Turbulent Dissipation Measurements

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1. Introduction

Turbulence is a fundamental process in the ocean and, together with its counterpart, advection, causes the distribution of material and momentum. The range of turbulence scales covers many orders of magnitude down to small scale turbulent fluctuations which have been measured at scales of 1 cm (Belyaev *et al*, 1975). In this report we describe the use of a probe that makes measurements at the smallest scales of turbulence with the aim of determining the vertical component of mixing in the upper 300 m of the ocean.

The existence of thermal microstructure, and its relationship to mixing in the ocean, has been known for a long time, since the advent of profilers that could make continuous measurements of temperature and salinity (see *e.g.* Stommel and Fedorov, 1967). Observations of fine scale turbulent velocity fluctuations, however, using a forerunner of the Canadian FLY probe, were not made until the early 1970's (e.g. Osborn, 1974). The free falling instrument was built around a glass sphere and contained a fast response thermistor and a two-directional shear probe. As it fell, at about 25 cm s^{-1}, data were relayed to the ship via an XBT wire; ballast was released to allow it to return to the surface. A subsequent development of this was the 'Camel' (Crawford, 1976, Osborn, 1980), which was constructed from a 3 m long aluminium tube, weighted at one end with expendable ballast, and designed to fall at between 40 and 50 cm s^{-1}. As before, it relayed data via an XBT wire. This instrument eventually evolved into the FLY probe described below. For completeness it should be noted that marine turbulence probes have also been developed elsewhere, for example the former Soviet Union had a whole suite of measurement systems, including free fall probes (see *e.g.* Ozmidov, 1980 and Belyaev *et al*, 1975).

One of the novel objectives of OMEX II is to make turbulence measurements concurrently with observations of biological and biochemical variables in order to provide a better understanding of their vertical distribution. In WPI the intention is to make the measurements in summer a) on the shelf, where internal waves and tidal stirring are important sources of turbulent energy, and b) in the ocean across a filament. In WPII, it is to measure the spatial distribution of turbulence in winter, although it is recognised that distribution in the surface waters will tend to be dominated by wind (and convective) effects - particularly in the open ocean. However below the mixed layer, and on the shelf other factors (*e.g.* the mixing of water masses and tidal stirring) will also be important. To date only field work for WPII has been conducted, during cruise CD110 in January 1998.

2. The FLY Free Fall Probe

The FLY probe used in OMEX (Fig. 1) is the most recent of an evolving line of instruments developed from an original by Osborn (1974). At the heart of the system are two fast response shear sensors, the design and principal of which have remained almost unchanged. The sensor is made of a small piezoceramic bimorph plate which responds to a shear strain by generating a voltage, in a manner similar to gramophone cartridge. The plate is embedded in a plug of soft epoxy having an airfoil shape (Fig. 2) originally used for aerodynamic problems by Siddon (1965, quoted by Osborn, 1974). In this configuration the probe is able to detect shears of between 0 and 4 s^{-1} (e.g. 0 to 4 cm s^{-1} cm^{-1}) with a precision of ± 5% and a response length of 1-2 cm (Dewey *et al*, 1987).

As the probe falls through the water with a velocity, *W*, it experiences a sideways lift force due to the horizontal component of the turbulent velocity fluctuations, *u*', which is given by (Crawford, 1976)

$$F = \frac{1}{2}\rho W'^2 A \sin 2\alpha \tag{1}$$

where $W'^2 = W^2 + u^2$ is the apparent velocity past the probe; A is the effective cross-sectional area of the probe; ɥ is the density of seawater; and $\alpha = \tan^{-1} u'/W$ is the angle of W' to the probe (see Fig. 2). From (1) we have

$$F = \rho AWu'$$

and hence, as the output voltage, V, is proportional to F:

$$V = CWu' \tag{2}$$

where C is a calibration constant. Certain conditions are required for C to be constant, the main being that α is small (° 5ʦ), a condition which is usually attained (Dewey *et al*, 1987). The value for the instantaneous shear is obtained from (2) as

$$\frac{\partial u'}{\partial z} = \frac{1}{W}\frac{\partial u'}{\partial t} = \frac{1}{CW^2}\frac{\partial V}{\partial t} \tag{3}$$

Common practise has been to take the initial processing a little further, in view of the large number of data points measured and the difficulty in interpreting the discrete time series. This is done by dividing the water column into a series of discrete lengths (typically 2 m) and estimating the variance or energy in the turbulent shear in the form

$$\varepsilon = 7.5\mu\left\langle\left(\frac{\partial u'}{\partial z}\right)^2\right\rangle \tag{4}$$

where the angle brackets indicate an average over distance and μ is the dynamic viscosity of seawater (*c* 1.073×10^{-3} kg m^{-1} s^{-1}). The result is an estimate of turbulent dissipation, ε, *i.e.* the rate at which turbulence is being dissipated by viscous forces, in units of Watts m^{-3}. (Some authors use the kinematic viscosity of seawater (μ/ρ) instead of μ and quote ε in units of cm^2 s^{-3}, roughly Watts $m^{-3} \times 10$, or m^2 s^{-3}, roughly Watts $m^{-3} \times 10^{-3}$). The calculation of ε needs to be conducted with some care, in order to take into account body movements of the FLY at the low wavenumber end of the signal, and attenuation of the signal at the high wavenumber end. Suitable filtering of the time series and boosting of the output is required to get an acceptable estimate of dissipation, but a description of this aspect of the processing is beyond our scope here.

The instrument carries a total nine sensors, data from which are relayed at various rates to a recorder on the ship, via a flexible, strong, multi-conductor cable which is fed out from the ship is such a way that does not cause vibrations of the probe during its fall at a rate of about 70 cm s^{-1}. The sensors comprise two identical shear probes (sample rate 280 Hz), a fast response thermistor (140 Hz) and six slow sensors (pressure, conductivity, temperature, two tilt sensors and battery voltage; 20 Hz). On board the data are stored in binary format on an Iomega Jaz drive, by a Pentium PC, and are subsequently converted to Ascii text. Display of the main variables, processing up (4) and calculation of average values is then performed by a second, networked, PC, using software developed for OMEX by Dr Inall.

During CD110 measurements were made with a series of drops of the FLY probe to depths of up to 300 m from the stern of the *Charles Darwin* as she moved slowly ahead, at typically 0.5 to 1 knot. On each occasion a succession of drops were made in order to permit a statistical picture of the distribution of turbulence to be developed. The cruise was dogged by very poor weather conditions, and in the event only seven stations were occupied (see the Table below and Fig. 3):

Series	Date	Time	Duration	Station	No of drops
1	10 Jan	21:07	0:52 h	near V1150	6

2	11 Jan	20:20	2 :24 h	T2500	15
3	14 Jan	04:58	1:04 h	P2800	6
4	14 Jan	20:34	1:05 h	P200	8
5	15 Jan	01:06	1:01 h	P200	8
6	15 Jan	04:30	1:01 h	P100	12
7	15 Jan	19:14	1:05 h	P1000	6

In addition to the FLY a recording meteorological package was attached to the monkey island of the *Charles Darwin* and made good measurements of wind, temperature and relative humidity throughout the cruise. The ship's ADCP provided a record of the vertical shear in the water column in 8 m bins. (Unfortunately, the conductivity sensor broke down during the cruise and salinity data need to be mapped from the CTD). As can be seen severe weather conditions were encountered during most of the cruise and, in particular there was a large swell for much of the time.

3. Preliminary Scientific Results

The average dissipation and temperature profiles from four stations along the P line are shown in Fig. 4. These figures show the best estimates of dissipation, with the application of calibration coefficients derived from Sy-Tech, the manufacturers of the instrument, after the cruise. They give a good indication of the variability in dissipation from the shelf region into the deep ocean. Very high levels of turbulent dissipation (ε) were measured in the top 20 m of the water column at all stations, but it is not certain whether these observations are valid. They could be due to the ship's wake, although the FLY did not appear to be in it; they could be due to the large background shears in the wave zone, where particle velocities were up to 3 m s^{-1}, or even higher, and may have caused unacceptably large values of α in (1) or significant variations in the value of *W*; they could also be due to the presence of bubbles in the surface layers; or they could be due to a combination of the above, including the possibility that the observations are correct. More work can, and is intended, be done on this problem.

Relatively high levels of ε were encountered down to the thermocline where sometimes there was a drop in turbulence, particularly in cases where the temperature gradient was sharp. In some deep ocean profiles the turbulence levels then increased again at deeper depths. Somewhat surprisingly, in view of the potential for tidal stirring on the shelf, the turbulence levels at the station on the shelf were relatively small except very close to the seabed where, presumably, tidal effects were present.

4. Conclusions

UWB-b did not intend to be very active in OMEX in year 1, since our main funding does not commence until year 2. Nevertheless we have participated fully in the project and collected a useful dataset during a very difficult winter cruise (CD110). Work by Dr Inall on a parallel project has seen the development of a suite of post-processing software which was successfully tested at sea during CD110. A preliminary analysis has been conducted on the data obtained so far, but further work is required particularly to assess the performance of the instrument near the surface in the presence of a large swell.

References

Belyaev, V.S. *et al*, (1975). Spectral characteristics of small-scale fluctuations of hydrophysical fields in the upper layer of the ocean. *Journal of Physical Oceanography*, **5** (3), 492-498.

Crawford, W.R. (1976). *Turbulent energy dissipation in the Atlantic Equatorial undercurrent*. PhD Thesis, University of British Columbia, 149 pp.

Dewey, R.K. *et al*, (1987). A microstructure instrument of profiling oceanic turbulence in coastal bottom boundary layers. *Journal of Atmospheric and Oceanic Technology*, **4**, 288-297.

Osborn, T.R. (1974). Vertical profiling of velocity microstructure. *Journal of Physical Oceanography*, **4**, 109-115.

Osborn, T.R. (1980). Dissipation measurements of oceanic turbulence. In: *Marine Turbulence*, (Ed. J.C.J. Nihoul), Elsevier Oceanography Series 28, 143-155.

Ozmidov, R.V. (1980). Small-scale oceanic turbulence. In: *Marine Turbulence*, (Ed. J.C.J. Nihoul), Elsevier Oceanography Series 28, 167-174.

Siddon, T.E (1965). *A turbulence probe using aerodynamic lift*. Tech, note 88, Institute for Aerospace Studies, Univeristy of Toronto, 14 pp.

Stommel, H. and K.N. Fedorov (1967). Small scale structure in temperature and salinity near Timor and Mindanao, *Tellus*, **19**, 306-325.

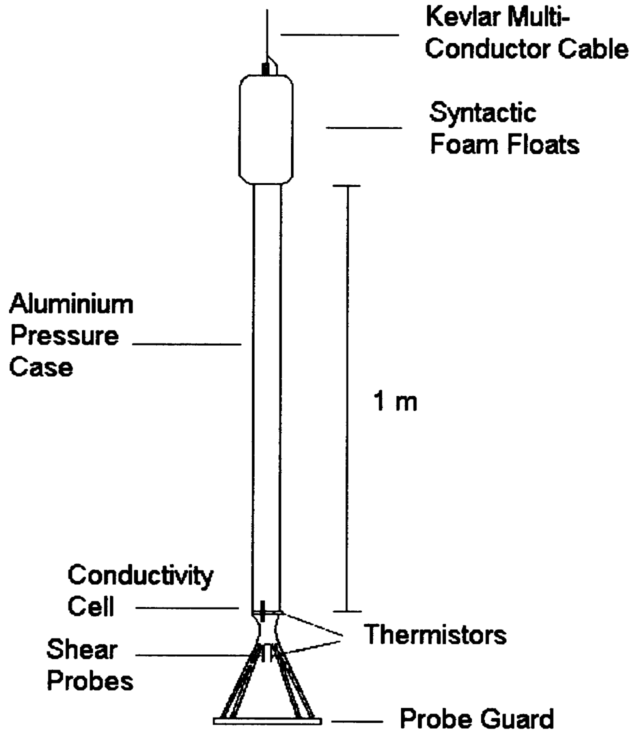

Figure 1. Schematic representation of the FLY probe

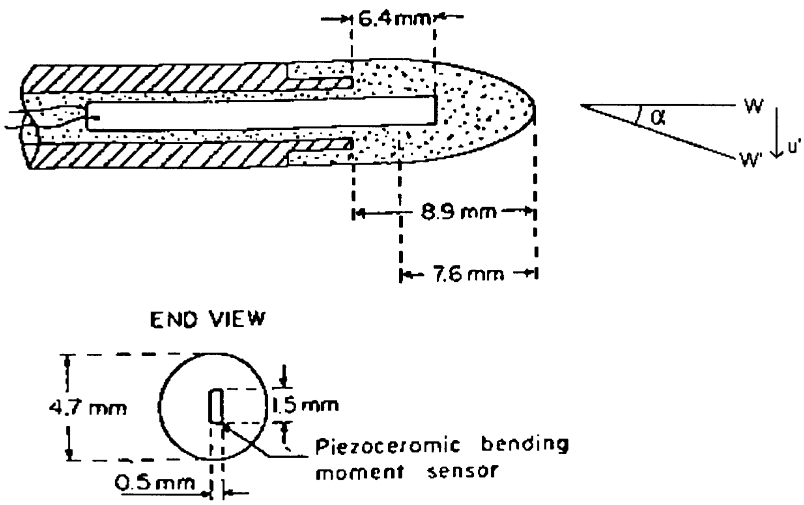

Figure 2. Sketch of the shear sensor (from Osborn, 1980)

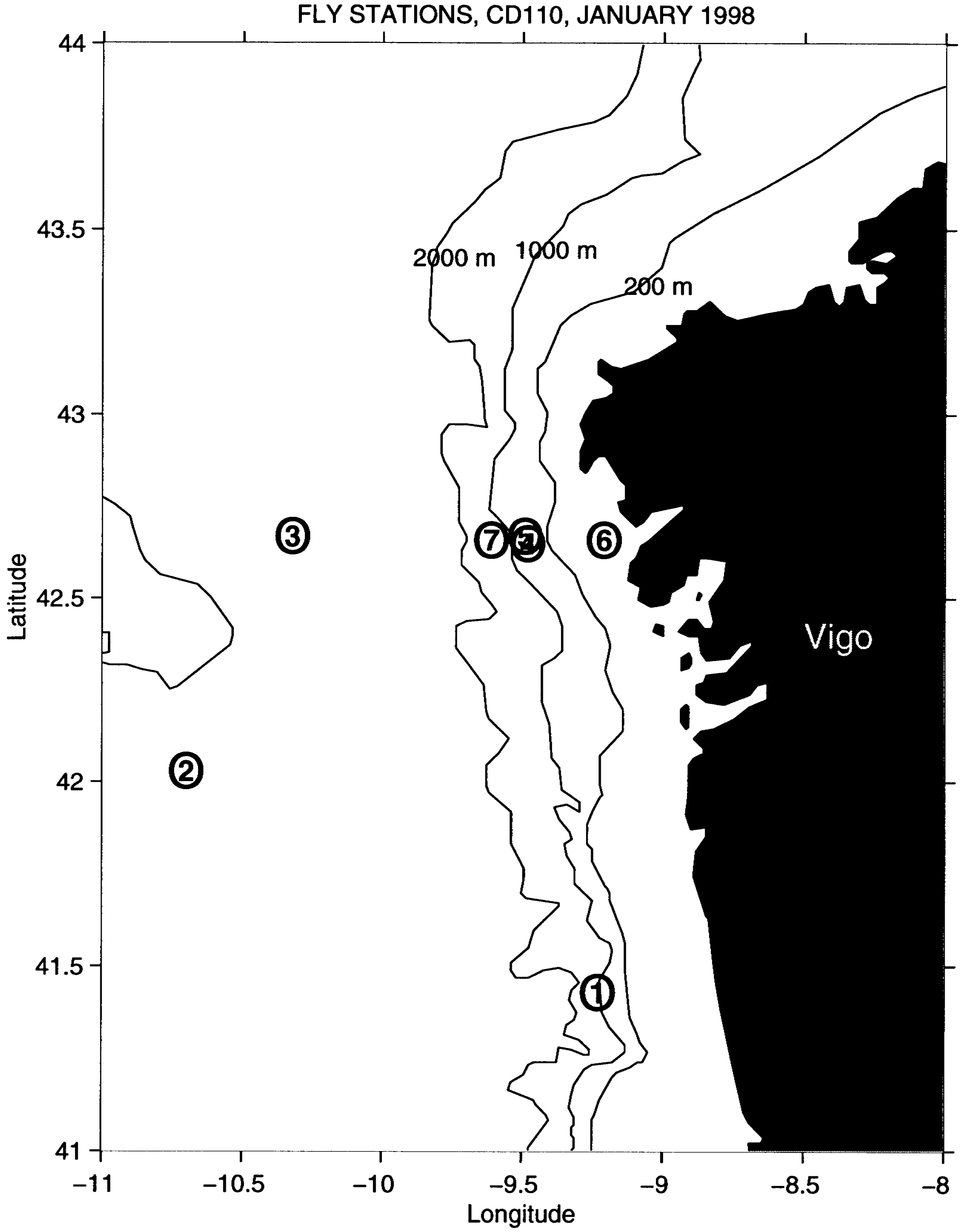

Figure 3. FLY station positions during CD100.

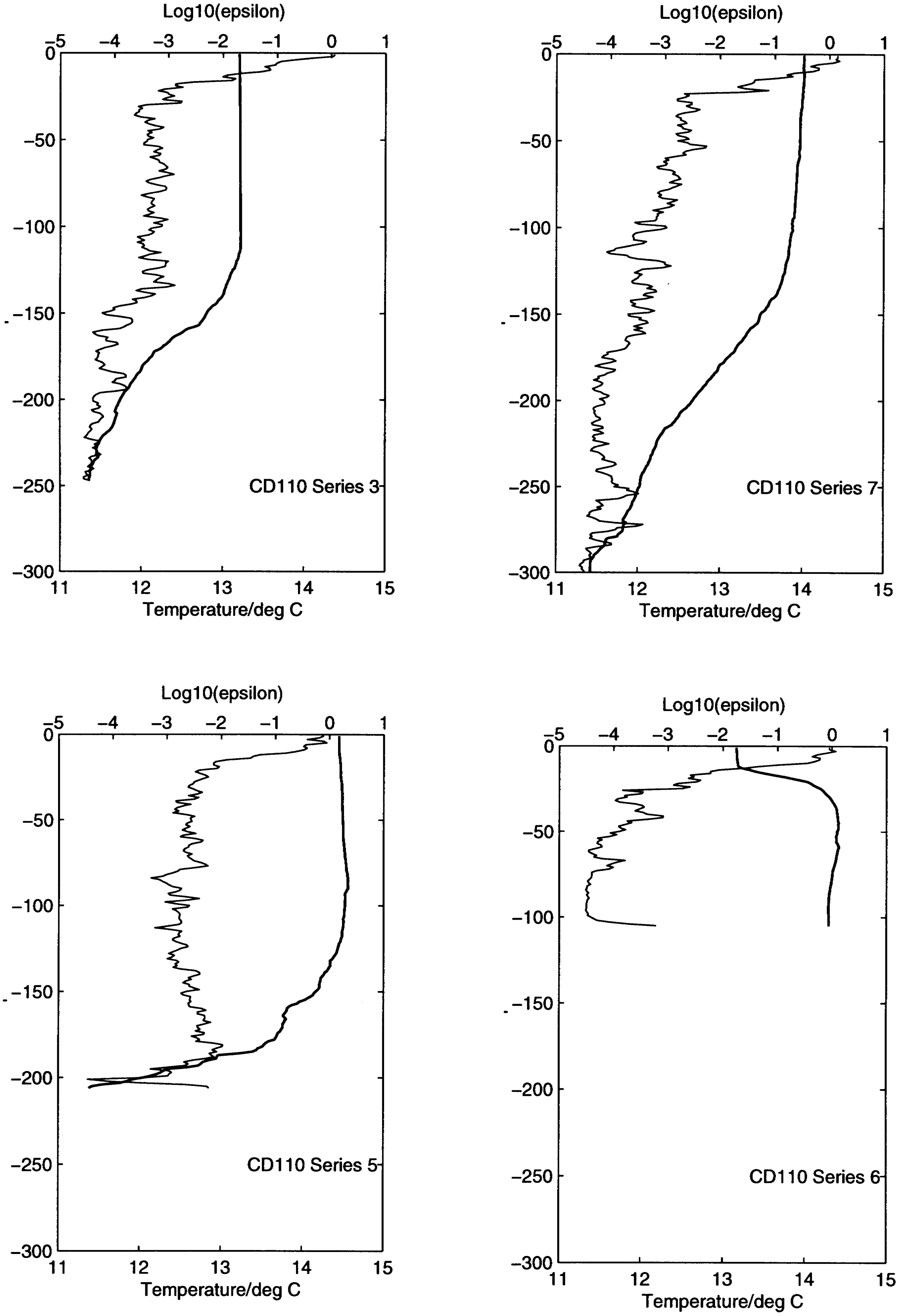

Figure 4 Averaged dissipation (thin) and temperature (thick) profiles along the P line during CD110. Top row: series 3 (in deep water); series 7 (on the 1000 m isobath). Bottom row: series 5 (at the shelf break); series 6 (near the coast).