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PRELIMINARY ANALYSIS OF DEEP-WATER MOVEMENTS IN THE EASTERN NORTH ATLANTIC

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ABSTRACT

This paper describes a short-term but intensive study of deep-water movements within a localized area of the eastern Atlantic in November-December 1976. The study area, centred on 46°N 17°W, is the site of an existing disposal area for low-level radioactive waste and incorporates one of the long-term full-depth current meter moorings maintained by the North East Atlantic Dynamics Study (NEADS) Group of SCOR Working Group 34. Morphologically the site takes the form of a re-entrant valley on the northern slopes of the Azores-Biscay Rise. Using both neutrally buoyant floats and near-bottom current meter moorings, the flow in the near-bottom layer was found to be cyclonic around and above this valley with an apparently strong morphological control. The current meter records were dominated by motions close to the local inertial period of 16.5 h and speeds did not exceed 14 cm sec^{-1}. Average speeds of 1.8-2.6 cm sec^{-1} were observed at 50 m above the bottom and 1.0-4.7 cm sec^{-1} at 1000 m above the sea-bed. The overall mean speeds of 5 neutrally buoyant floats at depths greater than 3000 m ranged from 2.2 to 3.4 cm sec^{-1}. Plans are described for longer-term monitoring of the deep circulation at this site to assess the variability of the mean flow.

INTRODUCTION

The deep current measurements to be described were conducted during RV CIROLANA cruise 10/76 in November-December 1976. As shown in Figure 1, the study area in the eastern Atlantic was centred on 46°N 17°W at the location of an existing dump site for the disposal of radioactive low-level waste. This site is also the location of one of the long-term current meter moorings maintained by the NEADS* Sub-group of SCOR WG 34. Hydrographically (as typified by the Nansen cast from Station 86, Figure 2) North Atlantic Central Water occupies the uppermost 800 m (approximately) of the water column, underlain at 800-1200 m depth by the conspicuous

*The NEADS network of moorings is shown by triangles in Figure 1.

salinity maximum marking the core of Mediterranean Water, and at deeper levels (> 2000 m) by the relatively uniform characteristics of North Atlantic Deep and Bottom Water. Topographically the study area takes the form of a north-south valley indenting the northern slopes of the Azores-Biscay Rise with a maximum depth exceeding 4750 m and opening northwards on to the Porcupine Abyssal Plain. The detailed bathymetry of the area is shown in Figure 3.

INSTRUMENTATION AND METHODS

Two methods of direct current measurement were employed. First, 9 neutrally buoyant floats were deployed at a variety of depths along a north-south transect through the deepest part of the valley and were tracked by ship for up to 17 days. As detailed in Table 1, two floats were set at 1000-1200 m to describe water movements in the core of the Mediterranean Water, while the remainder were deployed in the deepest part of the water column at depths ranging from 3356 to 4675 m.

During tracking, the position of each float was fixed with reference to three moored acoustic beacons (also shown in Figure 3) whose location had been accurately pre-determined by repeated SATNAV fixes. Where possible float positions were measured 3-4 times per day but the severe weather prevailing for much of the cruise meant that, in practice, fixes had to be made whenever the opportunity arose; during the extreme weather conditions of 5-7 December with gusts exceeding 90 knots, delays of up to 2 days occurred between successive fixes.

These estimates of Lagrangian drift within the central part of the study area were supplemented by current meter observations at three moorings around the perimeter of the valley. The locations of these three moorings (stations 23, 35 and 40) are indicated on Figure 3. At each station the mooring (multiplait) was restricted to the near-bottom layers with two current meters per mooring (modified Aanderaa Model 4 with pressure cases tested to 7000 psi, 10 min sampling interval). In conformity with the depths of the deeper floats, the upper meters were placed to lie in a common horizontal plane 3700 m below the surface while the bottom meter on each mooring was placed 50 m above the sea-bed. Performance details of these instruments are listed in Table 2.

RESULTS

(a) Floats

The trajectories and depths of the seven successful floats are summarized against the local bathymetry in Figure 3. As illustrated, the floats at 1000 and 1172 m in the core of the Mediterranean Water moved rather directly toward the west or north-west at overall mean speeds of 7.7 and 8.8 cm sec^{-1}, and were evidently isolated from the sense of the drift in deeper layers. The deeper floats were apparently constrained by the bottom topography to follow a cyclonic path around the central valley area at lower overall mean speeds ranging from 2.2 to 3.4 cm sec^{-1}. In the case of the deepest floats at 4234 and 4675 m some topographic control is of course inevitable since the valley sides rise locally to 3500 m in the west, > 4000 m in the east and > 4250 m to the south. However topographic control seems to have been equally strong in the case of the shallowest of this group of floats at 3356 m depth. The northernmost float at 3648 m did not participate in the general cyclonic valley circulation; apparently influenced by the spur at the western entrance to the valley the float became detached from the main group and was directed out of the valley towards the north-west.

(b) Current meters

The overall current vectors at the three moorings around the periphery of the valley are also shown at true geographical scale in Figure 3. At each mooring the vector labelled "B" corresponds to the bottom current meter, 50 m above the sea-bed, while the vector labelled "UB" (upper bottom) corresponds to the meter placed 3700 m below the surface. The records on which these vectors are based are generally between 21 and 25 days in length with the exception of the bottom meter at station 35 which provided only a 7-day record through a malfunction in the clock.

The characteristics of these records are as follows. First, in the short term, the 10-minute mean speeds did not exceed 14 cm sec^{-1} at any of the three stations; the actual distributions of 10-minute values are summarized in Table 3. In the longer term, this table also shows that mean daily residual speeds* ranged from 1.8-2.6 cm sec^{-1} in the near-bottom records and from 1.0-4.7 cm sec^{-1} in the "upper bottom" records, in broad agreement with speeds of floats in the 3300-4700 m layer. Second, these current meter records are characteristically dominated

*24 h 50 m mean centred on mid-day.

throughout their length by short-period motions close to the local inertial period (16.5 h) as illustrated in the time plots of hourly values from station 23 ("upper bottom" meter; Figure 4). The coherence of this inertial signal from record to record and its comparison with the theoretical local inertial frequency are currently under examination. As with the float trajectories, a third general feature of these current meter records concerns the fact that some topographic control appears to be implied in the residual drift in both the near-bottom and upper-bottom layers (see, for example, Figure 3). We can perhaps also see something of this influence not merely in the direction of residual drift per se, but also in its stability with time. For each complete current meter record a stability factor can be calculated which expresses the mean vector speed for the entire record as a percentage of the mean scalar speed (Ramster and Hughes, 1976). For the records under discussion this stability factor was high in 4 (possibly 5) of the 6 records (Table 4):

Station	Stability factor % Bottom meter	Stability factor % Upper-bottom meter
23	66.7	80.0
35	94.5*	6.7
40	90.7	98.9

*Short record.

The extreme stability in the direction of residual drift at station 40 is further illustrated by the progressive vector diagrams of daily residuals shown in Figure 5.

DISCUSSION

As described above, this short-term but relatively intensive study of deep-water movements in a localized area of the eastern Atlantic does appear to show some evidence of "system" in the deep circulation. The Eulerian and Lagrangian estimates of drift appear consistent in both speed and direction and both imply some topographic control of the near-bottom circulation. Consistency is also shown when these direct estimates of drift are compared with the geostrophic flow calculated from two short hydrographic sections which were worked across the area from north to south and east to west. Figure 6 for example shows good general agreement between the paths of the two upper floats at 1000-1100 m and the distribution of dynamic height anomaly at 1000 m (relative to 4100 m), while Figure 7 also confirms this good agreement in comparing float velocities (east-west components) with the vertical velocity profile calculated for the north-south section.

Nevertheless, despite the fact that these observations appear to show a relatively simple deep circulation within the area during the four-week period of study it would be naive to suppose that this simplicity was characteristic of the area in anything but the very short term. Even if the apparent topographic control is real (lending some degree of stability to the circulation) it is entirely likely that in the longer term the deep circulation will be subject to radical change, for example, through the interaction of transient mesoscale features with the mean flow. Indeed at the full-depth NEADS mooring maintained in the centre of the study area, preliminary results for the period December 1976-February 1977 provide ample evidence that the circulation at 4000 m depth is subject to major long period variations (Gould, pers. comm.). For this reason it is planned to extend the pilot study of November-December 1976 into a nine-month exercise using four long-term moorings during the period autumn 1977 to summer 1978.

ACKNOWLEDGEMENTS

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REFERENCE

RAMSTER, J. W. and HUGHES, D. G., 1976. A stability factor for estimating variability of residual drift in current meter records of 20 days or more in length. ICES CM 1976/C:6, 3 pp. (mimeo).

Table 1 Float release and recovery positions, CIROLANA cruise 10/76

Channel	Planned depth (m)	Actual depth (m)	Release time	Position		Recovery time	Position		Duration of tracking	Mean speed (cm/sec)*
7	3350	3356	0207/19 Nov	46°06'N	17°12'W	1210/ 5 Dec	45°52'N	17°21'W	16d 10h	3.3
8	4700	on bottom	1619/20 Nov	46 02	17 14	1230/22 Nov	46 02	17 14	-	-
9	3700	3576	1813/20 Nov	46 14	17 11	0928/ 8 Dec	45 58	17 33	17d 15h	2.8
11	3700	3648	2006/20 Nov	46 20	17 10	1304/27 Nov	46 29	17 21	6d 17h	3.4
14	3700	4234	1239/22 Nov	46 02	17 14	1316/ 5 Dec	45 56	17 22	13d 1h	2.2
8	1000	1172	1616/22 Nov	46 10	17 13	1050/26 Nov	46 10	17 36	3d 18h	8.8
4			0324/24 Nov	46 08	17 11		L O S T			
15	4700	4675	0200/25 Nov	46 08	17 11	1022/ 8 Dec	45 58	17 27	13d 8h	2.7
8	1000	c.1000	2243/26 Nov	46 10	17 03	1332/ 4 Dec	46 30	17 36	7d 15h	7.7

*The mean residual current speeds indicated by the floats varied in magnitude by up to 50% during the tracking period.

Table 2 Summary of current meter data, north-east Atlantic: 17 November-13 December 1976

Station		Sounding at launch (m)	Meter number	Height of meter above bottom (m)	Length of record			Timing discrepancy (min)	Notes on performance
					days	hours	min		
23	46°34.8'N	4705	607	1005	25	03	31	- 1	Good record (T)
	17°07.2'W		414	50	25	03	30	0	Good record (T)
35	45°38.8'N	4520	703	820	24	04	51	- 1	Good record (T)
	17°45.8'W		629	50	7	01	50	-	Meter clock stopped prior to recovery; no timing check possible (T)
40	45°47.3'N	4567	095	870	22	01	01	+ 9	Good record (T)
	16°44.1'W		538	50	21	23	00	+10	Good record (T)

(T) indicates that thermistor fitted to meter.

Table 3 Distribution of 10-minute mean speeds, all records, and mean daily residual speeds, cm sec^{-1} (* = short record)

Data interval (cm sec^{-1})	Station 23		Station 35		Station 40	
	B	UB	B*	UB	B	UB
0.0- 0.9	3	2	0	21	21	5
1.0- 1.9	775	828	290	1767	823	385
2.0- 2.9	171	252	90	345	246	66
3.0- 3.9	275	458	134	372	303	175
4.0- 4.9	564	757	190	513	603	514
5.0- 5.9	411	444	142	255	358	500
6.0- 6.9	605	341	124	192	401	681
7.0- 7.9	358	134	26	18	167	314
8.0- 8.9	263	215	21	3	116	314
9.0- 9.9	109	78	3		48	148
10.0-10.9	59	75			36	67
11.0-11.9	15	36			28	5
12.0-12.9	12	2			12	2
13.0-13.9	1				2	
Total no. of values	3621	3622	1020	3486	3164	3176
Mean speed (daily residual, cm sec^{-1})	1.9	2.2	1.8*	1.0	2.6	4.7

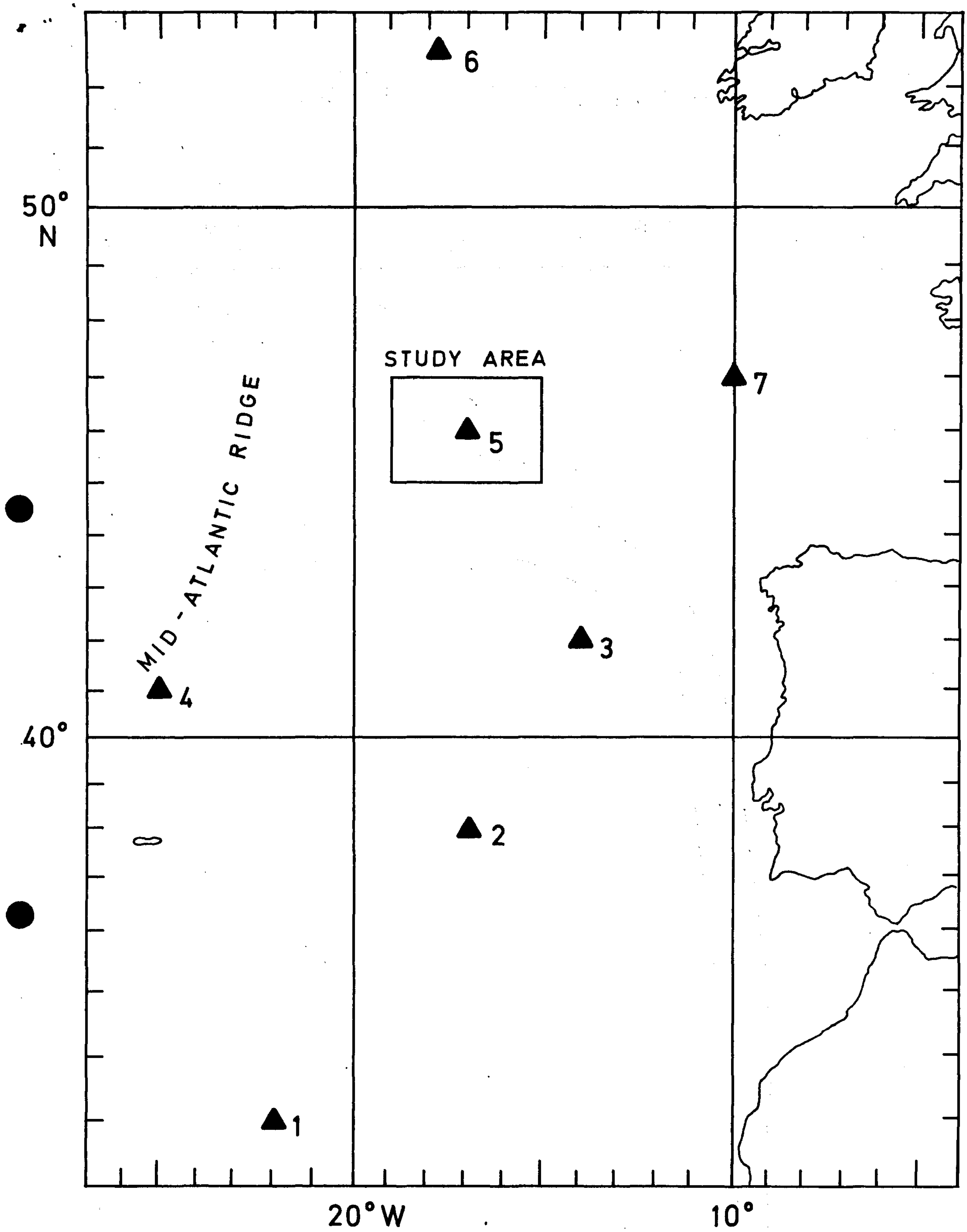


Figure 1 Location chart showing study area and sites of existing NEADS moorings (triangles).

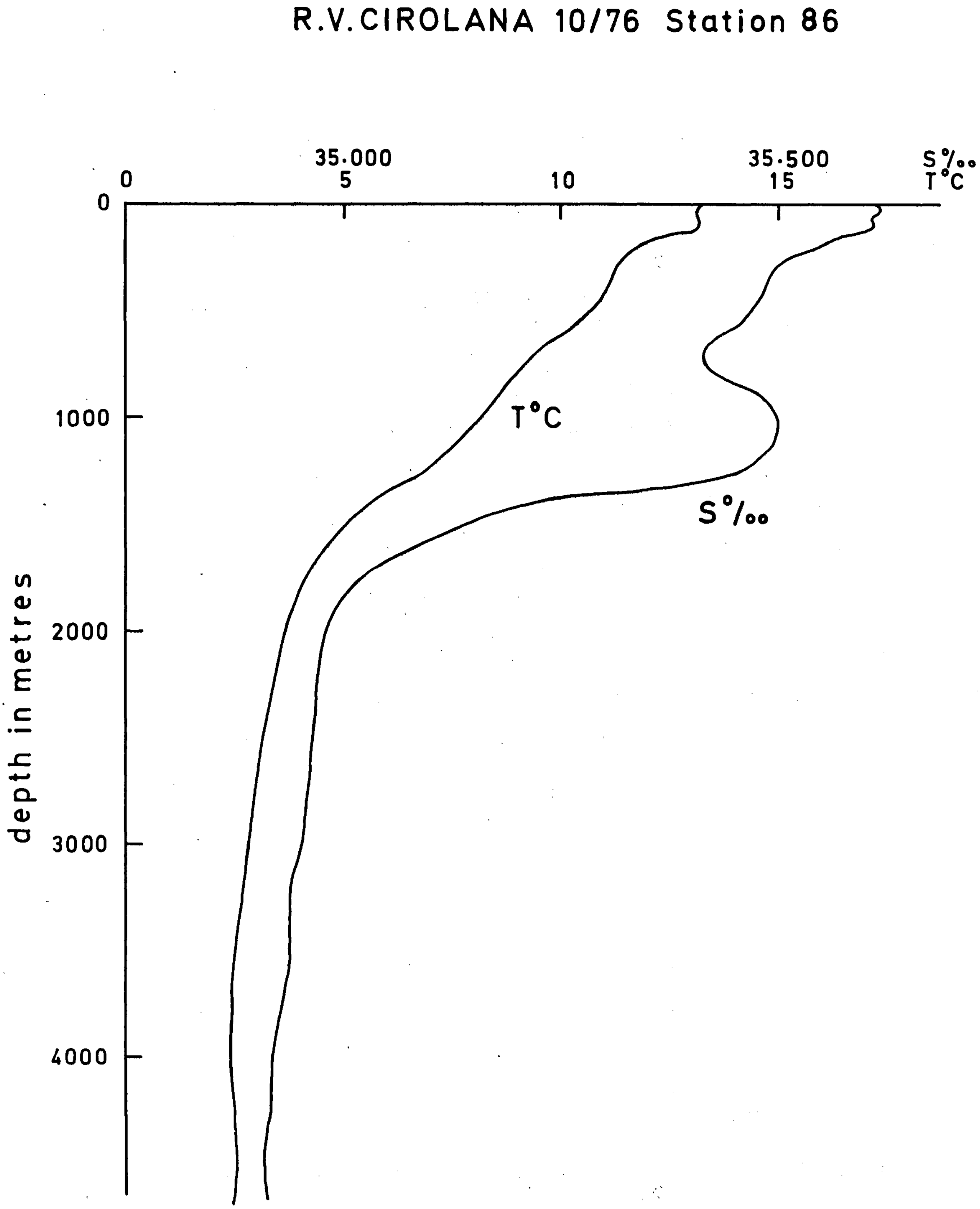


Figure 2 Temperature and salinity profile for Station 86 (46°08'N 17°11'W).

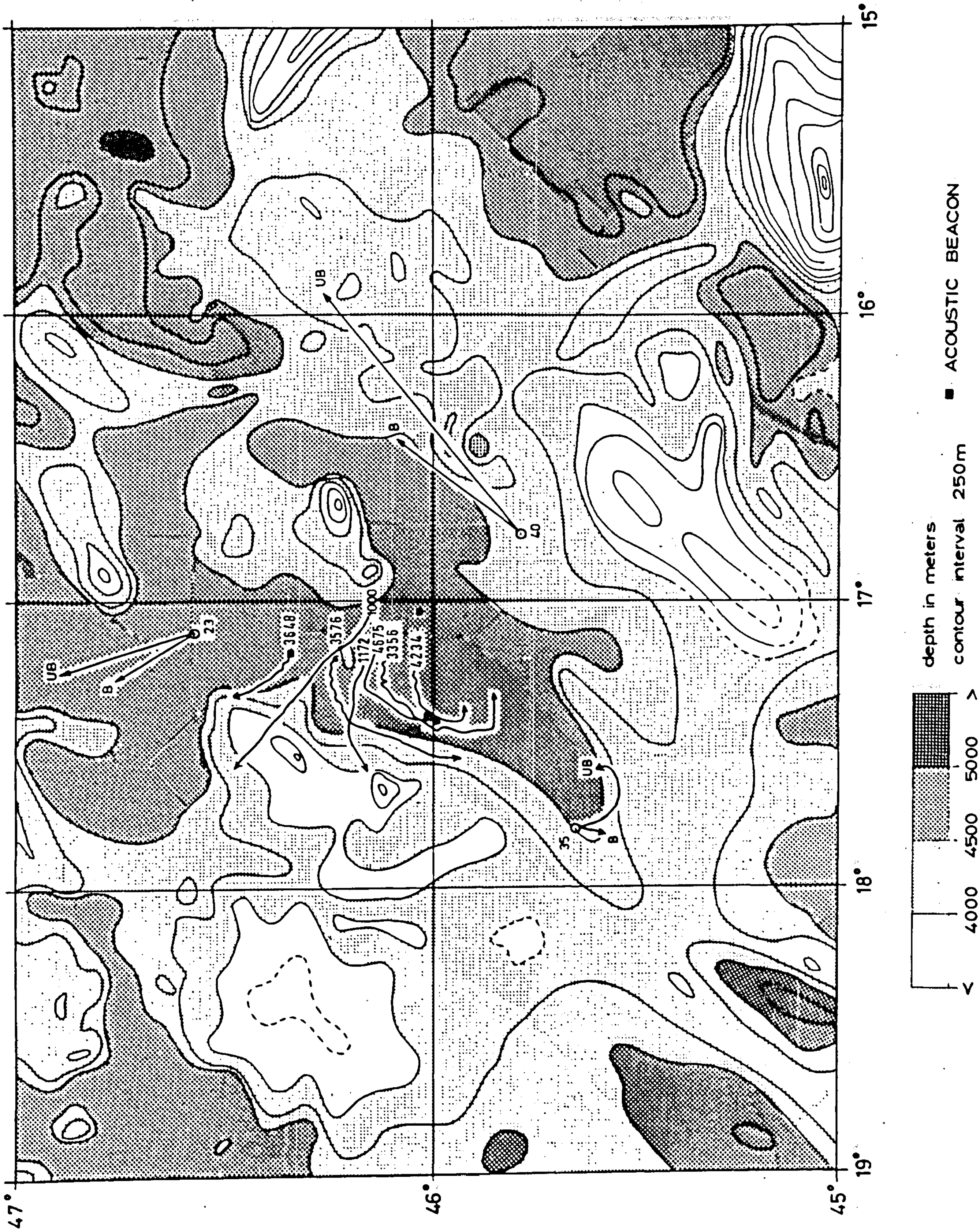
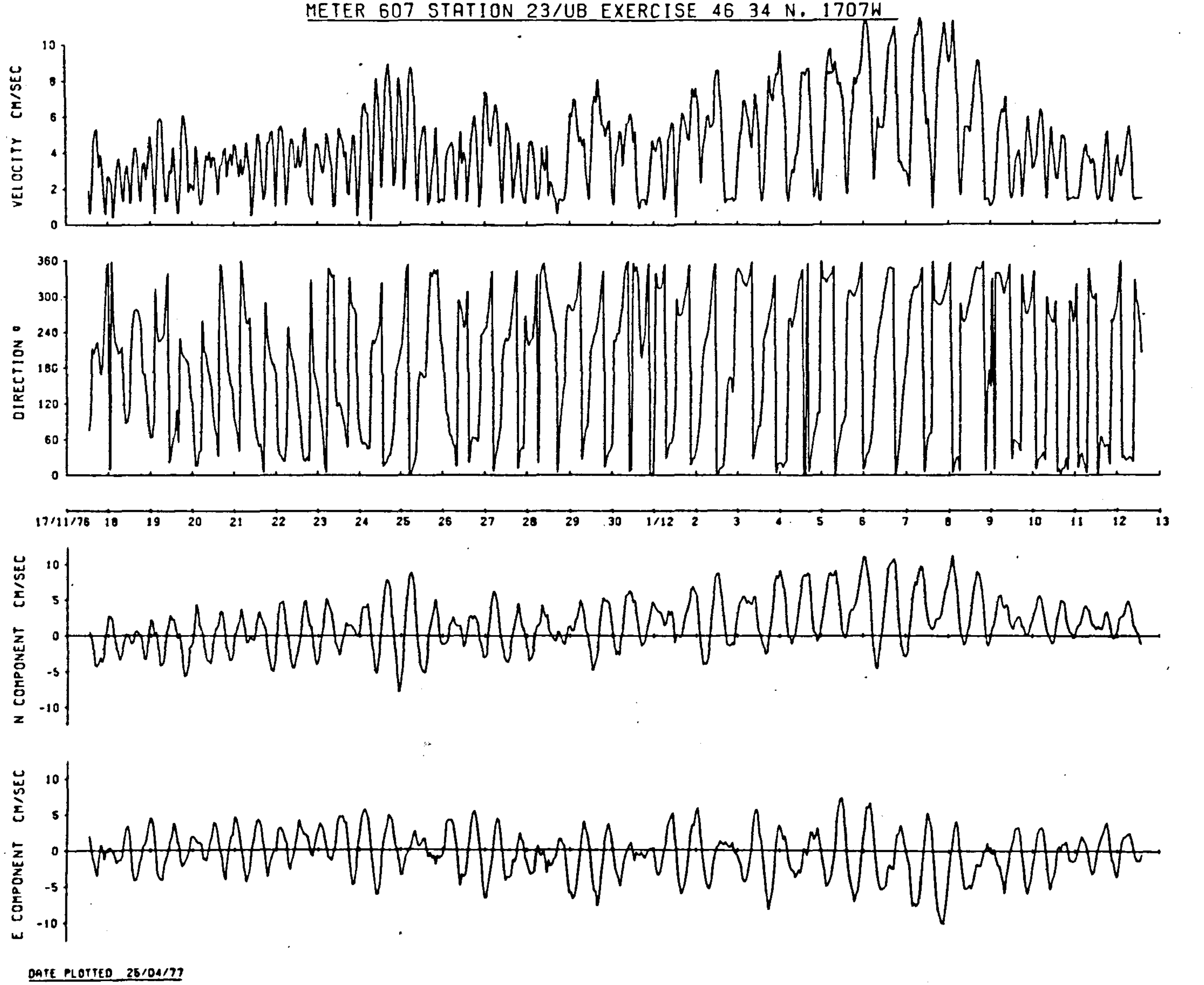


Figure 3 Bathymetry of study area (m) together with paths of neutrally-buoyant floats at the listed depths (m) and progressive vector diagrams for bottom (B) and upper bottom (UB) current meters at Stations 23, 35 and 40.

Figure 4. TIME PLOTS OF HOURLY VALUES

METER 607 STATION 23/UB EXERCISE 46 34 N. 1707W



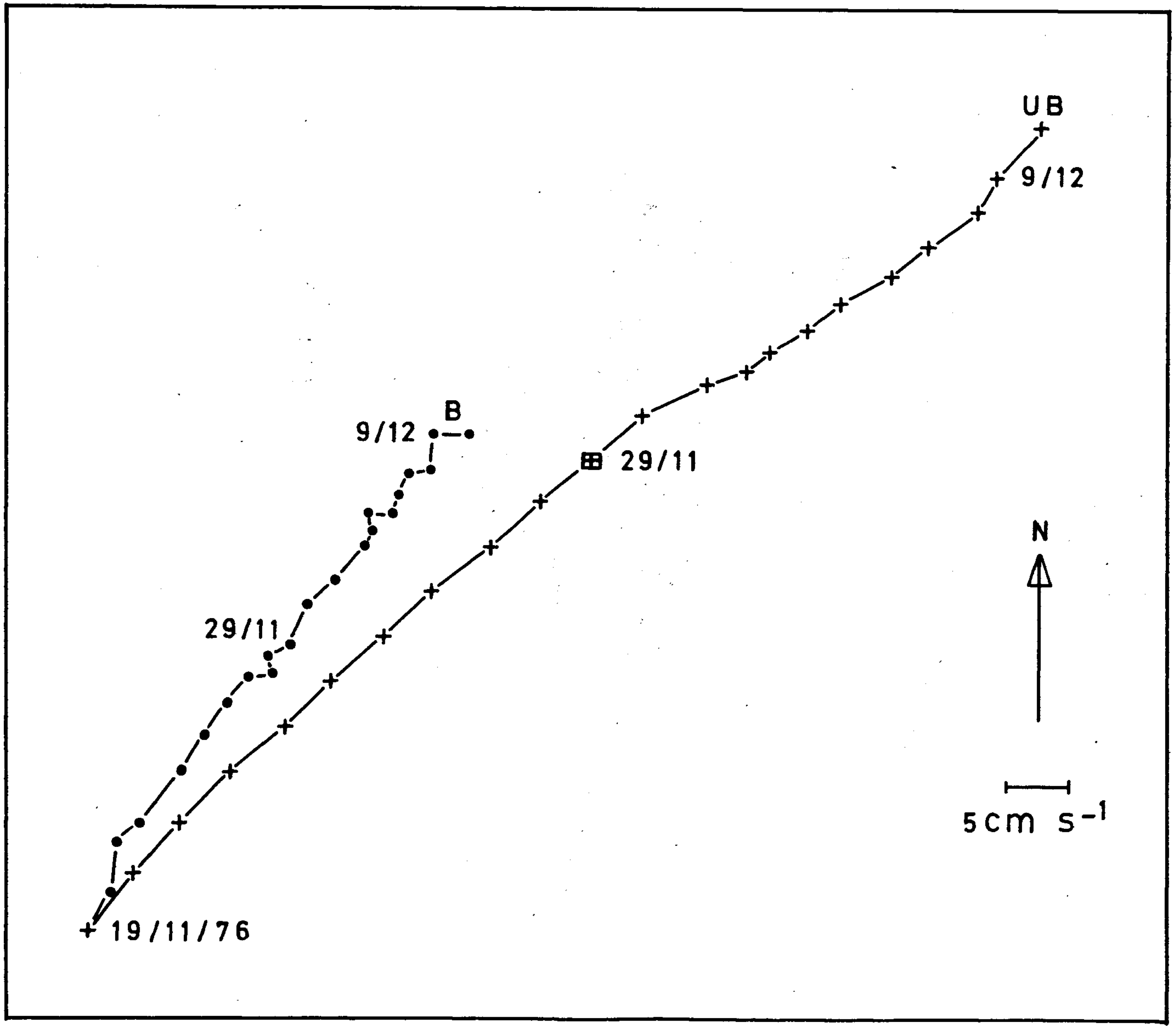


Figure 5 PVD daily residuals. Station 40/B,UB, Exercise 4547N, 1644W.

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Dynamic Height Anomalies relative to 4100 m at 1000 m

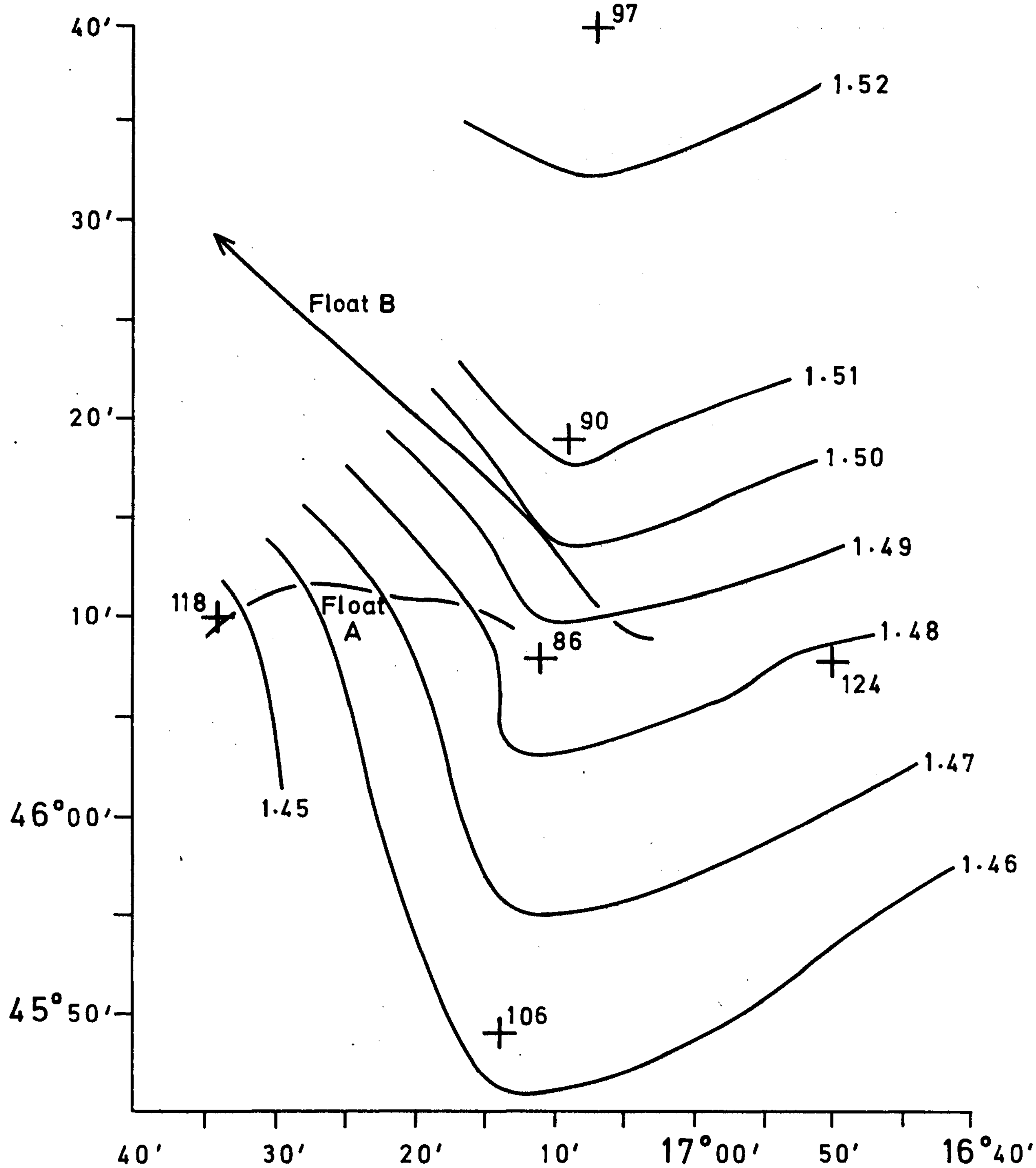

Figure 6 All hydrographic stations worked between 22 and 26 November 1976. Float A tracked from 22-26 November, Float B from 26 November-4 December 1976.

Figure 7

CIROLANA 10/76 Velocity Profiles, Stations 97-90-86-106

⟵ = Float position