J. Cons. int. Explor. Mer, 43: 261–267. 1987

Drifting buoys in the Northeast Atlantic

D. A. Booth and D. T. Meldrum

Booth, D. A., and Meldrum, D. T. 1987. Drifting buoys in the Northeast Atlantic. – J. Cons. int. Explor. Mer, 43: 261–267.

A series of satellite-tracked buoys was deployed in Rockall Trough during the period May 1983–January 1984 to investigate the circulation near the surface. Currents near steep topography were strong and tended to follow depth contours, as illustrated by a northeastward flow over the eastern slope of the Faroe–Shetland Channel and by a branching into the Norwegian Trench from northward-flowing Atlantic water. In Rockall Trough, a general northeastward drift was weak and was obscured by small-scale features of the flow, particularly eddies which were found near both the Anton Dohrn seamount area and Porcupine Bank.

D. A. Booth: Institut Maurice-Lamontagne, 850 Route de la Mer, C.P. 1000, Mont-Joli, Québec, Canada G5H 3Z4. D. T. Meldrum: Scottish Marine Biological Association, Dunstaffnage Marine Research Laboratory, P.O. Box 3, Oban, Argyll PA34 4AD, Scotland.

Introduction

Near-surface Atlantic water flowing northeastwards between Scotland and the Faroe Islands is considered to be the major component of the inflow to the Norwegian Sea (Worthington, 1970) required to balance deep, dense outflow back into the Atlantic. This flow has been inferred both from surface patterns of temperature and salinity and from geostrophy based on water density measurements across the Faroe–Shetland Channel (Tait, 1957) and is supported by results from recording current meters on fixed moorings (Dooley and Meincke, 1981).

To clarify the history of Atlantic near-surface water inflow to the Norwegian Sea, a series of eleven satellite-tracked buoys, specifically designed for following currents, was deployed in Rockall Trough during the period May 1983–January 1984. Results in the form of drift tracks are presented below and are especially intended to convey the pattern of currents observed over a period of 14 months. Individual events such as eddies are still being studied and will be reported later. A detailed data report is also available (Booth and Meldrum, 1985).

Description of buoy and drogue

The buoys, attached to subsurface drogues which act as sea anchors, were designed to minimize wind drag, and thus also slippage past the drogue. They were pear shaped, 0·5 m in diameter, 0·6 m in height, and weighed 25 kg including instrumentation and batteries. Large windowblind drogues (5 m × 12 m) were supported by buoyant tetherlines (Fig. 1) which reduced the shock loadings on the rigging and also helped to

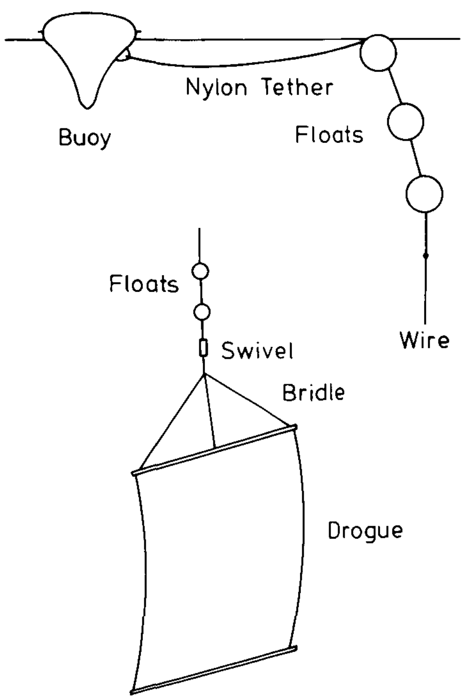

Figure 1. Buoy, drogue, and rigging. Note that buoy and drogue are not drawn to scale. Diameter of buoy, 0·5 m; width of drogue, 5 m.

minimize the drag on the buoys in waves (Booth, 1981a). It should be emphasized that the area of the drogue relative to the dry frontal area of the buoy and floats was large compared with many other drogue systems used for tracking currents. Position fixing was by Service Argos.

Equating horizontal drag forces above and below the surface indicates that the slip velocity past the drogue is less than $1{\cdot}4 \times 10^{-3}$ of the wind velocity for steady conditions. For this calculation, a drag coefficient for the drogue of 1·5 was taken from Vachon's (1973) tests, and the wind drag coefficient for the buoy was estimated experimentally with a full-scale floating hull in realistic wind speeds.

Some indication of drogue performance can be given by the correlation coefficients of buoy drift and wind. Using daily buoy velocities and near-surface winds estimated from atmospheric pressure gradients, together with some nearby coastal wind observations from the Faroes and Shetlands, these coefficients were generally insignificant (i.e., less than 1 % level assuming that daily values are independent), except for buoys which had lost their drogues. Further evidence of drogue loss includes an increase in regression coefficients for buoy velocity against wind, an increase in noise in the velocity records, and unimpaired drift into shallow water. Four buoys appeared to lose their drogues, and there are doubts concerning another two. Data after indication of drogue-loss are not included in the following track plots. In particular, the drift track of Buoy 71 was excluded from the figures since drogue-loss soon after deployment is suspected. The plots may thus be considered to represent water movement at the depth of the drogues.

Buoys were deployed at three locations, namely the southern, central, and northern parts of Rockall Trough during May 1983, December 1983, and January 1984, respectively (Table 1). Drogue depths were 16 m, 66 m, 116 m, and 166 m and are indicated in brackets after buoy numbers below.

Table 1. Details of buoy deployment.

Deployment	Date	Position	Buoy number (drogue depth)
A	16 May 83	54°50′N 15°29′W	72 (16 m) 75 (66 m) 76 (166 m)
B	12 Dec 83	59°30′N 9°00′W	74 (16 m) 73 (66 m) 78 (116 m) 80 (166 m)
C	25 Jan 84	57°32′N 11°42′W	71 (66 m) 82 (116 m) 79 (166 m)
D	25 Jan 84	57°22′N 10°53′W	77 (116 m)

Results and discussion

A general northeastward drift from Rockall Trough through the Faroe–Shetland Channel and up along the Norwegian coast is clear in Figure 2. Average northeastward velocity was 0·14 m s^{-1}, although drift speeds were occasionally in excess of 0·80 m s^{-1}. The average velocity through the Faroe–Shetland Channel was 0·33 m s^{-1}, and all but one of the drogued buoys travelled northwards along the eastern side of the Channel (Figs. 2 and 3). Taking the cross-sectional area of unmodified Atlantic surface water (Dooley and Meincke, 1981), which has a typical depth of 200 m and lies above the eastern slope of the Channel, the total transport is 3×10^6 m^3 s^{-1}. This compares well with other estimates (Tait, 1957; Dooley and Meincke, 1981).

Two buoys, 73 (66 m) and 82 (116 m), which travelled northeastwards along the Scottish shelf edge rather than above the slope and at a slower rate than those in deeper water, followed topographic contours north of Shetland and turned southwards into the Norwegian Trench (Fig. 3). Other workers using parachute drogues in a study of continental slope currents have noted similar behaviour in this area (Dooley and Martin, 1969). Although Buoy 82 was prematurely picked up, Buoy 73 spent three months (March to May) wandering between warm, salty Atlantic water (Lee, 1980) and cold, northward-flowing Norwegian coastal water (Mork, 1981), with a temperature difference of over 2 °C. Both the northeastward plume from the Atlantic and this southward extension into the Norwegian Trench are visible on satellite infrared images (University of Dundee, pers. comm.).

In Rockall Trough, the three buoys 72 (16 m), 75 (66 m), and 76 (166 m), released together, were caught up in a large anticyclonic gyre with periods of between 4 and 11 days (Fig. 4). Typical speeds were 0·5 m s^{-1}, and the buoys travelled between one and three orbits before separating. Buoy 77 (116 m) also picked up an anticyclonic gyre in the same area a year later (Fig. 5). Satellite infrared images (e.g., Fig. 6) show that this area just off the northwest corner of Porcupine Bank, where the shelf edge changes orientation, is often occupied by a pair of oppositely rotating vortices at the end of a westward double-filament stem, apparently originating at the slope region. Barotropic instabilities over the slope may be involved, but whatever the generating mechanism may be, these eddies probably contribute to the mixing of inhomogeneous waters in the southern part of Rockall Trough as they travel northwards towards the Anton Dohrn seamount area where temperatures and salinities appear more uniform (Ellett, 1979; Ellett and Martin, 1973).

Having left the gyre the three buoys separated (Fig. 4). Buoy 72 (16 m), with its drogue above the seasonal thermocline, crossed the slope and spent almost two months near the top of Porcupine Bank before drifting over the Irish shelf, where a north–south rever-

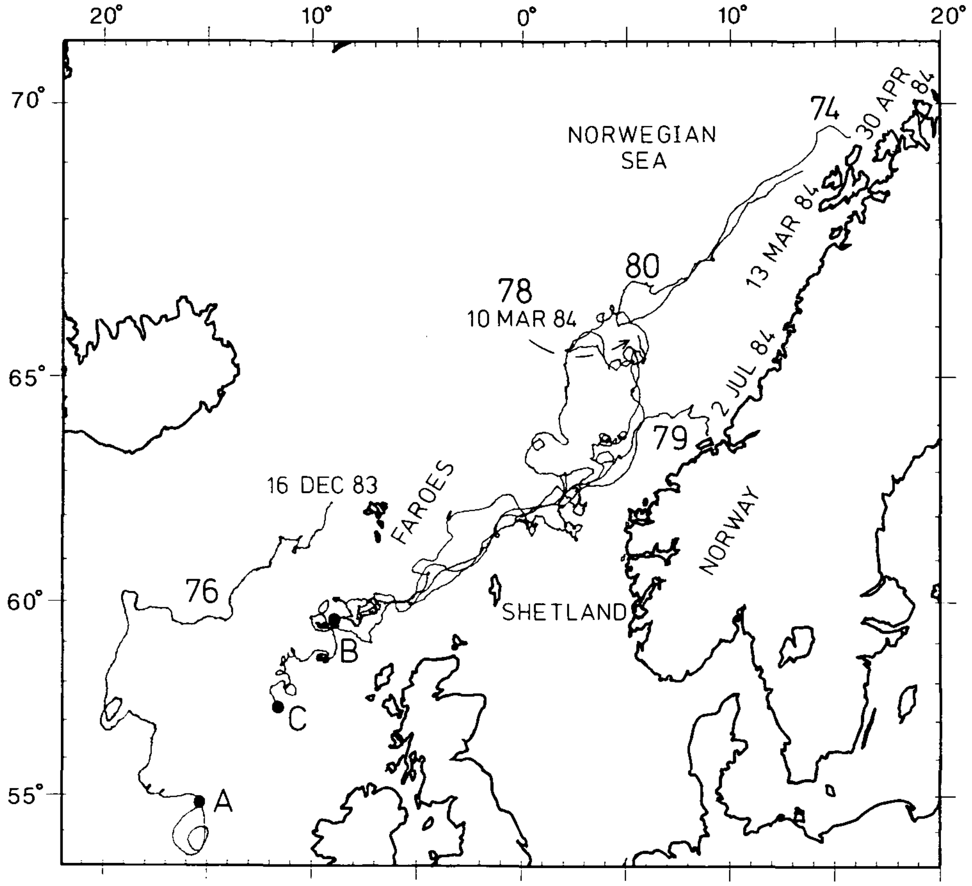

Figure 2. The general northeastward drift. Letters refer to deployment; numbers identify buoys.

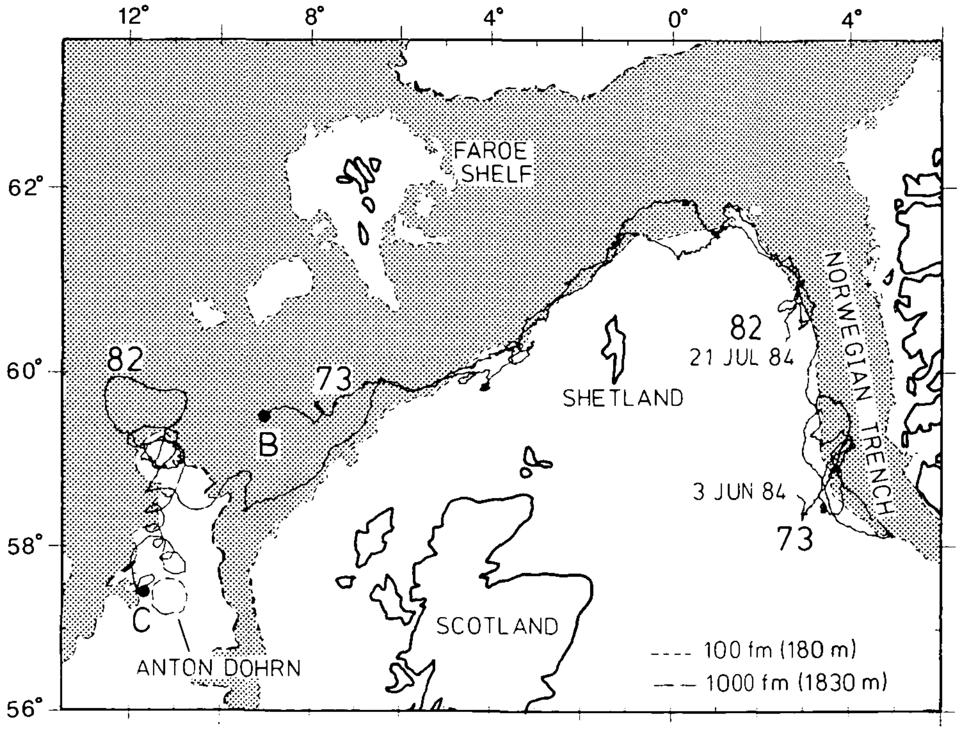

Figure 3. Topographic guiding into the Norwegian Trench. Letters refer to deployment; numbers identify buoys.

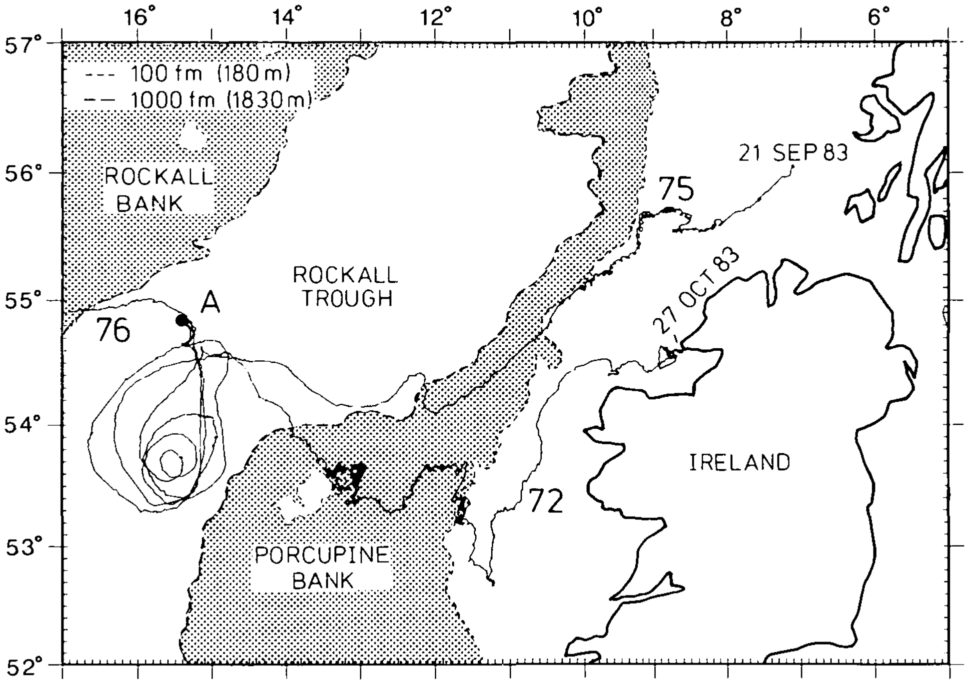

Figure 4. An eddy northwest of Porcupine Bank. Letters refers to deployment, numbers identify buoys. See Figure 2 for continuation of Buoy 76 around south of Rockall Bank.

sal in its track coincided with the passage of two deep atmospheric depressions. Buoy 75 (66 m) became caught in the poleward slope current (Huthnance, 1984; Booth and Ellett, 1983) before drifting over the Scottish shelf, where it oscillated with the unusual diurnal tidal currents of the region (Cartwright *et al.*, 1980). Buoy 76 (166 m) headed westwards and tended to follow depth contours, going anticyclonically around banks such as Rockall, Hatton, and Lousy until it lost its drogue west of the Faroes (Fig. 2).

Buoy 77 (116 m) was deployed on the east side of Anton Dohrn seamount a few hours after deployment of three others (Buoys 71, 82 and 79) on the west side. It soon picked up cyclonic eddy motions with periods of two days on the east side of the seamount and one day on the south side (Fig. 5). Speeds were about 0·5 m s^{-1} and radii were 10 km, comparable to the internal radius of deformation (Emery *et al.*, 1984), suggesting that baroclinic instability may be involved in the generating mechanism. Two buoys, 79 and 82, were also caught in cyclonic eddies of two-day periods on the north side of the seamount.

The Anton Dohrn seamount breaks through the main thermocline and is high enough to generate an anticyclonic Taylor column (Hupper and Bryan, 1976) with the observed background stratification and a flow of 0·1 m s^{-1}. The barotropic M_2 tide in the region has a velocity of 0·05 m s^{-1} with a north–south rectilinear axis (Booth, 1981b). Low-frequency Eulerian currents can be as large as 0·4 m s^{-1} but are generally about 0·1 m s^{-1} (Booth, 1983). Several of the 15 east–west temperature and salinity sections across this area completed by SMBA between 1975 and 1982 showed slight doming of contours near the top of the seamount. The most marked case, with isotherm displacements of over 200 m, was during October 1981 (Booth, 1985) at the end of a period of unusually intense low-frequency current kinetic energy (Booth, 1983). Thus water structure observations are consistent with a Taylor column, and indeed the buoys taken as a group did rotate anticyclonically round the seamount. However, theoretical and numerical work (Hupper and Bryan, 1976) suggest that for subcritical flow a neighbouring cyclonic eddy, produced to the right of the flow, remains in the vicinity when the current velocity is small, but is advected away when the internal Froude number (based on seamount height) is increased above 0·1, a condition which applies to the Anton Dohrn seamount in reasonably strong background flows. Thus the cyclonic eddies seen by the buoys are probably warm anomaly eddies shed from the seamount. Additional evidence is produced by large gradients at the main thermocline, with warm anomalies above, which were occasionally found just to the east. Other banks in the area are also likely to support a Taylor column and associated warm eddies.

The net southward drift of Buoy 77 (Fig. 5) opposed the weak general northeastward drift. Initially, at least, transfer from one feature to another contributed to this drift. An anticyclonic flow around Anton Dohrn and a southward flow over the eastern slope of Rockall (also anticyclonic) transported the buoy 100 km south of its deployment position. Evidence for eddy activity in the

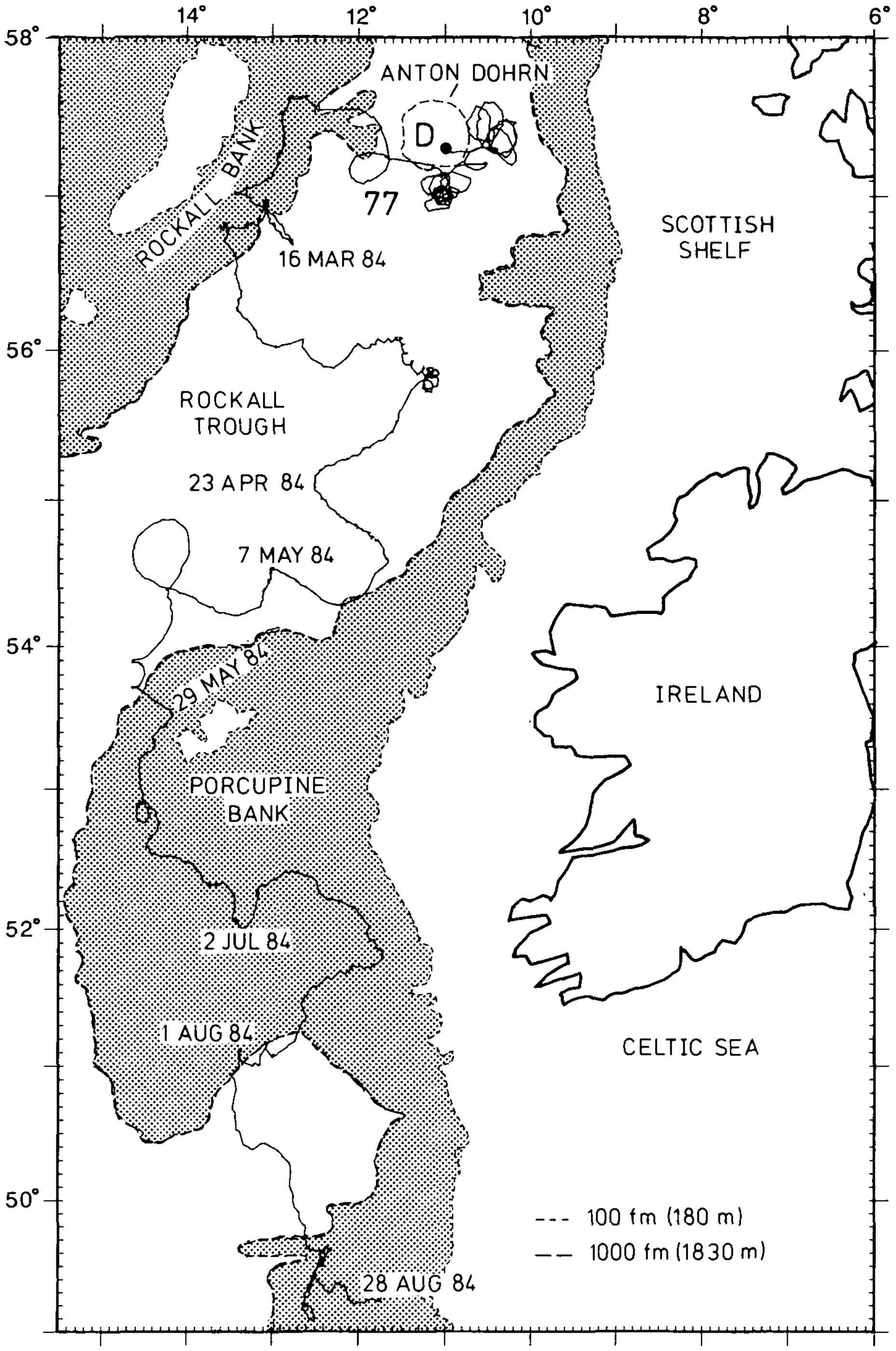

Figure 5. Southward drift and eddies found by Buoy 77.

middle of Rockall Trough and near Porcupine Bank makes a further southward drift by transfer between features very plausible, particularly as eddies themselves change with time. Development of an eddy amid others, some of which may be merely remnants, would result in erratic and irregular particle trajectories. If eddy activity is sufficiently intense, Lagrangian drifts against the general flow must be statistically possible. The behaviour of Buoy 77 thus serves to illustrate the variable nature of the currents in Rockall Trough.

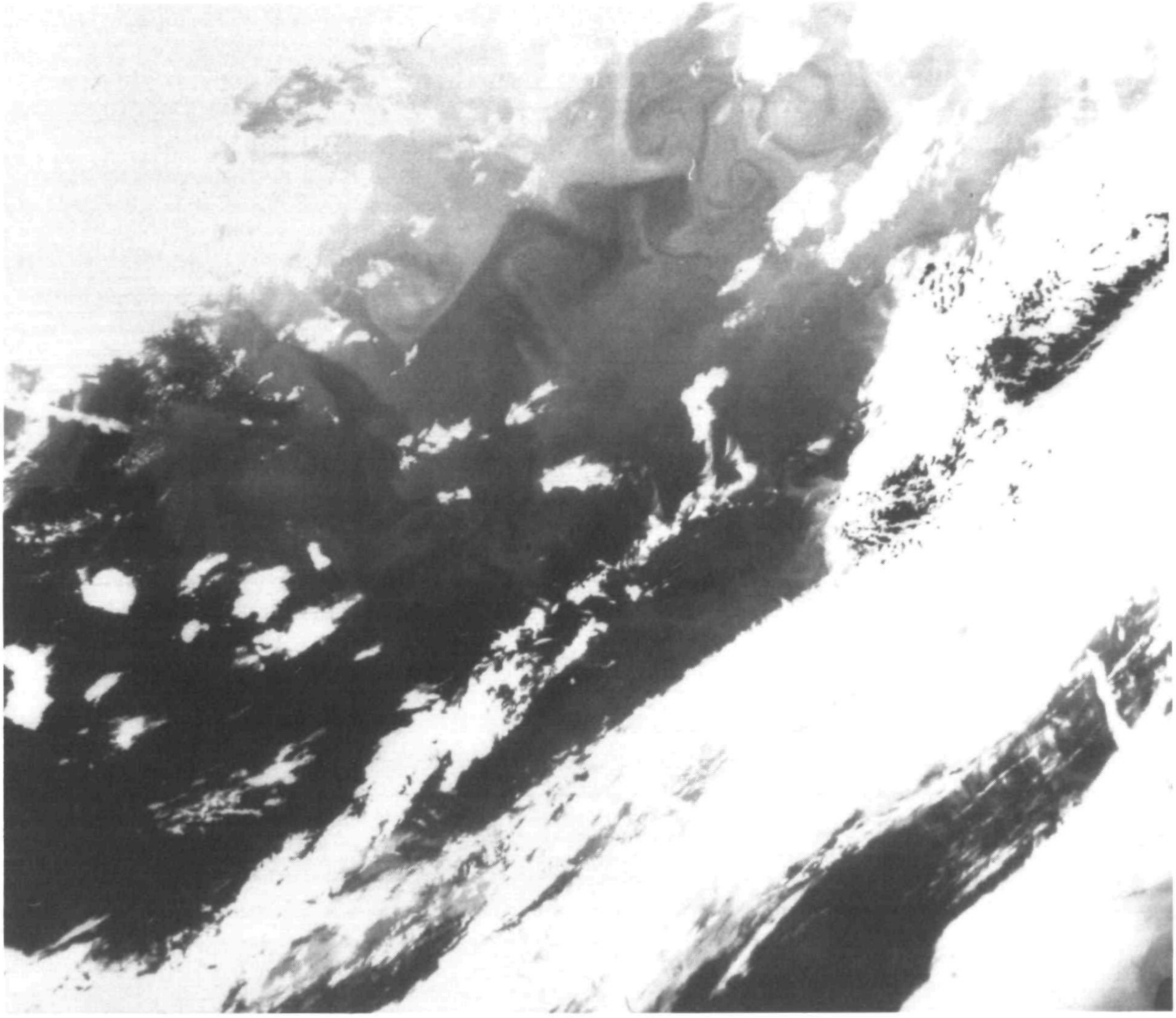

Figure 6. Infrared image for 3 August 1981 of the sea west of Ireland showing two pairs of eddies northwest of Porcupine Bank. White areas are cloud. Ireland is black and partially hidden by cloud. Dark and light greys are associated with warm and cool surface water, the surface water above Porcupine Bank being cool. The image was kindly provided by the Electronics Laboratory, University of Dundee.

Conclusion

The results clearly show the general drift of near-surface Atlantic water into the Norwegian Sea and Norwegian Trench. Flows were generally weak except, first, in regions of steep topography such as slopes and banks, and, second, in the presence of eddies which are shed from the banks. Between these areas the flows have an irregular interweaving nature indicative of large-scale stirring. These flows are perhaps the remnants of decayed eddies which are themselves produced by instabilities.

Acknowledgements

This work was funded by the Natural Environment Research Council, and the Department of Energy. All the members of the SMBA Marine Physics Group contributed to the success of the buoys.

References

Booth, D. A. 1981a. On the use of drogues for measuring subsurface ocean currents. Dt. hydrogr. Z., 34: 284–294.

Booth, D. A. 1981b. Oscillatory currents in the Rockall Trough. SMBA Marine Physics Group Report 15: 27 pp.

Booth, D. A. 1983. Non-tidal currents in Rockall Trough. SMBA Marine Physics Group Report 23: 39 pp.

Booth, D. A., and Ellett, D. J. 1983. The Scottish continental slope current. Continental Shelf Res., 2: 127–146.

Booth, D. A., and Meldrum, D. T. 1985. Northeast Atlantic satellite-tracked buoy drifts. U.K. Department of Energy Offshore Technology Reports.

Cartwright, D. E., Huthnance, J. M., Spencer, R., and Vassie, J. M. 1980. On the St Kilda shelf tidal regime. Deep-Sea Res., 27A: 61–70.

Dooley, H. D., and Martin, J. H. A. 1969. Currents at the continental slope of the northern North Sea. ICES CM 1969/C:4.

Dooley, H. D., and Meincke, J. 1981. Circulation and water masses in the Faroese channels during Overflow '73. Dt. hydrogr. Z., 34: 41–55.

Ellett, D. J., 1979. Hydrographic conditions in the Rockall Channel, January–March 1977. Annls biol., Copenh., 34: 56–59.

Ellett, D. J., and Martin, J. H. 1973. The physical and chemical oceanography of the Rockall Channel. Deep-Sea Res., 20: 585–625.

Emery, W. J., Lee, W. G., and Magaard, L. 1984. Geographic and seasonal distributions of Brunt–Vaisala frequency and Rossby radii in the North Pacific and North Atlantic. J. phys. Oceanogr., 14: 294–317.

Huppert, H., and Bryan, K. 1976. Topographically generated eddies. Deep-Sea Res., 23: 655–679.

Huthnance, J. M. 1984. Slope currents and "JENBAR". J. phys. Oceanogr., 14: 795–819.

Lee, A. J. 1980. North Sea: Physical oceanography. *In* Northwest European shelf seas, II, pp. 467–493. Ed. by P. T. Banner, M. B. Collins, and K. S. Massie. Elsevier. 638 pp.

Mork, M. 1981. Circulation phenomena and frontal dynamics of the Norwegian coastal current. Philosophical Trans. Roy. Soc., Lond., A 302: 635–647.

Tait, J. B. 1957. Hydrography of the Faroe–Shetland Channel 1927–1952. H.M.S.O. 309 pp.

Vachon, W. A. 1973. Scale model testing of drogues for free drifting buoys. Charles Stark Draper Laboratory, Technical Report.

Worthington, L. V. 1970. The Norwegian Sea as a mediterranean basin. Deep-Sea Res., 17: 77–84.