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# Satellite-tracked drogue paths over Faroe Bank and the Faroe-Iceland Ridge

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## ABSTRACT

Satellite-tracked drogues have confirmed the existence of an anti-cyclonic circulation around Faroe Bank during three periods of 1986-89, and also showed a predicted self-contained circulation in the upper waters of the Faroe Bank Channel. Upon the Faroe-Iceland Ridge drogues chiefly followed the isobaths and were largely consistent with the classical circulation schemes for the area. The four drogues observed to cross the ridge did so through two channels, both of them on the southeastern half of the ridge.

## INTRODUCTION

In 1986 the SMBA Dunstaffnage Marine Laboratory in Oban, Scotland and the Fisheries Laboratory in the Faroe Islands initiated a joint project to study the upper-water flow over Faroe Bank and in Faroese waters using satellite tracked drogues. Originally the project was concentrated on the Faroe Bank (Figure 1) and the first results were reported to the ICES statutory meeting in 1986 (Hansen et al., 1986). Together with evidence from hydrographic surveys and a current meter mooring these first results from the tracked drogues provided convincing evidence for a semi-closed anticyclonic circulation over the bank consistent with biological evidence indicating a fair amount of isolation of the bank water.

Since then the two drogues have been redeployed a number of times until they were both lost in 1989. The emphasis on the Faroe Bank circulation has continued; but in addition two other regions have been studied partly by design and partly by drogues drifting into the region after leaving the Faroe Bank. The two regions are the Faroe-Iceland Ridge and the Faroe Bank Channel (Figure 1).

Over the Faroe-Iceland Ridge warm and saline water from the Atlantic flows into the Norwegian Sea and shortly after passing the ridge it encounters the colder and less saline waters from the East Icelandic Current in the Iceland Faroes Front. The distribution of temperature and salinity makes it evident that there is a resulting eastward water transport over the ridge; but what is the flow pattern in more detail and where does the water cross the ridge? These are questions which as yet have been largely unanswered and were the reason for some of the drogue deployments.

The flow field of the Faroe Bank Channel has also been much discussed. In the deeper layers of the channel there can be no doubt about the direction of the flow of the cold "Overflow" water from the Norwegian Sea into the Atlantic; but how do the upper layers flow? The upper 300-500 meters of the channel are dominated by Modified North Atlantic Water (MNAW), which is found over large areas west of the Faroe Bank (Becker & Hansen, 1988); but this water could come either from north of the channel or from south of it and it has even been suggested that at least parts of this water could derive from the Faroe Shetland Channel having passed over the Faroe-Iceland Ridge and flowed southward east of the Faroes. In 1988-1989 one of the drogues made a round-trip through the Faroe Bank Channel and combined with the available hydrographic evidence the drogue track does give some insight into the circulation of the Faroe Bank Channel.

## MATERIAL AND METHODS

The two satellite tracked buoys used in these experiments, labeled 3973 and 3979, were developed at the SMBA Laboratory (Booth and Ritchie, 1983). They were drogued with a square sail having an area of 5x12 $m^2$ at a depth of 60 meters as described in more detail in Hansen et al. (1986). Experience in North European offshore waters (Booth and Meldrum, 1985) has indicated that the direct wind effect on the buoys is small and the first deployment on Faroe Bank gave very convincing evidence for that (Hansen et al., 1986).

The drogue deployments discussed in this paper were all made from the Faroese research vessel Magnus Heinason and usually the drogues were picked up by this vessel at the ends of the experiments. In the end, however, both drifters were lost as one of them went aground on the Faroes after having lost its drogue while logistical difficulties prohibited the recovery of the other drifter before it drifted too far from the area. In some cases the drogue has been lost during an experiment; but the change in behaviour and in the response to winds makes it fairly easy to establish the time at which the drogue was lost. If each deployment of a drifter is considered an experiment a total of 9 experiments were made. In Table 1 we summarize these.

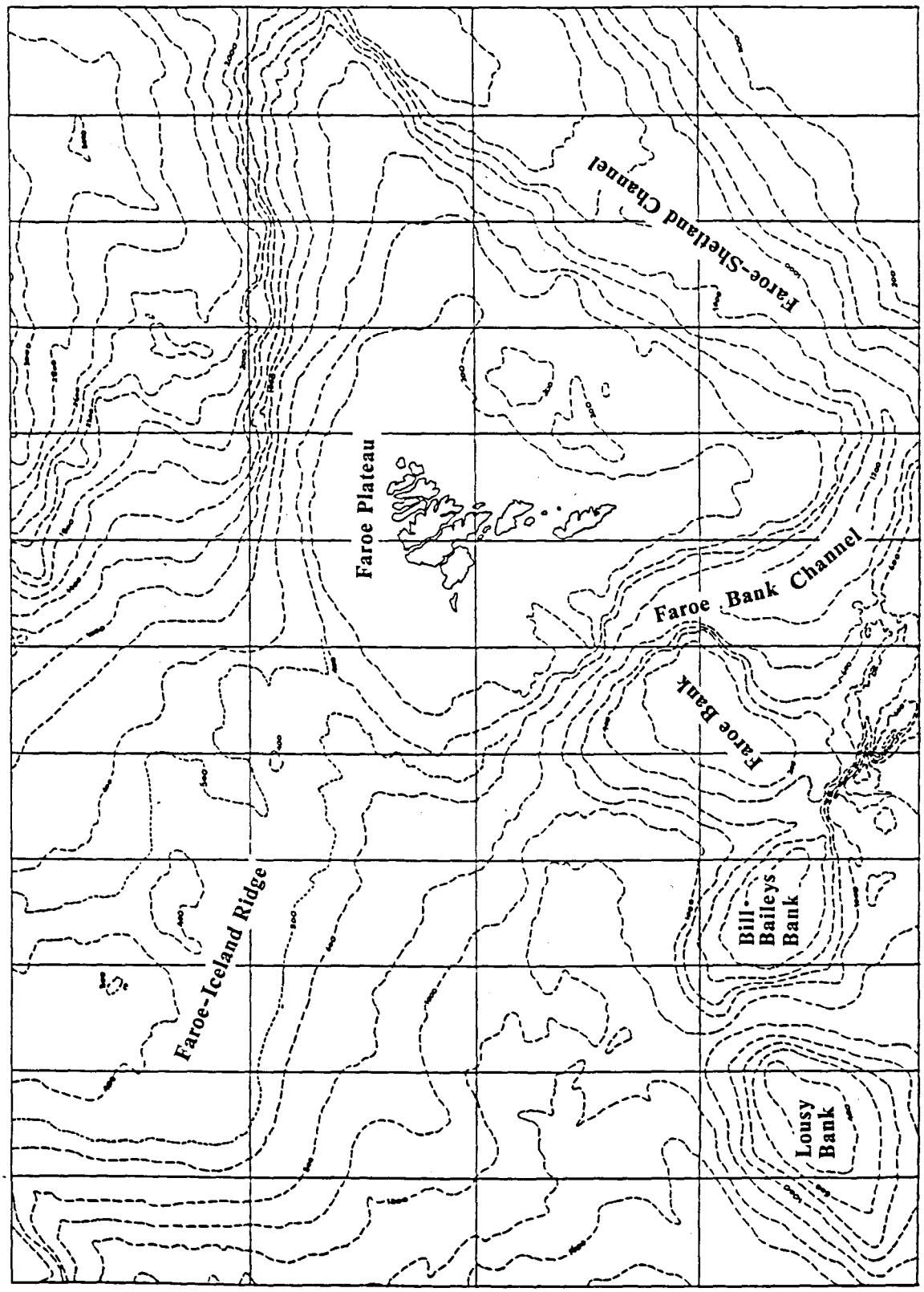


*Figure 1. Bottom topography of the area investigated.*

Table 1. Time and position of deployment for each experiment as well as the time of end either by recovery, by loss of drogue or by the drifter leaving the area. The columns labeled Day give the day number in the year.

| Drifter | Start of experiment | | | End of experiment | | |
|---|---|---|---|---|---|---|
| | Date | Day | Position | Date | Day | Status |
| 3973 | 10. Mar 1986 | 69 | 60°50'N 8°45'W | 3.May 1986 | 123 | Recovered w. drogue |
| 3979 | 10. Mar 1986 | 69 | 60°57'N 9°01'W | 22.Mar 1986 | 81 | Lost drogue |
| 3973 | 25. Apr 1987 | 114 | 60°54'N 8°59'W | 31.May 1987 | 151 | Recovered w. drogue |
| 3979 | 25. Apr 1987 | 114 | 60°50'N 8°44'W | 31.May 1987 | 151 | Recovered w. drogue |
| 3973 | 31. May 1987 | 151 | 62°01'N 10°00'W | 3.Jul 1987 | 184 | Recovered w. drogue |
| 3973 | 21. May 1988 | 142 | 62°00'N 10°59'W | 27.Nov 1988 | 331 | Recovered w. drogue |
| 3979 | 21. May 1988 | 142 | 61°30'N 11°00'W | 15.Nov 1988 | 320 | Recovered w. drogue |
| 3973 | 30. Nov 1988 | 335 | 61°24'N 7°59'W | 18.Feb 1989 | 49 | Left region w. dr. |
| 3979 | 1. Dec 1988 | 336 | 61°08'N 9°31'W | 11.Feb 1989 | 42 | Lost drogue |

## DROGUE TRACKS

During 1986-89, satellite-tracked drogues were released in three main areas; upon Faroe Bank during three periods, April-May 1986, April-May 1987 and December 1988-February 1989; to the west of the Faroes in June-July 1987 and May-November 1988; and in the Faroe Bank Channel in December 1988. General results were as follows.

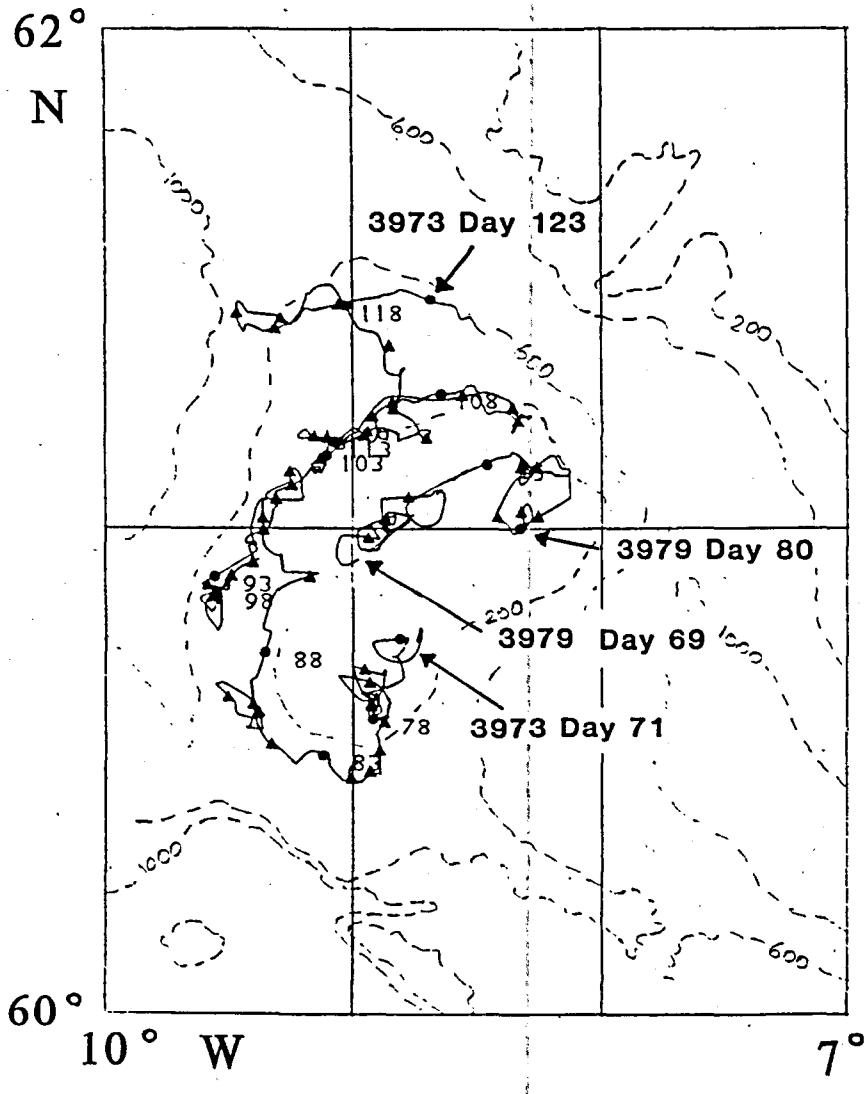


*Figure 2. Drogues 3973 and 3979 during April-May 1986.*

Faroe Bank The tracks of the two drogues released in April-May 1986 are shown in Figure 2, and have previously been described by Hansen et al (1986), where the net anticyclonic drift around the bank was noted to have been interrupted in the case of drogue 3973 by a period of southerly movement outside the 200m isobath to the west of the bank, and an excursion to the northwest towards the end of the drift. No obvious connection was seen between these movements and local winds. The releases of the following year (Figures 3 and 4) were more regular, although a diversion into deeper water off the northwestern quadrant of the bank was again apparent in the path of drogue 3979. Within the 200m isobath it took 30 days for drogue 3973 to return to its starting point. Drogue 3979 spent 15 days in rounding the southern fringes of the bank and then travelled northwestwards in depths of 200-400m during another 15 days.

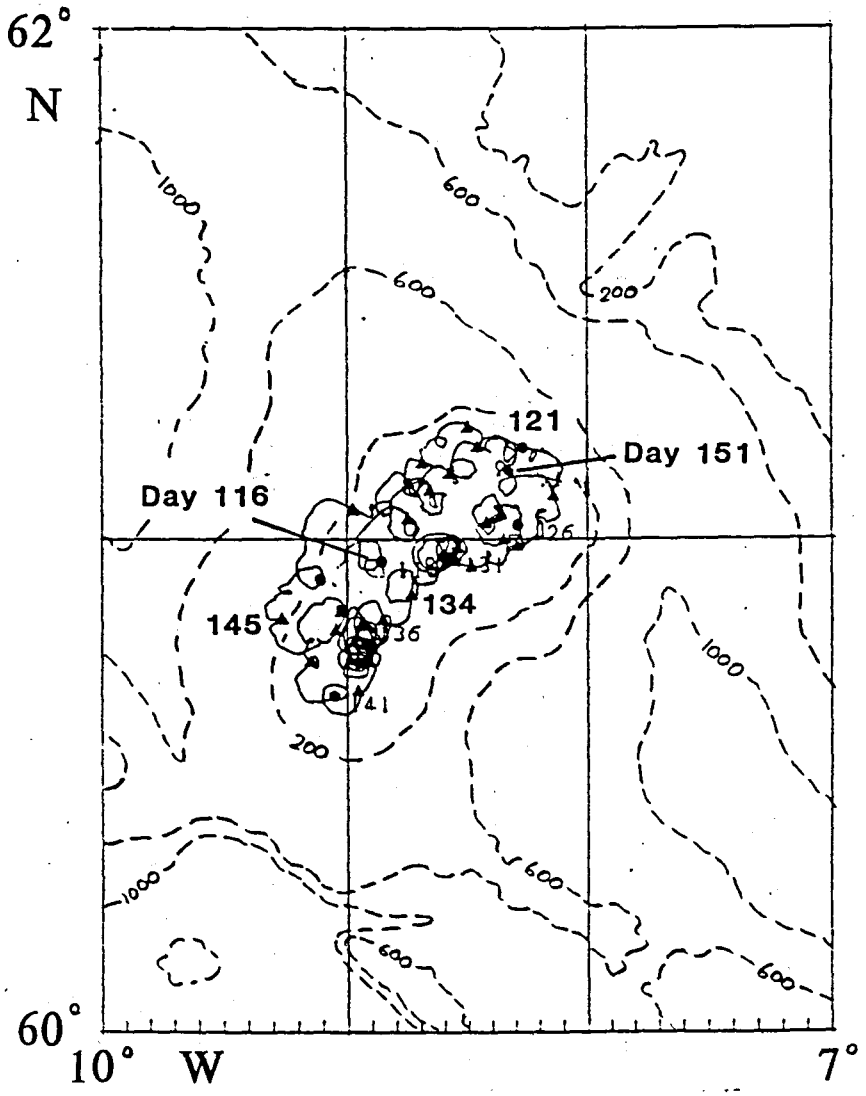


*Figure 3. Drogue 3973 during April-May 1987.*

In December 1988 (Figure 5), a drogue was launched to the west of the bank over soundings of 700-800m. Within a few days the drogue had begun a southward movement over the 500m isobath, which continued for about a week and which compares closely with the southward drift of 3973 in the same locality in 1986 (Figure 2). Subsequently it reversed its course and moved into shallower water and began an anticyclonic circulation around the bank, reaching the northeast corner after 30 days, passing down the east side over the course of about 25 days. Buoy and drogue moved around the western side of the bank and it seems probable that the drogue had become detached by day 42 of 1989, when an abrupt increase in drift speed occurred.

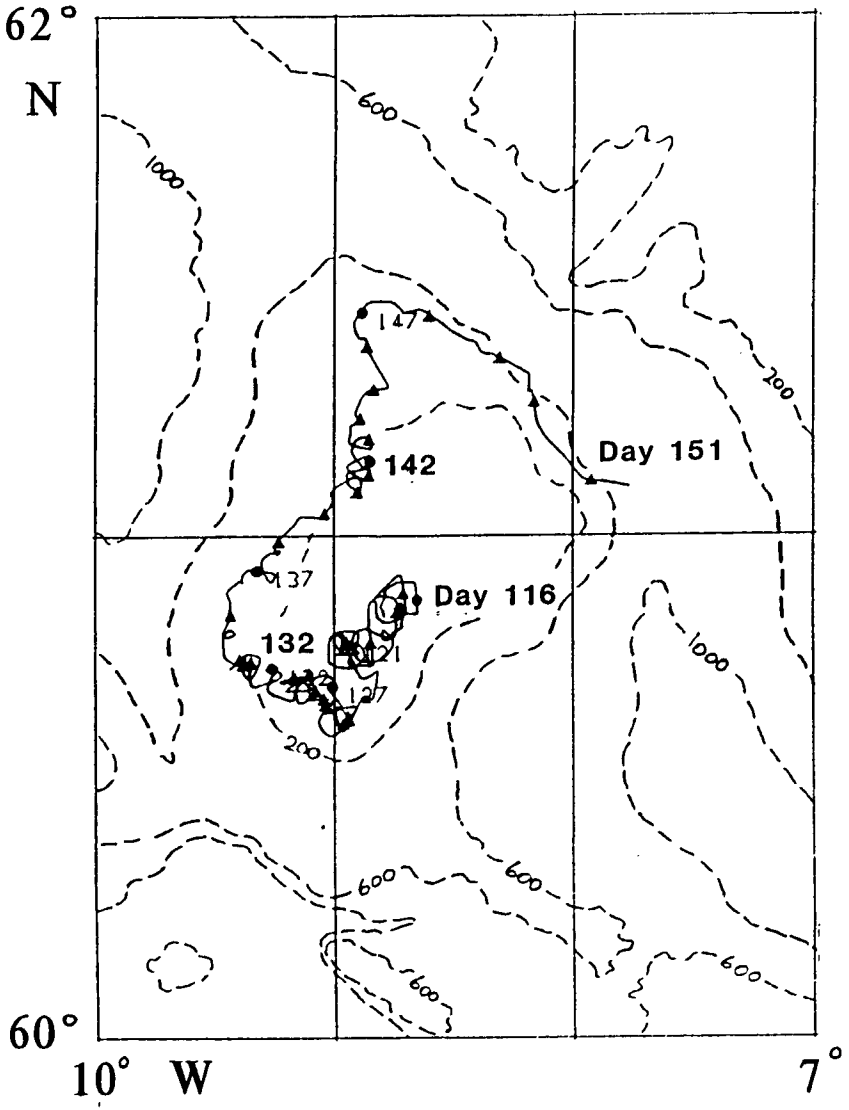


*Figure 4. Drogue 3979 during April-May 1987.*

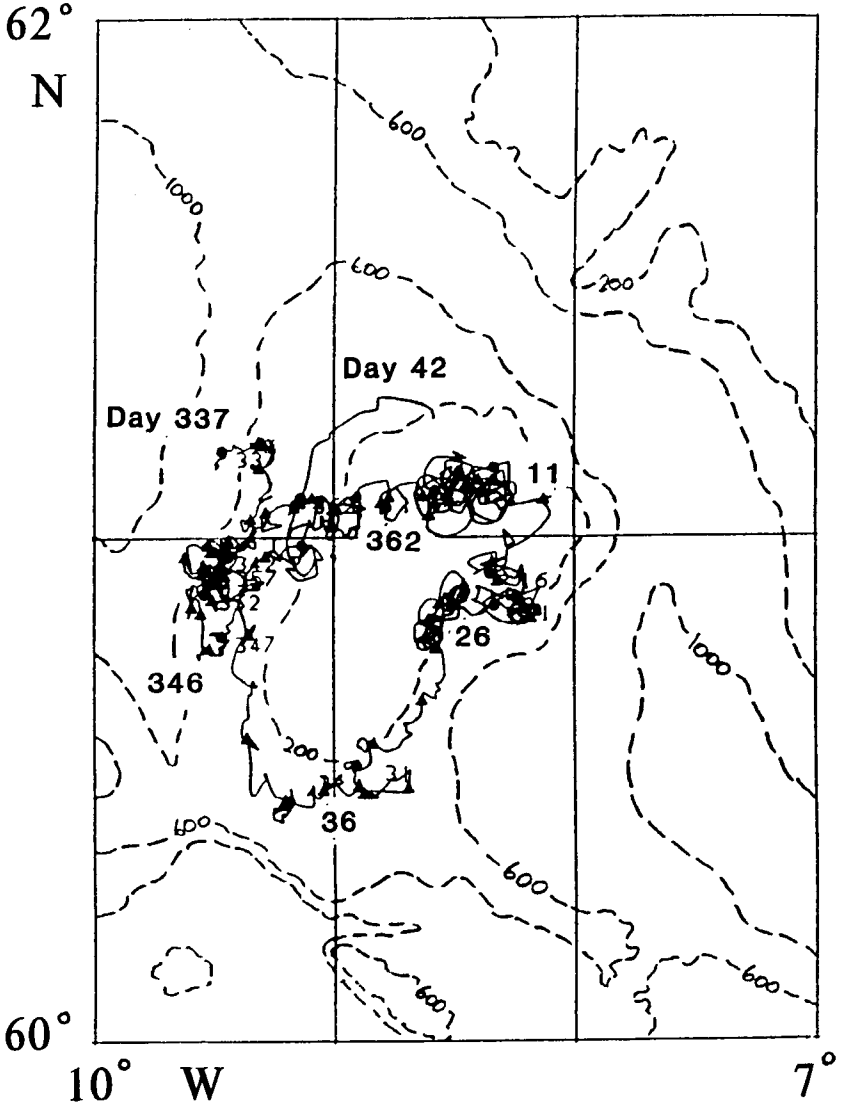


*Figure 5. Drogue 3979 during Dec.1988-Feb. 1989.*

All five of the drogue tracks on the bank gave clear evidence of an anticyclonic circulation and suggest a residence time for water upon the bank which is in excess of 30-40 days. In two cases one of the drogues completed more than a complete circle around the bank. Drogue 3973 in April-May 1987 (Figure 3) used 30 days for this while drogue 3979 in Dec. 1988 to Febr. 1989 (Figure 5) used 45-60 days for the roundtrip depending upon where the starting point is chosen. There may be various explanations for this difference. For one thing the track in 1987 was over shallower parts of the bank than in 1988-89; but also this later track is rather anomalous. The drogue in this case started west of the bank, was advected onto the bank and crossed over the shallowest part instead of following the isobaths round the northeastern corner. One reason for this anomalous behaviour may be wind. Just before Christmas in 1988 the most severe storm in recent times struck the Faroe Islands with extremely strong winds. The fact that the drogue kept over the bank during and after this storm says much for the persistence of the circulation.

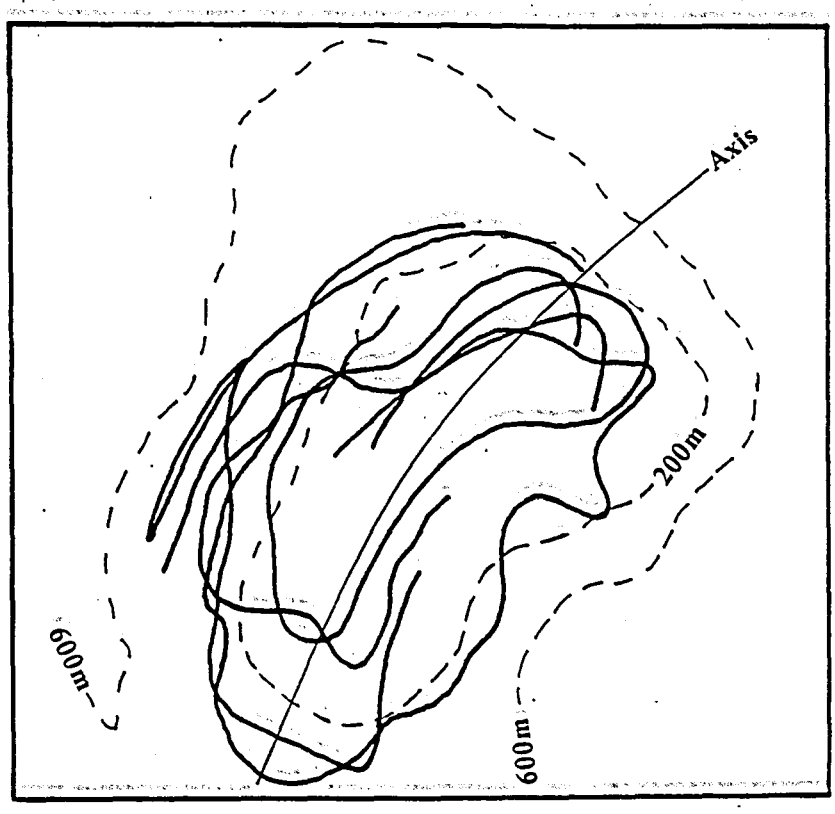


*Figure 6. Smoothed tracks from the five drogue experiments on Faroe Bank (full lines) superposed on bottom topography (broken lines).*

On Figure 6 smoothed drogue tracks from all five experiments on Faroe Bank are plotted on the same map. The smoothing was done by eye. If the bank is divided into two halves by the length axis shown roughly on Figure 6, then we may divide each drogue track into southwest-going and northeast-going subtracks. The Figure gives the impression that the northeast-going subtracks generally were over deeper water outside the 200 m isobath compared to the southwest-going subtracks which generally were within that isobath. Especially the first (western) part of the northeast-going subtracks seems to have been over fairly deep water. This indicates that the circulation may be non-symmetric and displaced towards the northwest with respect to the topography. A radial component of the flow, positive out from the bank may, however, also contribute.

A further asymmetry may be seen in the mean velocities. On the northeast-going subtracks the drogues generally seem to have moved about twice as fast as on the southwest-going subtracks. Thus in April-May 1987 drogue 3973 used 20 days for the southwest-going part of

the roundtrip and 10 days for the northeast-going part. This implies mean residual velocities on the order of 5 cm/sec on the southwest-going part and 10 cm/sec on the northeast-going. The difference could be due to the difference in water depth along the two subtracks if the speed of the circulation increases from the crest outward. The southwest-going flow may, however, in general be slower than the northeast-going flow taking into account that the main flow in the region is eastward. Between September 1987 and June 1988 current meters moored at 275m depth at a position in 700m soundings on the southern flank of Faroe Bank (60° 17.4'N, 8°N 46.4'W) showed steady eastward currents apart from short west-going periods in early March and early June 1988 (ICES C.M. 1991/C:41).

Anticyclonic semi-diurnal tidal ellipses clearly traced by drogue 3973 at a time of spring tides (from 26 April 1987) indicated speeds in excess of 50 cm/sec upon the bank top in soundings of about 100m. In 1913 Jacobsen (1915) measured tidal currents on Faroe Bank at a bottom depth of 110 m, close to the crest. He found anticyclonic tides with velocities approaching 1 m/sec during neap tides. His measurements lasted only about a day, however, and should not be used uncritically. A moored current meter on the easternmost edge of the bank with bottom depth of about 120 m gave $M_2$ amplitudes of 26 and 28 cm/sec respectively for the two velocity components (Hansen, unpubl. data).

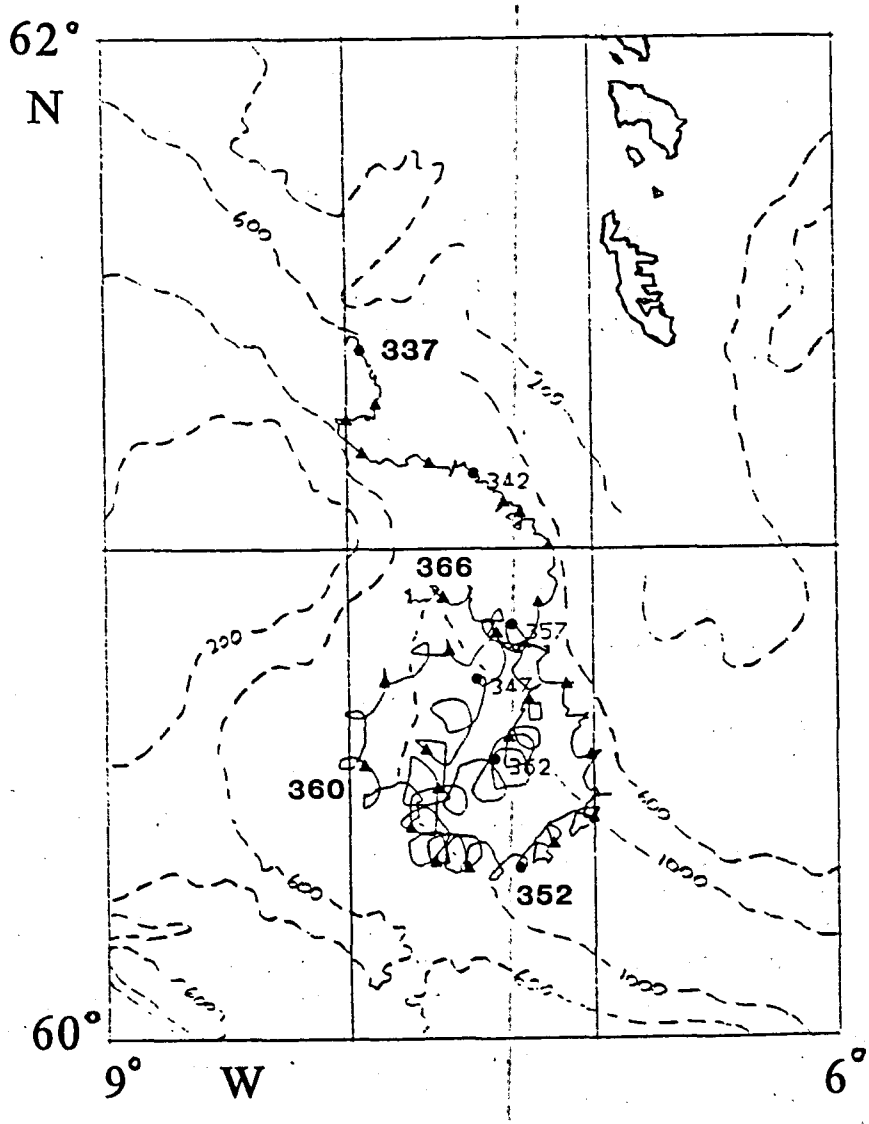


*Figure 7. Drogue 3973 during Dec.1988.*

Faroe Bank Channel Drogue 3793 was launched towards the northern exit of the Faroe Bank Channel in December 1988 (Figure 7). It travelled southwards to the region of divergent and deepening topography between the southern end of the Faroe Plateau, the Wyville-Thomson Ridge and Faroe Bank, where it made two large cyclonic circuits. Upon completing a smaller circuit in early January 1989 (Figure 8), it returned northwards in cyclonic paths which were north-going on the eastern side and south-going on the western side of the Faroe Bank Channel. Hansen (1985) has shown from temperature-salinity characteristics that there is little exchange of upper water between the Faroe-Shetland and Faroe Bank Channels, with evidence indicating that water which enters the latter at the northwestern end travels southwards along the western side of the channel and recirculates northwards along its eastern flank, and the drogue path seems entirely consistent with this analysis. Semi-diurnal tidal rotation of this drogue was anticyclonic along most of its track as on Faroe Bank. While travelling north through the Faroe Bank Channel, cyclonic paths were traced; but this could well reflect the horizontal shear across the channel rather than tidal currents. Certainly Sætre (1967) found anticyclonic tidal current ellipses in the Faroe Bank Channel using moored current meters.

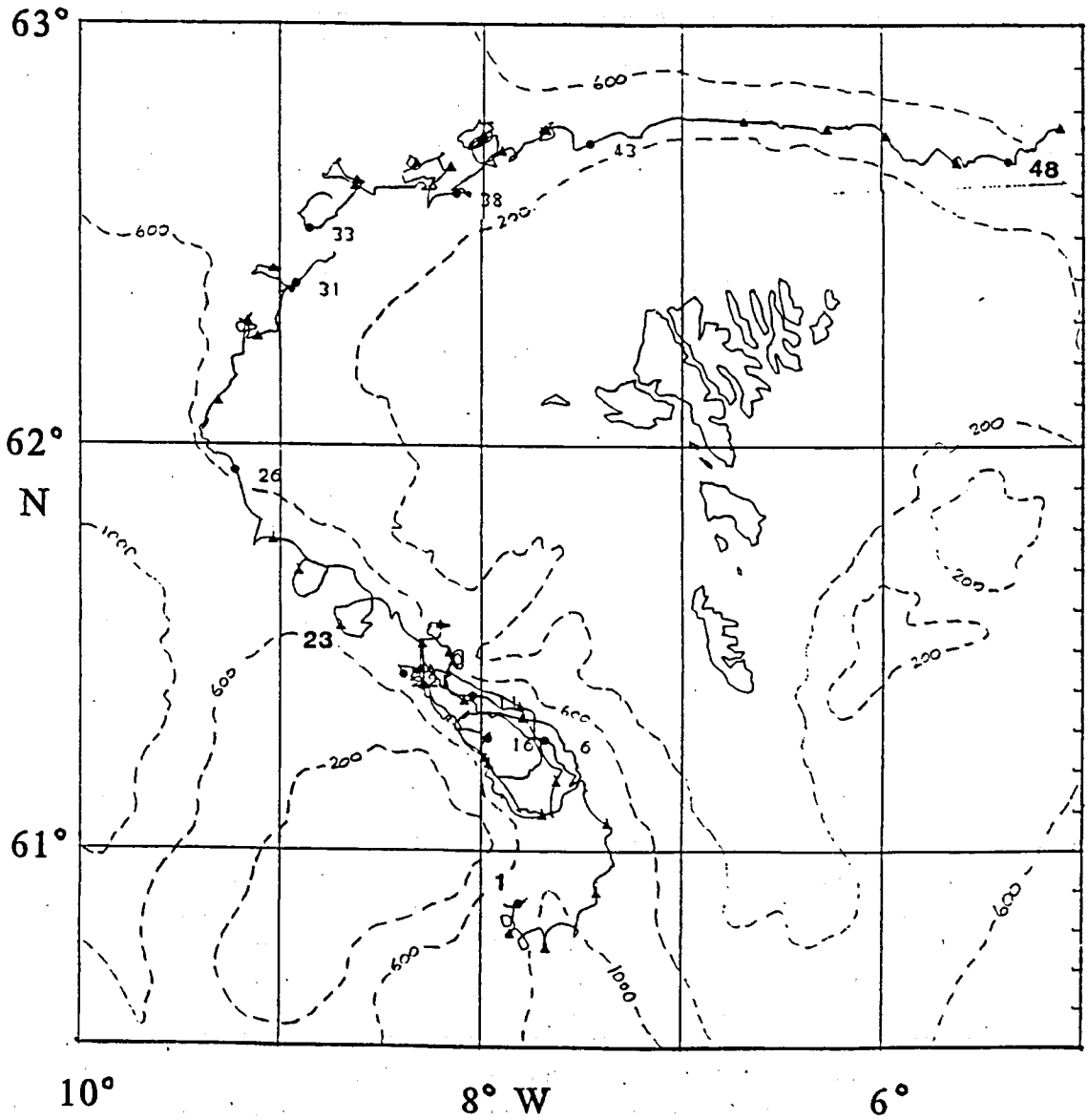


*Figure 8. Drogue 3973 during Jan.-Feb.1989.*

Faroe-Iceland Ridge Four drogue drifts investigated flow from the Atlantic to the Norwegian Sea across the Faroe-Iceland Ridge. The first of these was 3973, released in June 1987 in 62°N, 10°W, over soundings of about 750m west of the Faroe Plateau (Figure 9). This drogue moved northeastwards onto the ridge and then for a week travelled northwestwards along the 500-600m isobaths. It then moved northeastwards to the crest of the Faroe-Iceland Ridge, where it spent a further 10-12 days before moving west then north, to be recovered upon the Norwegian Sea flank of the ridge 32 days after being launched.

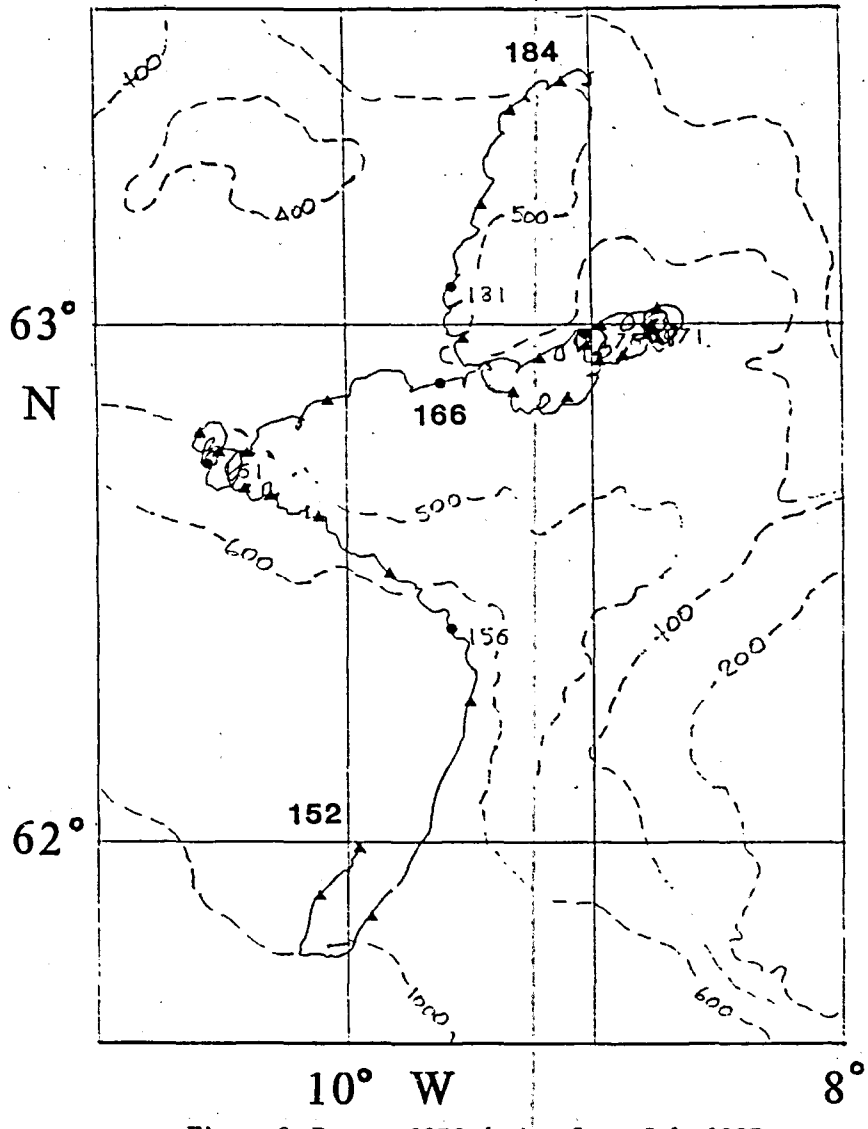


*Figure 9. Drogue 3973 during June-July 1987.*

In the following year, drogues released in 11°W showed much more reluctance to cross the ridge, spending 150-170 days upon their journeys (Figures 10 and 11). Despite spending about 40 days in June-July in the vicinity of the eastern ridge crest, drogue 3973 remained over the Atlantic flank and subsequently moved northwestwards along the 500m isobath towards the north-western low point of the ridge. Returning more slowly and irregularly to the east, it remained here until early November, when it moved northwards to spend a week in soundings of 500m on the Norwegian Sea flank of the ridge before moving more rapidly east and north into deep water. Drogue 3979, launched 30 n.ml. to the south, had a similarly protracted journey; after 60 days spent to the west of the Faroe Bank Channel, it followed the 600-800m isobaths northwestwards to the Icelandic end of the ridge where it passed a month, returning thereafter to the east and crossing the ridge-crest slowly over the course of some 14 days, after which it moved eastward into deep water.

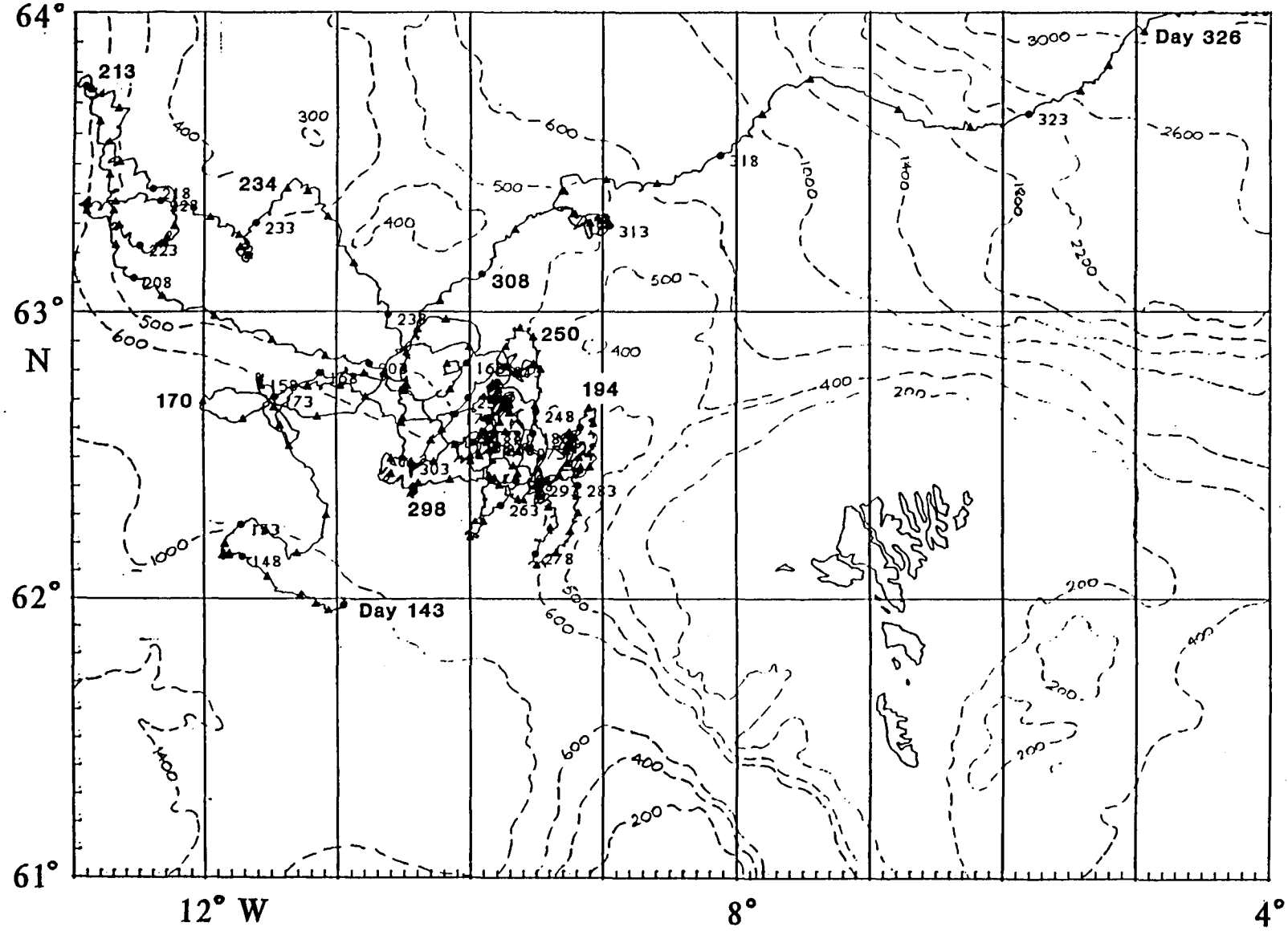


*Figure 10. Drogue 3973 during May-Nov. 1988.*

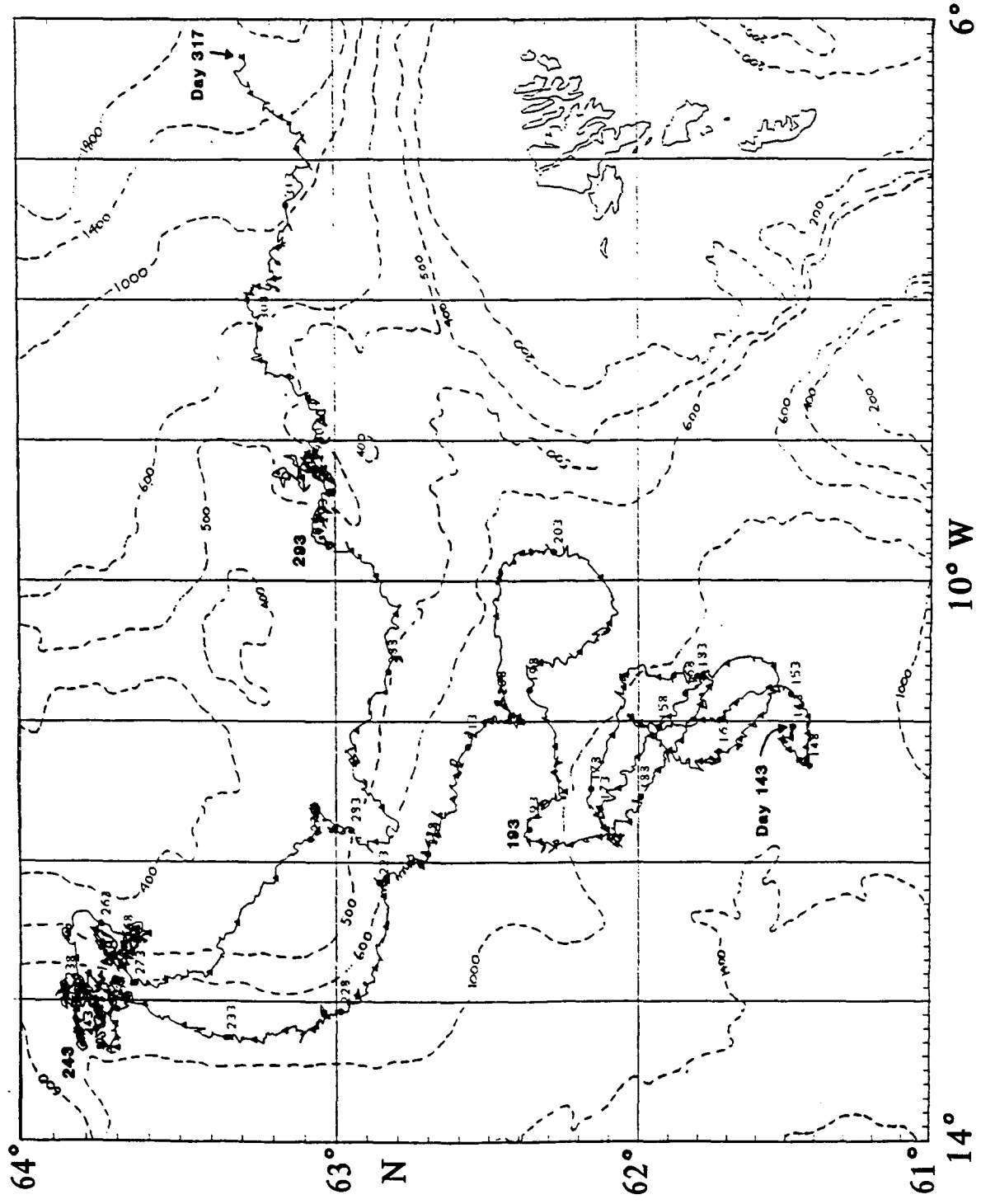


*Figure 11. Drogue 3979 during May-Nov. 1988.*

During August 1988 these two drogues were moving in opposite directions along the Atlantic side of the ridge (Figure 12).

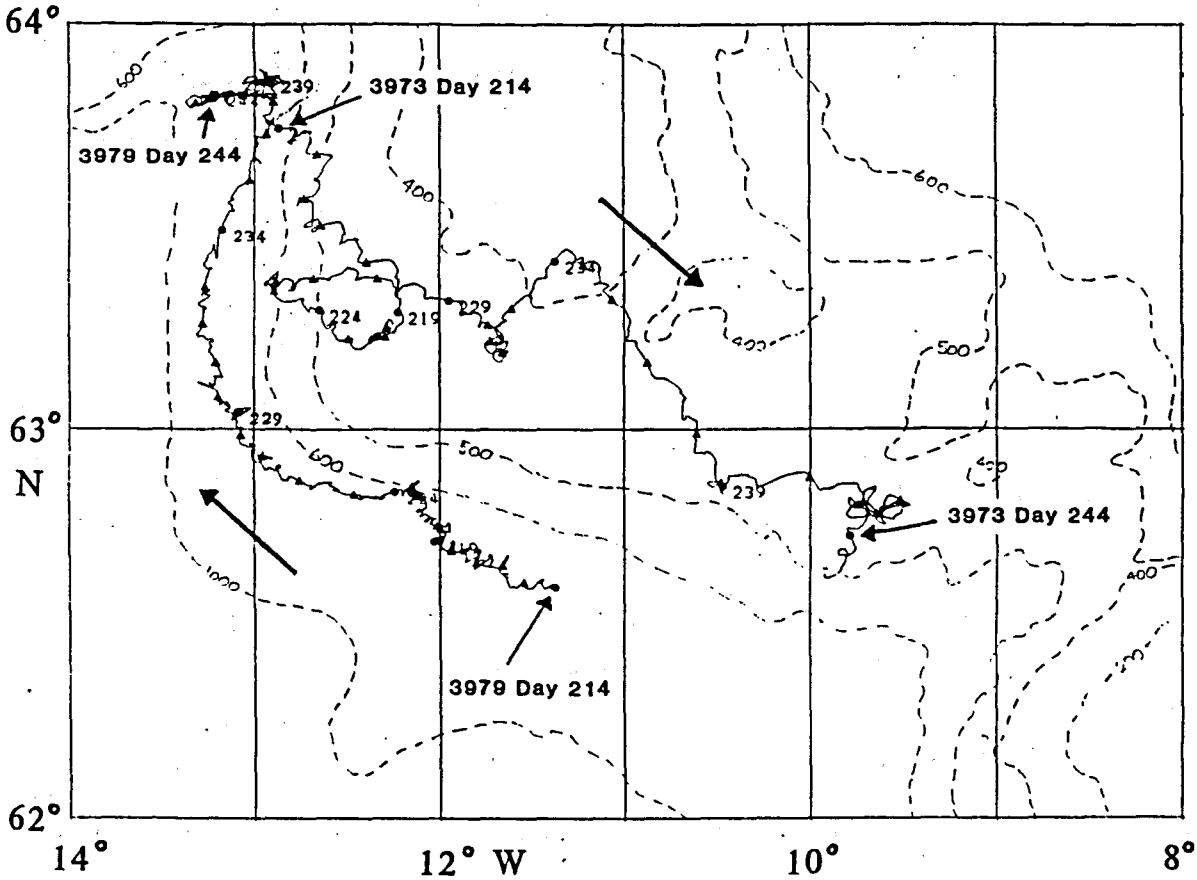


*Figure 12. Drogues 3973 and 3979 during Aug. 1987.*

The path of drogue 3973 in the Faroe Bank Channel has been described earlier. After reaching 62°N (Figure 8), it turned northwestwards and in the following 15 days crossed the ridge close to the northern Faroe Plateau slope. It continued to follow the 400m isobath until mid-February 1989. Its further path is not shown here, but it moved eastward into deeper water at the north-western entrance to the Faroe-Shetland Channel where it made two anticyclonic circuits before moving off northeastwards into the Norwegian Atlantic Current.

Thus, only the easternmost (Figure 8) of the four drogues released west of Faroe reached the Norwegian Sea by rounding the slope adjacent to the Faroe Plateau, and then only after an excursion into the westernmost Faroe-Shetland Channel. The remaining three drogues all eventually crossed the crest of the Faroe-Iceland Ridge close to 63°N, 9°30'W, where the chart of Fleischer et al (1974) shows the 500m isobath penetrating well across the ridge from a northeasterly direction. The drogue launched in 10°W showed the least diversion in its course to this crossing point, whilst those from 11°W contoured the southern slopes of the ridge in both directions before finally entering the Norwegian Sea.

Comparing the various drogue tracks, it may be noted that one drifter may cross a point on the track of a previous drogue; but continue along a quite different path. This demonstrates clearly the variability of the flow across the ridge. In spite of this variability the four drogues crossed the ridge, not at four distinct sites; but through the two channels over the ridge closest to the Faroes.

## ACKNOWLEDGEMENTS

The two buoys and satellite transmitters were kindly provided by the UK Department of Energy, after use in earlier DML drogue tracks. The recovery of drogues under often bad weather conditions requires exceptional eyesight and experience for which the authors want to compliment the crew of the Magnus Heinason.

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