

# Velcro Measurements of Turbulence in Coastal Oceans

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## LONG-TERM GOAL

Significant turbulent transports within coastal oceans have been shown to be highly sporadic in both time and space, challenging present ship-based, labour-intensive turbulence measurement techniques. My long-term goal is to lower the cost and effort required to find those locations which dominate coastal mixing, to describe their time evolution, and to quantify their effects. The ultimate objective is an automated system, operating without ship support and returning data via local radio (cell-phone) networks or by underwater telemetry.

## SCIENTIFIC OBJECTIVES

The goal of this project is to develop survey tools - instrumentation and analysis techniques - which will produce 2-dimensional fields of important turbulent quantities simultaneously with the mean shear fields which generate them. Such survey tools are essential to locate the 'hot spots' of coastal ocean turbulence, allowing more expensive techniques to be concentrated in these areas. Survey instruments are also necessary for adequate description of turbulent flow evolution over the enormous range of temporal scales which are relevant to coastal oceans, from the semi-diurnal tidal period through annual and interannual variations in buoyancy forcing.

## APPROACH

My approach has been to modify a standard acoustic Doppler current profiler (rotating one beam to vertical) to measure directly the field of vertical velocity ( $w$ ) in highly energetic coastal mixing flows. An unambiguous measure of  $w$  then allows estimation of turbulence properties such as turbulent kinetic energy  $E$  and its dissipation rate  $\varepsilon$  from measurement of the largest energy-containing eddies. In the case of  $\varepsilon$ , this approach has been calibrated against now-standard estimates of  $\varepsilon$  from airfoil probes carried on microscale profilers. Thus calibrated, the "Velcro" acoustic large-eddy technique provides 2-dimensional swath mapping of  $\varepsilon$ .

## WORK COMPLETED

I have developed a refined estimate of turbulent kinetic energy dissipation rate  $\varepsilon$  from large-eddy characteristics, as determined from the field of vertical velocity measured by the specialized DOT (DOppler Turbulence) acoustic profiler. This estimator has been calibrated against standard airfoil estimates, using data taken with the IOS FLY profiler (cruise JA90) and the Oregon State University profiler Chameleon (cruise FB90), and a manuscript (Gargett 1998) has been submitted for publication in the Journal of Atmospheric and Oceanic Technology.

# Report Documentation Page

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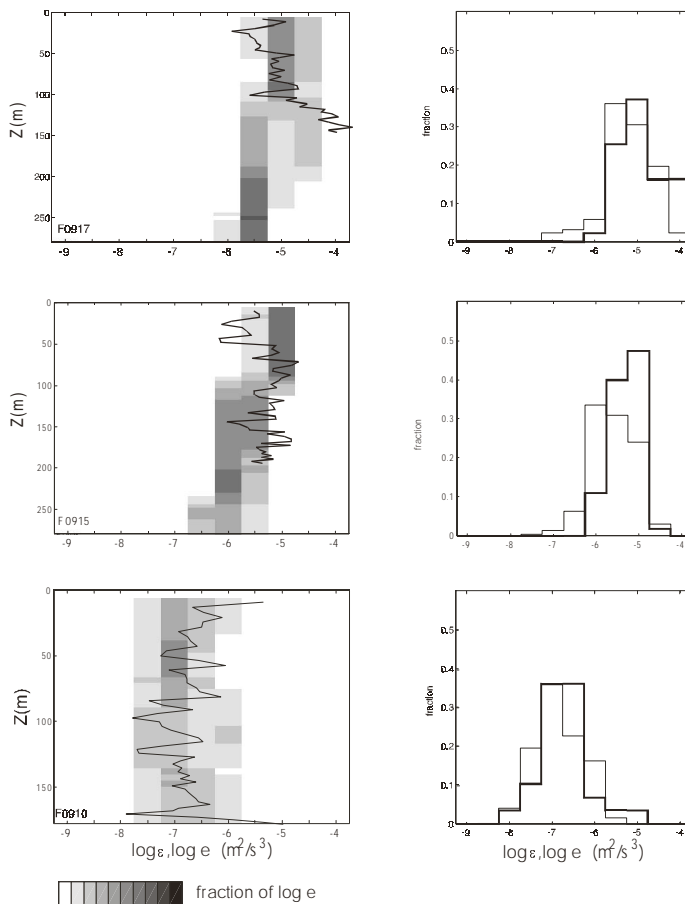
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In fall of 1997 (cruise OC97), I successfully tested a new technique for obtaining CTD casts with finescale resolution, freefalling an Ocean Sensors CTD down a near-vertical taut cable. The resulting density profiles are being used to provide estimates of vertical (Thorpe) overturning scales and (with Doppler shear data) of mean flow Richardson number in the turbulent outflow of a coastal tidal constriction.

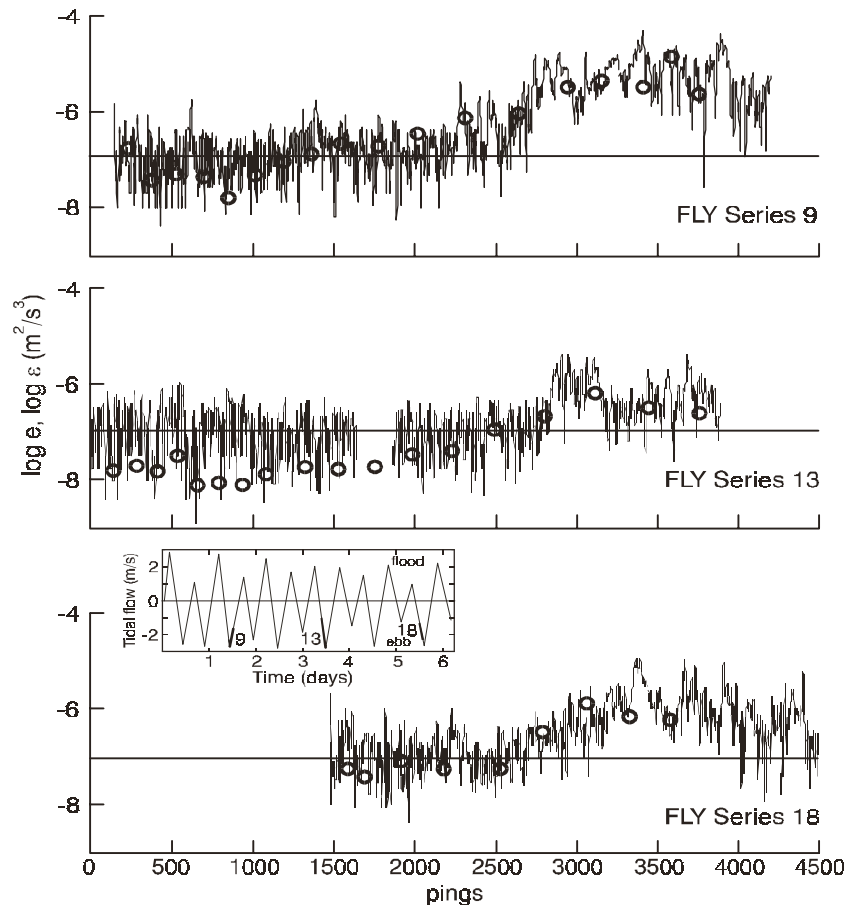
## RESULTS

The algorithm for estimating turbulent kinetic energy dissipation rate  $\varepsilon$  from large-eddy properties determined from acoustic measurement of the vertical velocity field has been calibrated against a subset of microscale profiler data obtained during cruise JA90 (Figure 1). With the calibration constant thus determined, the algorithm successfully describes the remaining data available from this cruise, as well as data taken with a different microprofiler during the subsequent cruise FB90.



**Figure 1: Comparisons of vertical profiles and probability distribution functions for  $\log \varepsilon$  and  $\log e$ . Measurements of small-scale shear from airfoil probes on the microprofiler FLY produce the individual profiles of  $\log \varepsilon$  in the left-hand panels, heavy histograms at right. In the leftmost panels, grey-scale histograms at each Doppler depth bin display the probability distribution functions (fraction) of the DOT large-eddy estimates  $\log e$ , as determined over a 101-ping (approximately 200m) “neighbourhood” of the FLY release ping. The overall histograms of  $\log e$  values over the depth intervals of the associated FLY profiles are the light histograms at the right.**

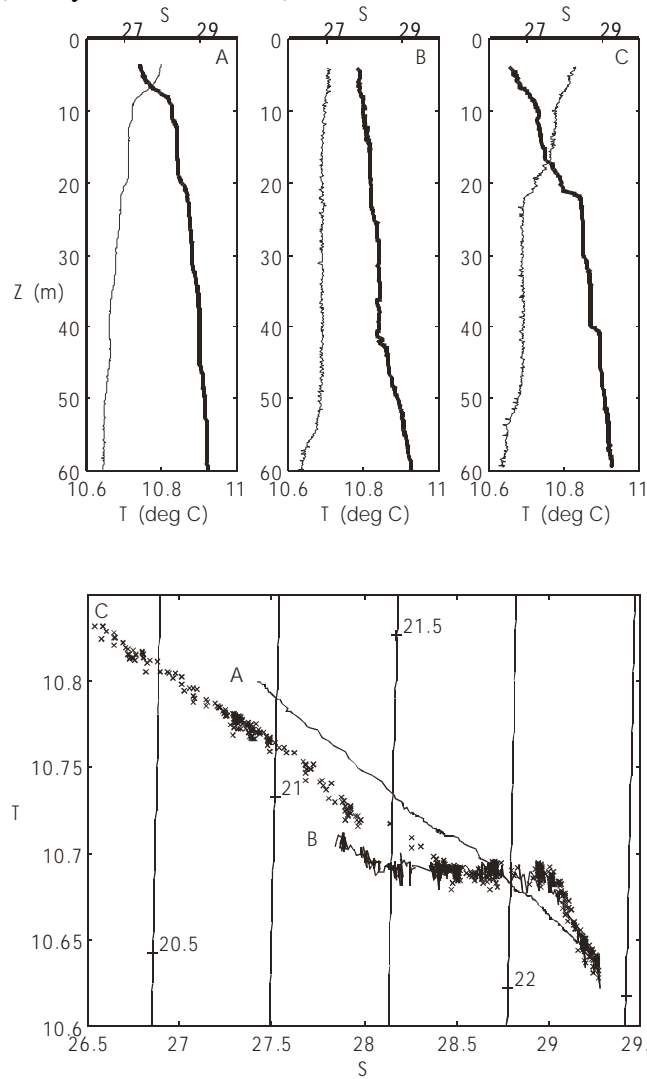
The large-eddy “Velcro” technique provides unparalleled spatial resolution of the dissipative structure of turbulent flows in the coastal ocean. Fig. 2 shows three transects of a tidal front: values of  $\log \epsilon$  averaged over the FLY profile depth (circles) are superimposed on curves of comparable values of  $\log e$ . Within the fronts, where signal levels are above noise ( $\log e \sim -7$ ), this comparison reveals how poorly standard microprofilers sample these strong, complex, and rapidly changing flows. The semi-automated character of DOT measurements provides a cost-effective means of examining evolution of strong coastal mixing flows under changing conditions of tidal flow and/or buoyancy forcing. The limited set of frontal transects shown in Fig. 2 already suggests that a decelerating tidal flow may produce stronger turbulent dissipation (transport) than an increasing flow of the same magnitude.



**Figure 2: Comparison of time/space series of depth-integrated turbulent kinetic energy dissipation rates, as determined by sporadic microscale profiles (circles) and by DOT velocity profile measurements taken every 2 s (1 ping, approximately 2 m horizontally), for three transects of the same tidal front (records are aligned so that the surface expression of the front is encountered around ping 2500). Although taken over similar ranges of ebb tidal speeds (see insert), the top record, taken on a decreasing rather than an increasing ebb, is characterized by significantly larger mean dissipation rates.**

Preliminary analysis of freefall CTD data obtained during cruise OC97 suggests the action of differential diffusion, ie preferential turbulent transport of temperature (T) over that of salt (S) in

conditions where the mean gradients of both components are stabilizing (Figure 3). If this interpretation can be confirmed, these will be the first oceanic observations of an effect which has been observed in both laboratory experiments (Altman and Gargett 1987; Saylor 1993) and direct numerical simulations (Merryfield et al. 1998).



**Figure 3:** The upper panels show free-fall CTD profiles of T (light lines) and S (heavy lines) taken from an anchored ship at (A) high water slack tide, and (B,C) as an ebb tidal flow increased over the subsequent 3 hours. “Ordinary” mixing of the water column in (A) would retain the linear relation shown in the T/S plot below. Instead, the turbulence (revealed variously by large overturning scales (B) and, in other parts of the data set, by critical mean shears and large vertical velocities) results in a strongly nonlinear deformation of the T/S relation, in the direction expected from differential diffusion with  $K_T > K_S$ .

## IMPACT/APPLICATIONS

This research has demonstrated that microscale profilers cannot be operated fast/frequently enough to do an adequate job of sampling turbulent dissipation in strong coastal mixing flows,

much less survey for the locations and time development of such flows. These inadequacies are addressed by the semi-automated acoustic remote sensing system developed during this research. Such a survey tool has an essential part to play in the measurement of turbulence in coastal regimes, although further platform development is necessary to transition this tool to exposed coastal environments. The robust nature of the sensors (relative to airfoil probes) and the low data rate (relative to microprofilers) make this a very promising technique for AUV applications.

The possible presence of differential diffusion in the ocean has enormous implications for the interpretation of standard microscale mixing estimates, for estimates of mixing from conservative tracer release experiments, and consequently for the parameterization of vertical mixing in all numerical models of the ocean.

### **TRANSITIONS:**

not yet

### **RELATED PROJECTS**

Work will continue (with J. Moum of OSU) to investigate the relationships among various vertical length scales associated with stratified turbulence. During past cruises, microprofilers have been used to measure Thorpe (overturning) scale LT and Ozmidov scale LO, while the DOT system determined the large-eddy vertical length scale LV. During one cruise (JL92), we also made direct eddy-correlation measurements of the buoyancy flux and the scales which dominate it. We will attempt to discover whether and how these scales are related across the variety of Reynolds and Richardson numbers encountered in the field.

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