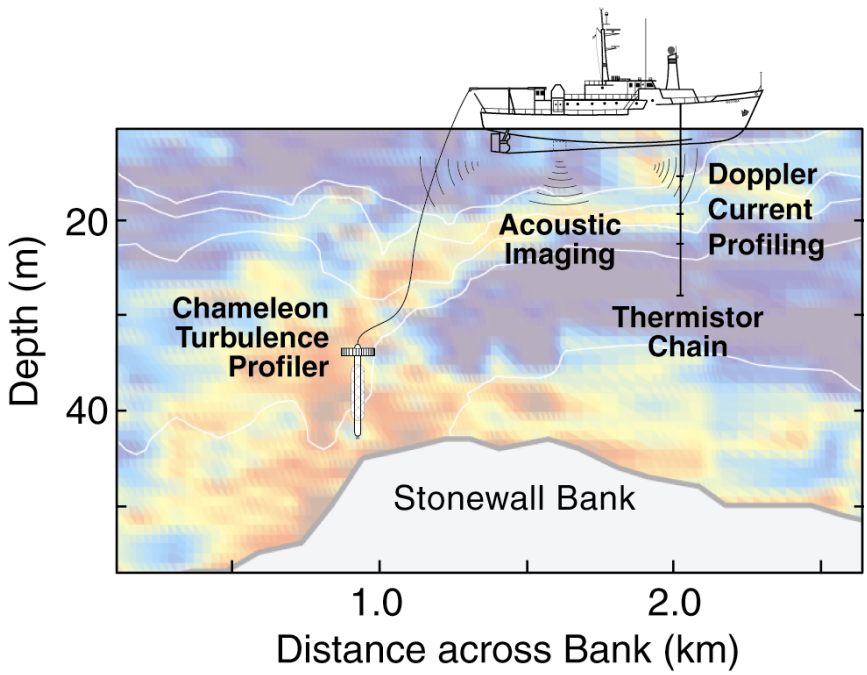

Figure 1 - Experimental deployment of instrumentation over Stonewall Bank (thermistor chain not used in 2000). A similar deployment was used to study internal solitary waves. Background image shows turbulent dissipation rate; red is several orders of magnitude greater than blue (Moum and Nash, 2000).

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. The method for determination of salinity variance dissipation rate and estimation of turbulent diffusivity for salinity from high wavenumber conductivity gradient measurements have been demonstrated in a paper published. 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 has been submitted on this topic. The use of a thermocouple to resolve temperature gradient spectra has been documented in another paper.

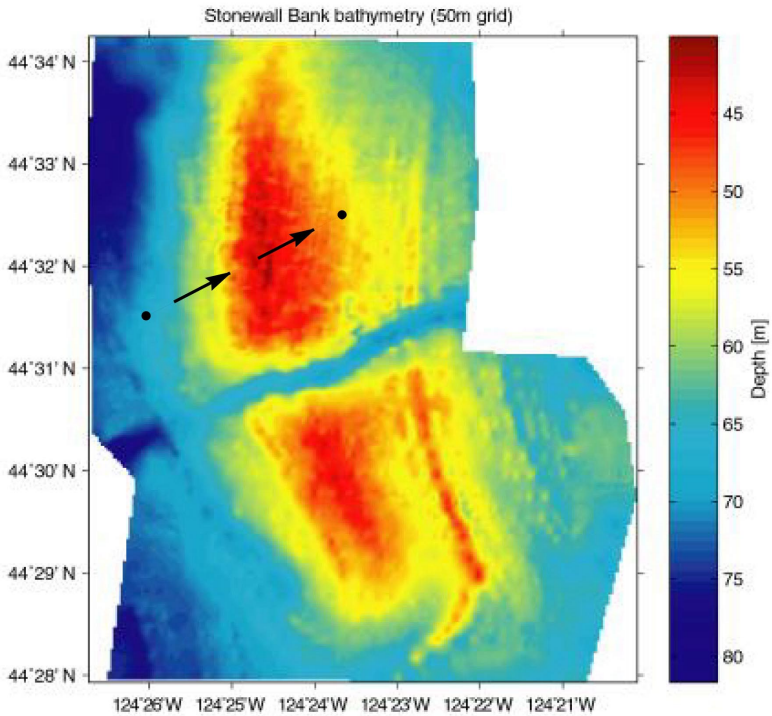

Figure 2 – Bathymetry of Stonewall Bank derived from surveys in June 2000. Predominant flow was from NE to SW over the bank. The transect shown in Figure 3 is aligned with and in the direction of the arrows.

RESULTS

Because existing bathymetry of Stonewall Bank was inadequate, we surveyed a grid using ship's 12 kHz echosounder. The result was a new three-dimensional image of the bank in much demand by local fishermen (Figure 2). For many of the traverses across Stonewall, the flow appeared to be controlled at the crest, resulting in a classical internal hydraulic response downstream (cf Farmer and Armi, 1999; Moum and Nash, 2000; Nash and Moum, 2000 and as in Figure 1). Although detailed analysis has yet to be carried out, preliminary analysis of the data implies that there were situations when this response did not occur and a different behaviour was observed. In these cases the interface did not immediately plunge down the lee face of the bank in the asymmetric response expected for control at the crest, but instead remained approximately horizontal for some distance before jumping down sharply to match the downstream conditions. Figure 3 shows such an example, with the primary flow in the upper layer from right to left and aligned with the vessel's track. High values of ε were observed at the interface between upper and lower layers west of the crest (Figure 3).

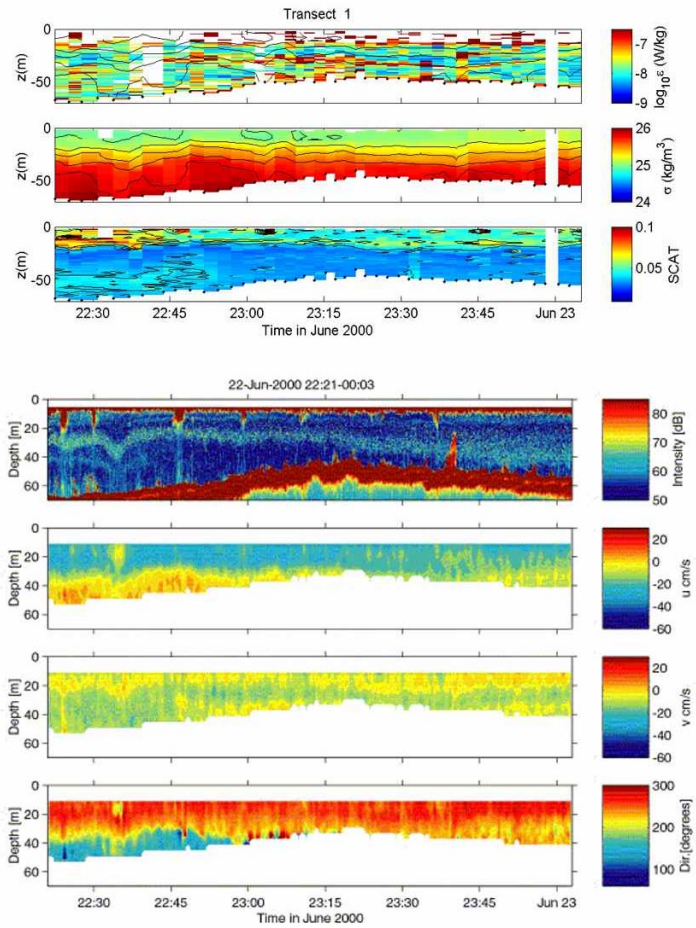

Figure 3 – Example of a transect over Stonewall Bank going from SW to NE over the bank as indicated in Figure 1. The upper 3 panels show data taken by our microstructure profiler, CHAMELEON. Top panel shows turbulent dissipation rate (ε), followed by σ_θ (panel 2) and optical backscatter intensity (panel 3). 4th panel: acoustic backscatter image (Farmer). 5th panel and 6th panels: ADCP speeds in direction of and orthogonal to ship track. Bottom panel: orientation of flow vectors relative to N.

Following the study of Stonewall Bank we focused our attention on internal solitary waves. Repetitively traversing the shelf at speed, we used the back scatter sonar to identify a near surface interfacial disturbance, which subsequently evolved into a train of solitary waves propagating onshore. This we followed for some 30nm to about 40 m water depth. Many rapid traverses were made, followed by slow traverses in the other direction during which multiple *CHAMELEON* profiles were obtained (Figure 4). In the example shown, the density interface is depressed vertically 15 m from its original 3 m depth; the fluid was fully turbulent within the depression. Overturning scales are >5m and ε is almost 10^{-4} m^2s^{-3}, in the range of observed values 5 m below a field of breaking surface waves (Anis and Moum, 1995).

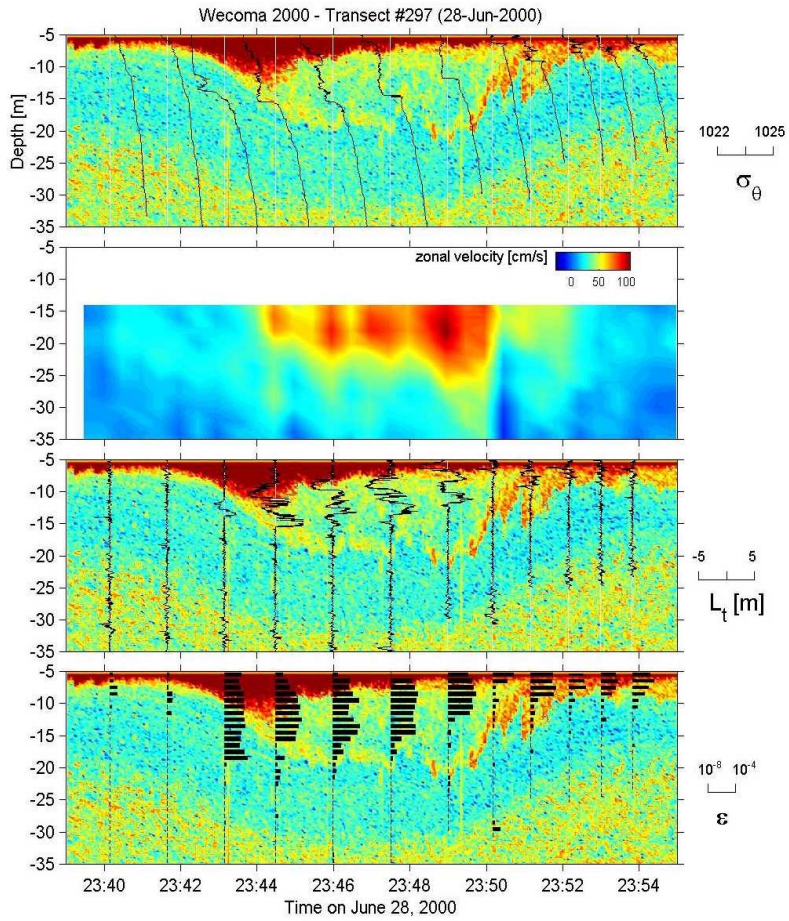

Figure 4 – Data profiles and acoustic image of an internal solitary wave propagating onshore to the left. Density profiles are overlaid on the upper panel, Thorpe scales (L_T) on the 3rd and and ε on the bottom panel. The 2nd panel shows onshore velocity as measured by shipboard ADCP.

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).

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