Turbulent Dissipation Measurements

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1. Introduction

The FLY probe is a free falling instrument which can be used to measure turbulent dissipation which can, in turn, be converted to an estimate of vertical diffusion, K_z, from a knowledge of the vertical density structure. The method operation of the probe, which is periodically dropped from behind a slowly moving ship, was described in the first year annual report. Within WP I the aim is to make measurements coincident with the drifting buoy experiment for comparison with the *in situ* biological measurements and the accompanying modelling exercises (**Task I.1**). Within WP II, it is to measure the spatial distribution of turbulence and to provide maps of K_z, for use in the large-scale models.
In the last year the main effort involved deployment of the probe in August 1998 during *CD114*, with a series of measurements made on the shelf and separately across a filament. In addition trials of the instrument were conducted in a local quarry and a post processing software suite was developed.

2. Vivian Quarry Trials

The Vivian Quarry is a small disused slate quarry in Snowdonia with a horizontal scale of order 50 m and depth of about 20 m and surrounded by high cliffs. The location appeared to be ideal for conducting threshold and other sensitivity tests of the FLY profiler, since its surface is undisturbed by wind and the quarry floor has no tidal currents. This assumption is supported by a temperature profile, which revealed that the quarry was thermally stratified with a temperature drop of over 2°C in the top 15 m when the trials were conducted on 13 July 1998. However, the quarry is also located close to the largest pumped storage power station in Europe, and is reported by some divers to be noisy.
The probe was dropped vertically from a small boat, a configuration which did not exactly match the conditions that occur at sea, where it is towed in horizontal position at about 1 knot from a distance of about 100 m behind the ship before being released. Various tests were divided into six separate series with different arrangements; for example, with and without the sensor guard on and with the initial release angle being either vertical or horizontal. Some of the drops were filmed with an underwater video camera.
In general, there appeared to be as much variability in the turbulent dissipation measured from individual drops as there was between the different series. Dissipation levels varied from 10^{-2} to 10^{-5} Watts m^{-3}, although most drops recorded values close to 10^{-5} Watts m^{-3} at some part of the water column. In fresh water the fall speed was about 0.8 m s^{-1}, with the probe reaching its terminal velocity within about 3 m of the surface (*i.e.*, about 6 s), after which it remained uniform. There was evidence that high values of dissipation were measured near the surface in the region where the probe was still accelerating. It may be useful at some stage to revisit the algorithm to calculate dissipation from shear in order to take account of the spectral shift in shear that occurs during the acceleration phase. It is interesting to note that the response time of the probe in the quarry was much faster than in the sea, where the probe can take between 20 and 50 m to reach its maximum velocity. It is likely that in the sea an additional drag is applied as the cable initially adjusts from being in the horizontal plane to forming a catenary in the vertical.
The high variability in the observed dissipation values are surprising, in view of the sheltered position of the quarry. The minimum observed levels were also high, compared with values as low as 10^{-6} W m^{-3} that were observed elsewhere (see section 4). Since the probe appears to give sensible readings in the sea it is concluded that either conditions in the quarry were not as undisturbed as anticipated

(there were divers in the water for part of the time), or that the probe is sensitive to acoustic noise generated by the power station. Despite these limitations the experiments still provided useful information about the performance of the FLY probe.

3. Observations during Leg A of cruise *CD114*

Direct observations of dissipation and mixing rates were made on the Iberian shelf in August 1998. In Phase 1 a six-day Lagrangian experiment was undertaken, following an instrumented drifting buoy (Fig. 1). Phase 2 was a Eulerian internal wave experiment lasting 36 hours, during which a thermistor chain along with a near surface current meter mooring were deployed. During both phases repeated turbulence measurements were made from the ship to quantify the vertical distribution of dissipation and mixing. All data have been calibrated and quality checked using the SPIDER software suite (see section 5). Phase 2 data have so far been analysed in greater detail than data from Phase 1 and the results of this analysis are presented below.

Data Collection and Quality Control
Details of FLY activities are given in Table 1. Approximately half the data were processed onboard to the level of turbulence dissipation rates using the SPIDER processing software. The instrument appeared to behave well, with data quality looking good. An accident, which resulted in the FLY cable becoming entangled with the ship's propeller, curtailed FLY usage for Leg A but fortunately did not result in equipment loss and it was able to be used again in Leg B. As a consequence of the accident an experiment planned to measure internal waves at three locations as they propagated on-shelf was abandoned. However, a 24 hour long FLY station was completed on 8 and 9 Aug. The measurements were made at 41°55.1'N, 9°19.3'W in about 167 m of water close to a mooring which comprised 9 Minilog thermistors deployed between 15 m and 100 m and an Inter Ocean S4 current meter located 10 m from the surface. These observations have revealed valuable information about the relationship between internal waves and mixing in the region.

Internal wave measurements
SAR satellite images received at RSDAS during the cruise showed the complex nature of the internal wave field in the region. Near the measurement site the orientation of waves in the images is in good agreement with that estimated from the *in situ* current measurements with an onshore propagation direction of about 14°N (Fig. 2a). The temperature record from the mooring shows a 12.4 hour period (M2) internal tide with an amplitude of approximately 25 m (Fig. 2b). Superimposed on this wave was a highly energetic, high frequency internal wave field, with a dominant frequency of approximately 3 cph and amplitudes of up to 25 m. High frequency internal wave amplitudes were generally greater in the trough of the internal tide. These observations are significantly different from those observed further south at 41°N during the MORENA project where waves of order 45 m appeared in discrete packets every tidal cycle.

Dissipation Rates
High turbulent kinetic energy dissipation rates (ε, of order 5 10^{-4} W m^{-3}) were observed within the thermocline and were associated with the high frequency waves. Fine scale temperature inversions were frequently observed (Fig. 3). These inversions convert into overturning length scales of up 5.2 m which imply (from Thorpe, 1977) turbulent kinetic energy dissipation rates in excess of 3 10^{-3} W m^{-3}, *i.e.*, two orders of magnitude greater than the background value. Vertical diffusion coefficients have been estimated from the dissipation rates using the expression

$$K_Z = 0.25\varepsilon / N^2$$

where

$$N^2 = -g\rho\, \partial\rho / \partial z$$

is the local buoyancy frequency (Osborn, 1980), and ρ is density. The table below shows that the depth and time averaged value for K_z was about 3.7 10^{-4} m^2 s^{-1}. The importance of internal waves in dissipating tidal energy is as great as the bottom friction layer which is in contrast to the Malin Shelf, where bottom friction accounts for a far greater portion of the total dissipation.

	Bottom boundary layer	**Within thermocline**
Depth integrated dissipation (W m^{-2})	1.5 10^{-2}	1.9 10^{-2}
Vertical eddy diffusivity, K_z (m^2 s^{-1})	-	3.7 10^{-4}

Partition of energy dissipation between the thermocline and the bottom boundary layer

4. Observations during Leg B of cruise *CD114*

The second part of *CD114* involved a drifter study in an offshore filament. During this study the FLY probe was deployed along a series of sections across the filament at about 42°N (see Fig. 4 and Table 2). Two series taken on contiguous days (17th and 18th Aug) along the 10°W meridian reveal the essential dissipation structure in the filament. The coolest surface water is located at about 41.9°N with a strong frontal structure to the north, and a weaker one to the south. In general the highest levels of dissipation where found in the frontal regions, particularly to the north of the filament where values of about 3 10^{-5} W m^{-3} were observed at 20 m. This is not surprising, since ADCP measurements (not shown here) suggest that this is the region of greatest vertical shear. Below about 80 m dissipation levels were generally small (less than about 3 10^{-6} W m^{-3}) under the cool surface expression of the filament, but were up to an order of magnitude larger than this at 100 m on the southern side (Fig. 5).

The relationship between vertical shear and dissipation values is highlighted in a close up of the southern frontal region (Fig. 6). Below the thermocline, where there was little shear dissipation was typically 10^{-6} W m^{-3}, but in the surface front at 41.75°N levels locally in excess of 10^{-4} W m^{-3} were observed.

5. SPIDER software suite

A suite of Graphical User Interface software (GUI), used to collect, quality control and process turbulence data, was beta tested during *CD110*. Significant further refinement was undertaken prior to *CD114*, and a technical manual produced (Inall, 1998). SPIDER now represents the integration of many, previously unpublished, analysis techniques and protocols with a state-of-the-art graphical interface. It is planned to use the manual as the basis of a technical paper.

6. Summary

The contractual requirements to make observations to map the turbulence dissipation have been fulfilled and its distribution is being investigated at present. The highest values of dissipation (about 3 10^{-3} W m$^{-3)}$ were measured in the seasonal thermocline during the internal wave experiment, although comparable values about 10^{-3} W m^{-3} were measured in the upper mixed layer of the ocean during the winter cruise of *CD110*. In the filament mixing levels were typically one to two orders of magnitude smaller than these values.

So far **Tasks I.1.b** and **II.3.1** have been completed with exception that the *CD114* data have yet to be sent to BODC, although the raw data will be banked by the end of June, as required.

One area that has not been completed as quickly as had been anticipated is the calculation of the vertical diffusion coefficient, K_z (in **Tasks II.3.1**, **II.3.2** and **II.7.2**). This calculation requires the computation of the density gradient $\partial\rho/\partial z$, which is based partly on the local salinity gradient. The work has been complicated by the fact that the conductivity sensor on the FLY did not perform particularly well and this has necessitated estimating salinity from CTD measurements. In addition, the temperature calibration constants supplied by the manufacturer have recently been found to be in error and the temperature data are having to be reworked. The work is in hand though, and it is hoped that computed vertical diffusion coefficients will be reported in the near future, and communicated to the relevant modelling groups.

References

Inall, M.E. (1998) *SPIDER - Software to Process and Image Dissipated Energy Rates*. UCES Report U98-7, UCES, University of Wales, Bangor, 20p.

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

Thorpe, S. A. (1977) Turbulence and mixing in a Scottish Loch, *Phil. Trans. R. Soc. London, Series A*, **286**, 125-181.

Table 1

Summary of FLY Dissipation Measurements
During the Drifter Study of *CD114A*

Series	Date	Start time	Latitude (°N)	Longitude (°W)	No of drops
1	3 Aug 98	11:40	42°32.6’	9°22.3’	8
2	3 Aug 98	16:00	42°30.5’	9°20.5’	14
3	3 Aug 98	21:06	42°25.7’	9°22.2’	15
4	4 Aug 98	10:10	42°19.6’	9°19.9’	7
5	4 Aug 98	15:48	42°18.5’	9°21.2’	7
6	4 Aug 98	02:31	42°15.7’	9°22.9’	6
7	5 Aug 98	15:37	42°11.2’	9°24.7’	1
8	5 Aug 98	02:07	42°9.8’	9°24.4’	1
9	6 Aug 98	01:05	42°7.8’	9°25.7’	11
10	6 Aug 98	16:25	42°6.8’	9°24.9’	7
11	6 Aug 98	21:35	42°3.7’	9°27.2’	4
12	7 Aug 98	01:05	42°5.9’	9°26.5’	8
13	7 Aug 98	01:03	42°3.8’	9°26.8’	12
14	7 Aug 98	14:37	42°4.5’	9°26.9’	14
15	8 Aug 98	08:31	42°3.6	9°25.5’	1
Internal wave experiment					
16	8 Aug 98	16:02	41°55.1’	9°19.3’	153

Table 2

Summary of FLY Dissipation Measurements
During the Filament Study of *CD114B*

Series	Date	Start time (h)	Start drop number	Longitude(°W)	Latitude (°N)	No of drops
17	14 Aug 98	14.68	1	9.85	41.93	
		16.47	12	9.87	41.94	12
18	14 Aug 98	19.85	1	10.04	42.3	
		22.52	9	10.02	42.2	9
19	15 Aug 98	08.85	1	9.86	42.	
		01.68	5	9.89	41.93	5
		15.13	6	10.00	41.88	
		17.38	13	10.01	41.94	8
		20.13	14	10.01	41.96	
		22.05	22	10.00	42.2	9
2	16 Aug 98	07.55	1	10.00	41.8	
		9.80	9	10.01	41.87	9
		15.97	1	10.00	41.63	
		19.38	23	10.00	41.76	14
21	17 Aug 98	07.38	1	10.08	41.84	
		10.30	11	10.02	41.87	11
22	17 Aug 98	15.20	1	10.08	41.75	
		17.37	12	10.08	41.77	12
		20.28	13	10.08	41.73	
		21.37	2	10.09	41.75	8
23	18 Aug 98	07.87	1	10.10	41.76	
		10.62	17	10.11	41.82	17
		15.03	18	10.10	41.85	
		22.45	39	10.14	42.13	22
24	2 Aug 98	09.45	2	9.59	42.64	
		13.03	12	9.81	42.75	11

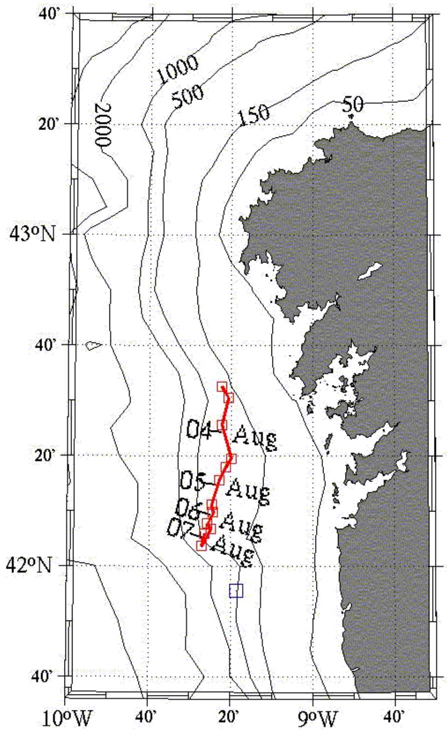

Figure 1. Track of Phase 1 Lagrangian experiment (dated line) and location of Phase 2 internal wave experiment (box) during *CD114A*.

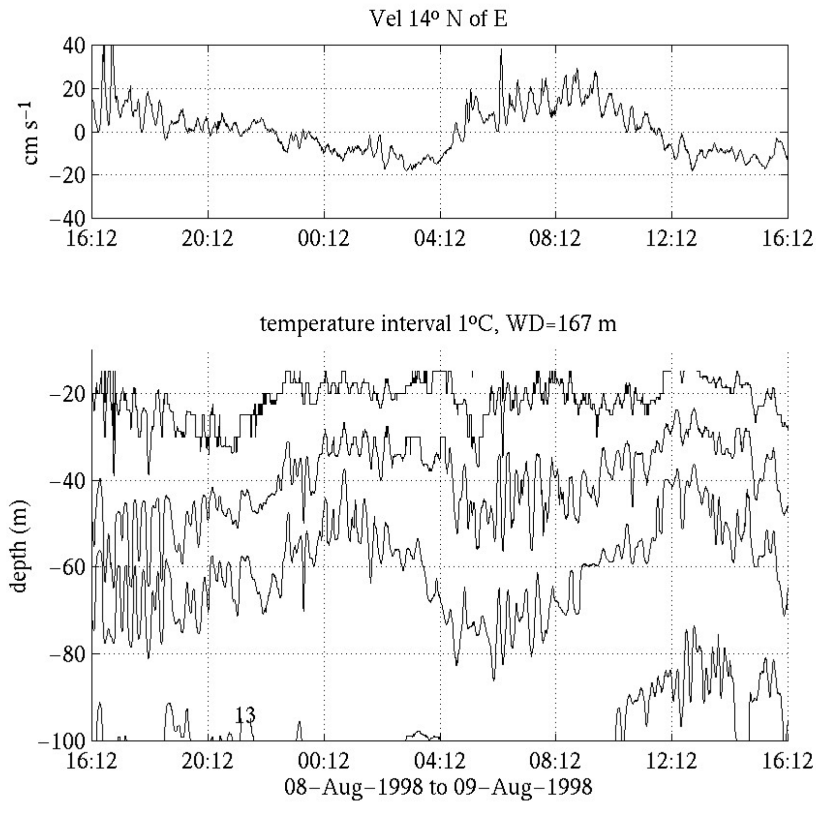

Figure 2. Time series of near surface currents (upper panel) and temperature structure (lower panel) during the internal wave experiment.

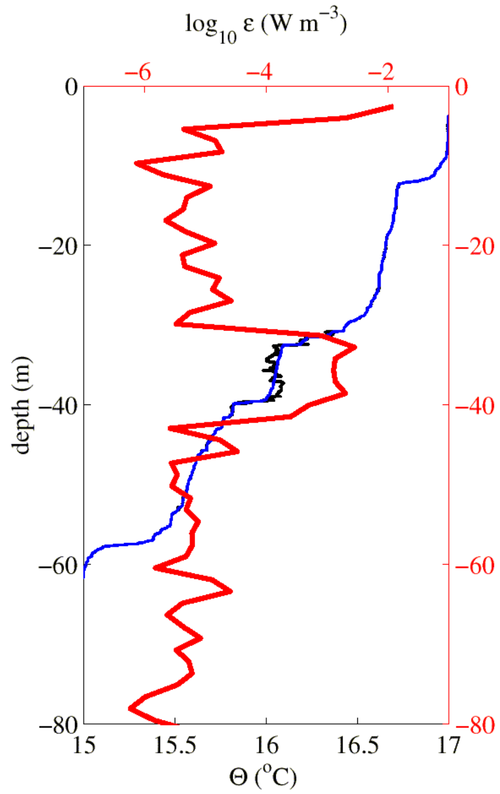

Figure 3. Profiles of dissipation (thick line) and temperature through a breaking internal wave. The observed temperature (thin line with overturn) and Thorpe ordered temperature profile (monotonic thin line) are also shown.

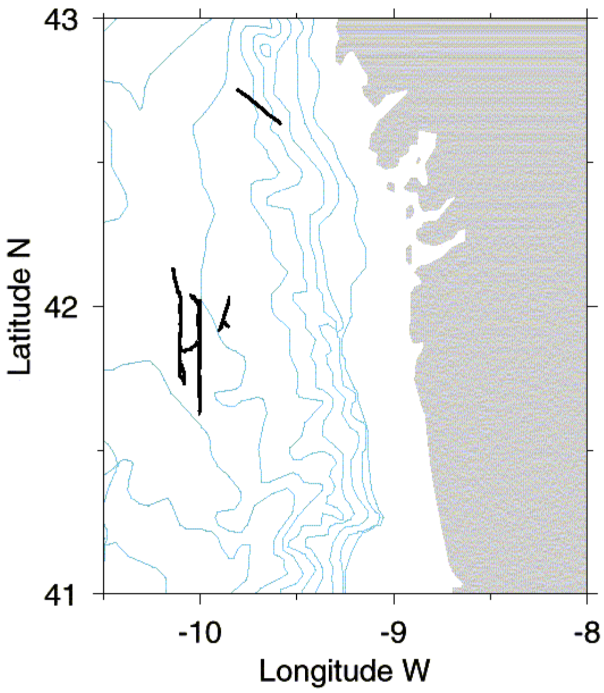

Figure 4. Locations of the FLY profiles observed during *CD114B*.

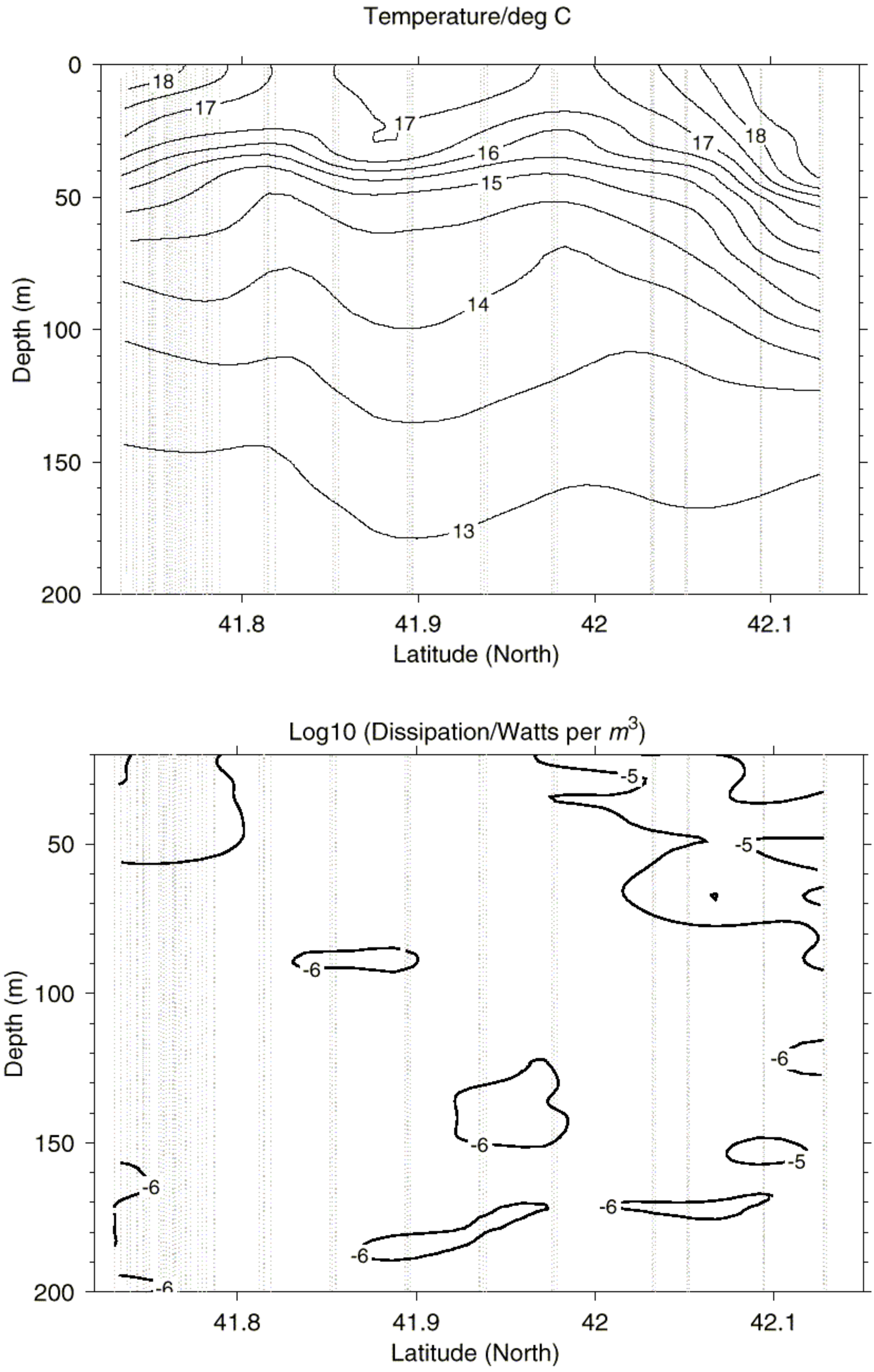

Figure 5. a) - above. Temperature section along 10°5'W derive from the FLY probe on 17th and 18th Aug. The data have been spatially smoothed. Note that wrong calibration has been applied - this figure should be used only to get a sense of the location of the main features across the filament.
b) - below. Dissipation values in the filament

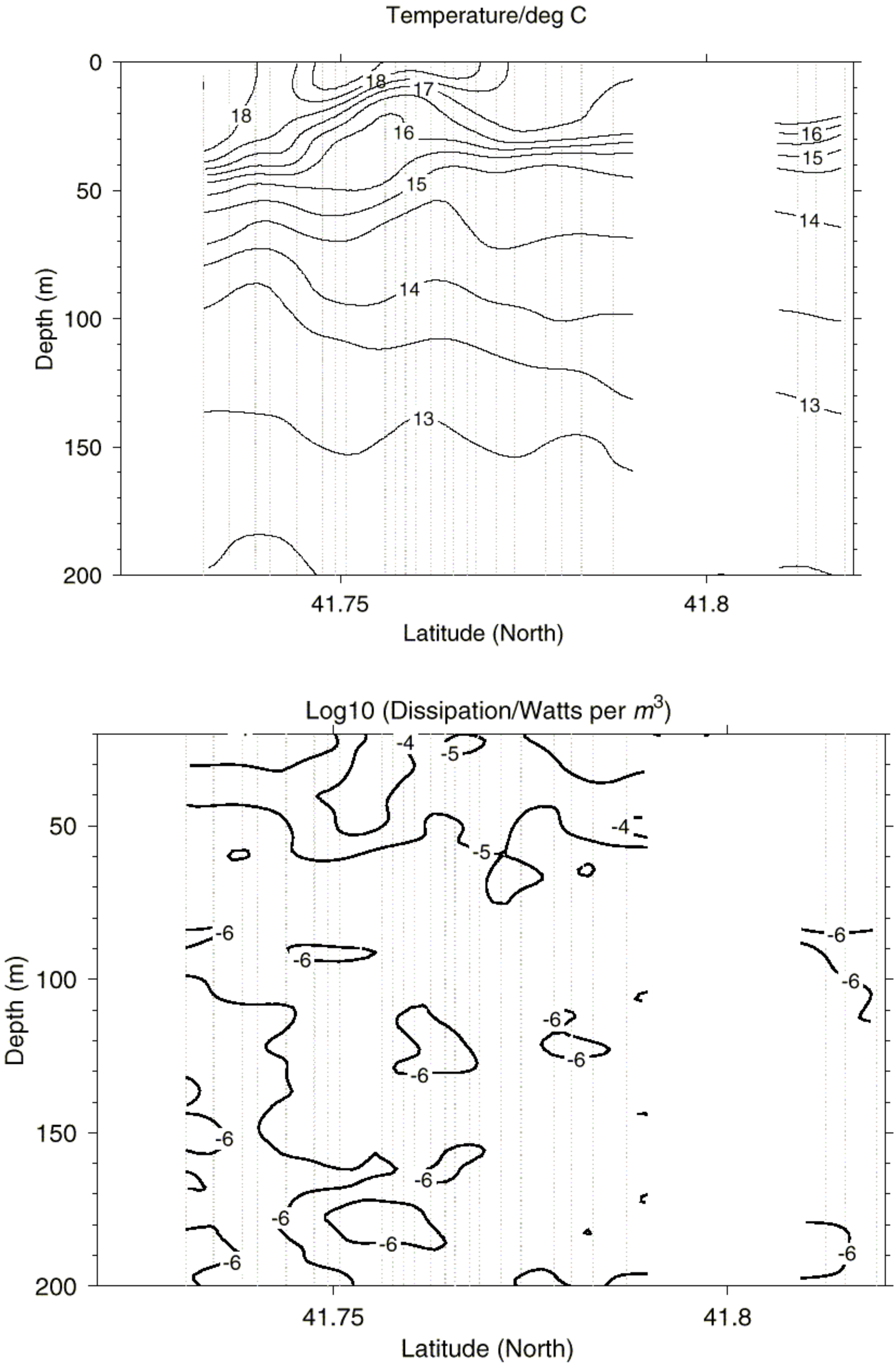

Figure 6. a) - above. As for Fig. 5a, showing the detail across the southern front.
b) - below. Dissipation values across the southern front.