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# An Application of Satellites and Remote Sensing to Studies of Surface Circulation in NAFO Subareas 3 and 4

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## I INTRODUCTION

Several projects supported by the Bedford Institute of Oceanography utilized satellite tracked drifting buoys in the 1979-80 period. In this document we describe some of the results from these projects, in order to demonstrate the valuable role that this particular technology can play in studying physical processes within the NAFO area.

As part of a more comprehensive oceanographic study off the Southwestern Scotian Shelf, 6 drogued buoys were released between August 1979 and January 1980. Comparison of buoy movements with the sea surface temperature patterns, derived from Satellite IR data and produced as weekly maps by the U.S. Naval Oceanographic Office Experimental Analysis, showed remarkably close agreement.

In conjunction with an oil monitoring program subsequent to the breakup of the "Kurdistan" in March 1979 in Cabot Strait - undrogued buoys were launched on the eastern Scotian Shelf and in an area about 100 miles south of Sable Island in the period May to August, 1979. The buoys were designed to track the residual movement of the water at and very near to the sea surface thereby simulating as closely as possible the movement of any bunker-C oil present in the area.

As part of the program of the NAFO Flemish Cap Experiment, a set of 6 satellite-tracked drifting buoys were released on Flemish Cap between June, 1979 and May, 1980 in order to shed more light on the circulation and residence time of water on the Cap.

## II BUOYS AND DATA

### (a) Buoys

The buoys, manufactured by Hermes Electronics, Dartmouth, Nova Scotia, were fitted with Handar transmitters and operated within the TIROS-ARGOS system. The buoys employed off Southwestern Nova Scotia and on Flemish Cap were fitted with a 2M x 8M window shade type drogue centered at about 6M depth (Fig. 1). The buoys released during the oil monitoring program were modified and launched without a drogue in order to simulate more closely the movement of the water within the upper fraction of a meter of the water column. All of the buoys were fitted with surface temperature sensors, and some with a sensor to detect whether the drogue was still attached. The buoys transmitted data at about one minute intervals, but data could only be received by the satellite when it was "in sight". In most instances about 7-10 buoy "fixes" were obtained daily. The buoys were designed to function for at least 12 months. In most instances they continued to transmit beyond this period provided they had not drifted ashore or were recovered by ship.

### (b) Data processing

The projects are in various stages of completion. Data received from Service ARGOS in the form of magnetic tapes and computer listings were checked for obvious errors. For the Southwestern Nova Scotia project buoy trajectories were plotted using all position fixes, and labelling at 5-day intervals. For the Flemish Cap project the arithmetic mean of all positions and temperatures were calculated over twelve-hour intervals. For the oil monitoring project buoy trajectories used all position fixes from the ARGOS system, symbols at two-day intervals at 1200 hrs GMT were added by linear interpolation, and surface winds were estimated at six offshore sites from pressure maps (Lawrence and Galbraith, 1980) and a spatial interpolation used at each six-hour time step.

## III RESULTS AND DISCUSSION

### (a) Southwestern Scotian Shelf

The location of 3 buoys released in August and the subsequent drift until mid-December for two of them is shown in Figure 2. Buoy 1302, released on Brown's Bank, left the shelf about one month later, and was caught in an eddy for the following month before being ejected and caught into the Gulf Stream and carried eastward. Buoy 1303, during the same period, moved slowly and erratically east-northeastward, eventually grounding on Sable Island in mid-December. Buoy 1304 (track not shown), remained on the Shelf for about 2 months before leaving and looping around the eddy that 1302 had been in earlier, then moving westward, making one loop around another eddy before entering the Gulf Stream.

Comparisons of buoy movements in the offshore area with surface features identified on the U.S. Navy Oceanographic Experimental Ocean Frontal Analysis Maps are particularly instructive. These maps, constructed from available satellite IR imagery and sea surface temperature observations by ships were prepared weekly. An extract of 4 of these is shown in Figure 3. Additionally, the buoy trajectories for the corresponding week are also plotted. In Fig. 3 (A) buoy 1302 has just left the Shelf and is moving rapidly eastward. This movement evidently is responding to a large Gulf Stream meander which appears to be entraining shelf water. In the following week the buoy moved in a complete circle suggesting that a Gulf Stream eddy had formed. It was not until the subsequent week that the eddy was identified as G-79 (Fig. 3 (B)) and the buoy had nearly completed another circuit of the eddy. The thermal map shows a large forked-tongue of cold shelf water extending southward from the Nova Scotia coastline and being entrained by both eddy G-79 as well as a new eddy (H-79) in the process of forming to the west of G-79. Although the area of interest is frequently covered or partly covered by cloud the TIROS-N IR picture of 28 September is particularly striking (Fig. 4 (A)). While the coldest shelf water present is just south of Cape Sable, cold shelf water is clearly continuous all the way from the Nova Scotia coastline to eddies G and H. Of interest as well is the surface penetration of Slope Water into Northeast Channel separating Georges Bank and Brown's Bank and extending onto both banks. By 7 October buoy 1304 was drawn off the Shelf under the influence of eddies G & H which were nearly stationary geographically. On 11 October buoy 1302, which had made 5 circuits of eddy G in the previous 28 days (Fig. 2), left the eddy. During the 14-20 October period, it moved rapidly (1 knot) southeastward very close to the northern edge of the Gulf Stream, while buoy 1304 commenced to circle eddy G. It did not however, become trapped by this eddy but rather continued to move westward (Fig. 3 (D)) and subsequently made one circuit around eddy H.

During the period 21-27 October, eddies H and I were both having a major effect on the Shelf surface waters of Georges Bank. Buoy 0620, which one would have expected to have moved south and southwestward on the eastern part of Georges Bank, instead moved eastward, and off the bank, evidently under the influence of eddy H. Interestingly, buoy 1301 located less than 20 miles to the north of 0620 appeared not to be moving in response to eddy H, but continued with a slow clockwise motion on the bank. (Fig. 3 (D)). Eddy I was producing an even more dramatic effect on Georges Bank water. Buoy 0703 moved rapidly southward passing by eddy I on its eastern side. A NIMBUS 6 IR picture of 22 October (Fig. 4 (B)) clearly shows a large tongue of Georges Bank water extending well out to sea on the eastern side of eddy I.

The presence of an eddy near the Shelf break does not in itself enable one to say that there will be significant excursions of water either onto or off the Shelf. Neither does the buoy data nor the IR thermal patterns tell us how deep a layer is involved in these offshore excursions. However, a current meter mooring on the Scotian Shelf near the Shelf break in August 1976 revealed major offshore excursions were taking place to at least 50M depth when eddy Q was present off the Shelf (Smith, 1979). From the thermal maps it appears that the eddies more frequently tend to extract surface waters from the Shelf rather than injecting Slope Water onto the Shelf. At greater depths, however, the reverse may be the case, since Slope Water is known to invade the deeper channels of the Shelf. It is yet to be determined whether or not the eddies play the dominant role in forcing these shoreward excursions.

(b) Oil Monitoring Releases

i. Inshore: Five deployments were made southeast of Cape Breton Island in the May-August period of 1979. On days 142 and 162 the release position was about 65 km from the coast and on days 201, 212, and 243 the release position was about 30 km from the coast. The subsequent drifts of two of these buoys are shown in Figures 5 and 6. Since the wind is known to produce surface drift at a speed of about 3% of the wind, the 3% of wind trajectories are also shown. In the days following 142, the wind trajectory moved west and north while the buoy moved northeast (Fig. 5). This suggests that there was a strong non-wind induced underlying flow to the southeast. The deployment on day 162 (Fig 6) also moved east-northeastward and eventually by day 210 had passed to the east of Cape Race. For the period from day 166 to 182, the buoy motion appeared to be mainly determined by the underlying current. For the period after day 182 only a slight rotation of the wind vectors ($20^{o}$ - $25^{o}$ clockwise) was enough to give good agreement between buoy and wind tracks.

ii. Offshore: To monitor possible oil slick movement, buoys were deployed on days 131, 146, 182 and 243 at the deepwater site where the Kurdistan bow section was sunk (42°N, 61°W, 4000M depth).

The first buoy moved northward in good agreement with the rotated (20° clockwise) wind, with an indication of underlying current only on a few days while crossing the shelf break (Fig 5). The second buoy (not shown) stayed in deep water, moving slightly northward under the influence of light winds, and a southwest current. The third buoy (See Fig. 6, day 182) moved generally eastward, with currents giving one major excursion loop southward and several minor ones northward. These currents are related to the Gulf Stream. Examination of the Ocean Frontal Analysis maps showed a strong loop in the Gulf Stream developed during days 168-174 and by days 182-188 had moved east to the longitude of the buoy. In response, the Shelf-Slope water boundary showed a very strong offshore movement. The surface water temperature measured by the buoy dropped from 17° to less than 15° C for two days. Between days 198 and 232 the wind and buoy trajectories have a similar resultant direction. The final buoys at both sites, deployed on day 243, were left in the water until they eventually drifted east out of the area of interest. One of the buoys (not shown) moved eastward to the Laurentian Channel and down to the Shelf break. Here it encountered currents that held it nearly stationary (days 274-287) then moved it southward (days 287-293) into deeper water. In deep water, both buoys followed the wind drift until about day 320 when they both appeared to encounter currents at the edge of the Grand Banks. Both were pushed as far south as 42°N before resuming an easterly course and rounding the tail of the Grand Banks.

(c) Flemish Cap

The drift tracks for six buoys released on Flemish Cap are shown in Figure 7. Buoys 2421 and 2426 were released in January 1979 and described a very slow, clockwise track around the shallowest part of the cap before being ejected in late February into the North Atlantic Current. At the time of ejection there was a strong, northerly wind that supposedly pushed the surface water to the south.

Buoys 2422 and 2425 were deployed in the latter half of March, 1979. Buoy 2422 took a very sluggish trajectory to the northwest until reaching the 400m isobath, at which point it picked up speed and proceeded clockwise around the northern and eastern flanks of the cap before being caught in the North Atlantic Current. There does not appear to be any drastic response to any strong meteorological forcing during its 72 days in the vicinity of Flemish Cap. Buoy 2425 described a very slow motion from the centre of the cap, eventually moving to the southeastern flank and then turning west before being caught up in the North Atlantic Current.

In early July 1979 buoy 2428 was launched in the central cap area. After several days of very little motion it proceeded west and got caught in the influence of the southward flowing Labrador Current. It was then blown to the east and moved back north to Flemish Cap in the region of mixed Labrador and North Atlantic Current waters. It moved eastward across the southern flank of the cap and was then carried away by the North Atlantic Current.

Buoy 2433 was deployed in late May, 1980. It described a clockwise motion around the shallow area before exiting into the North Atlantic Current.

The six trajectories present here represent residence times in the vicinity of Flemish Cap of 32 days to 72 days with an average of 50 days. The speeds observed were consistently less than 10 $cm \cdot s^{-1}$ while over Flemish Cap compared to more than 200 $cm \cdot s^{-1}$ when in the North Atlantic Current. Although each drifter track was unique, the composite results confirm the existence of a very sluggish, anticyclonic circulation around the interior of Flemish Cap. This is reinforced by data from three moored current meter records collected during the first half of 1979 (Ross, 1980). Noteworthy is the fact that all buoys exited from the cap in the southeastern quadrant where they joined the North Atlantic Current and were advected out of the region. Buoys drifting near the centre of the cap do appear to be influenced by strong meteorological forcing but it appears difficult to predict the individual tracks from a simple analysis of winds.

## IV SUMMARY

The application of satellite technology both through tracking drifting buoys and IR imagery of the sea surface is proving extremely valuable in developing a more realistic picture of oceanographic processes. The possibility of providing near-real time data is also of added value in operational applications such as tracking oil slicks, or in fisheries studies where one may wish to track or relocate larval patches.

## V. ACKNOWLEDGEMENTS

The authors wish to thank: EG&G, Environmental Consultants for permission to use buoy data taken on Georges Bank as part of a Bureau of Land Management Study of the New England Outer Continental Shelf; the U.S. Navy Oceanographic Office for use of the Experimental Ocean Frontal Analysis charts; and the Canadian Coast Guard for financial and operational support for the buoys used in the oil monitoring.

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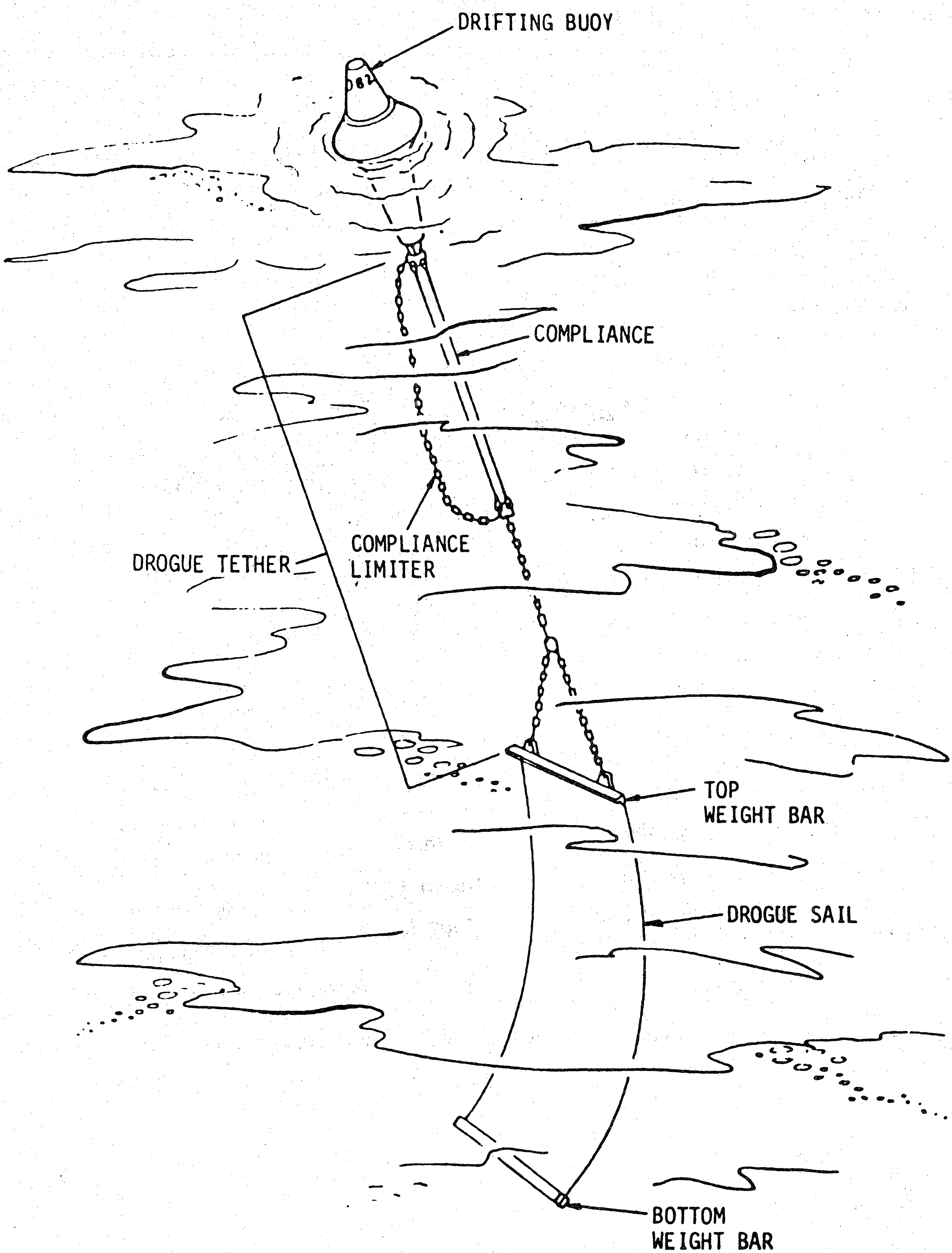


Figure 1 Schematic diagram of a drogued drifting buoy.

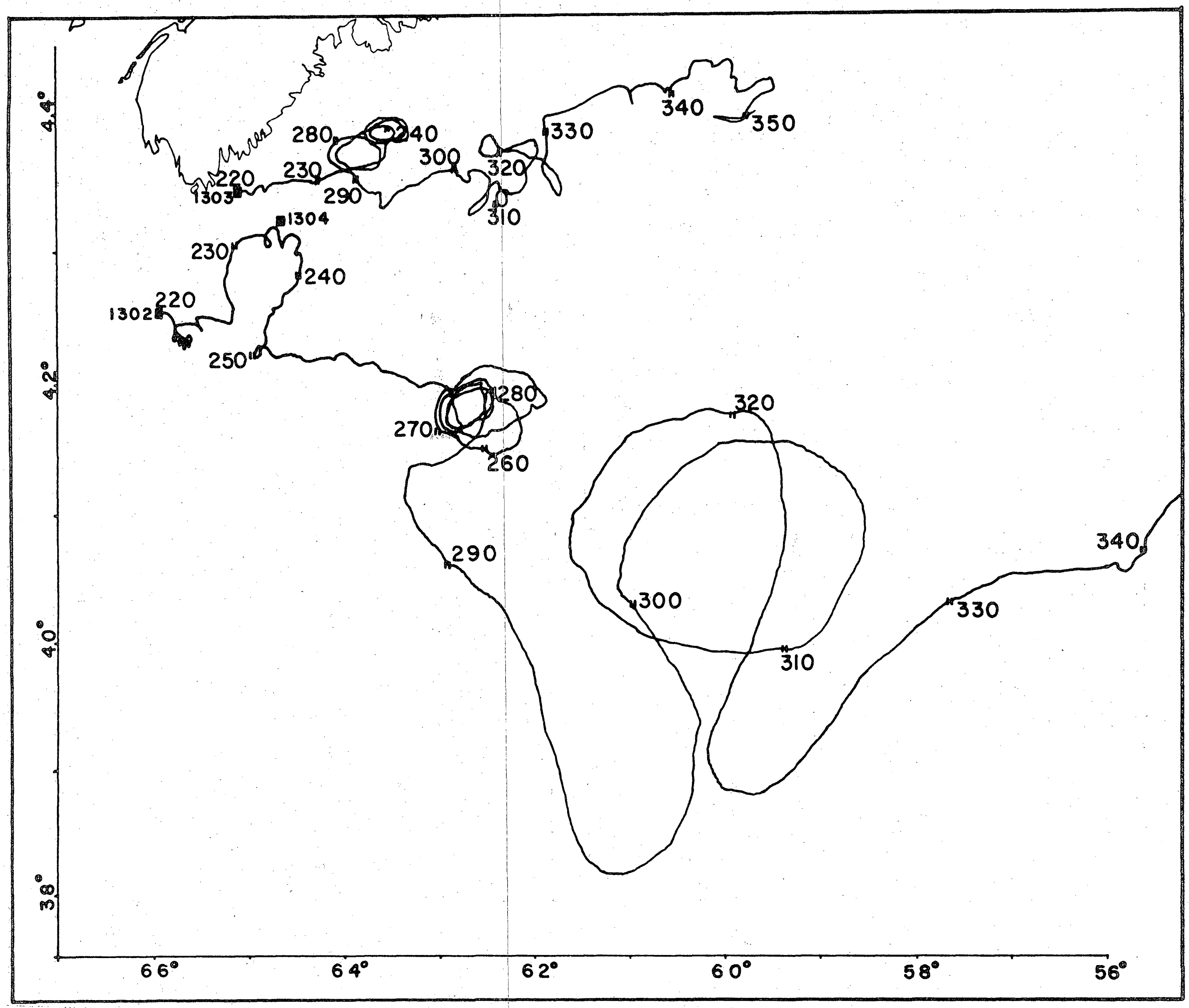


Figure 2 Map showing the location of three buoys released on the Southwestern Scotian Shelf on 8 August 1979 (day 220), together with the trajectories of two of them (#1302 and 1303) until mid December.

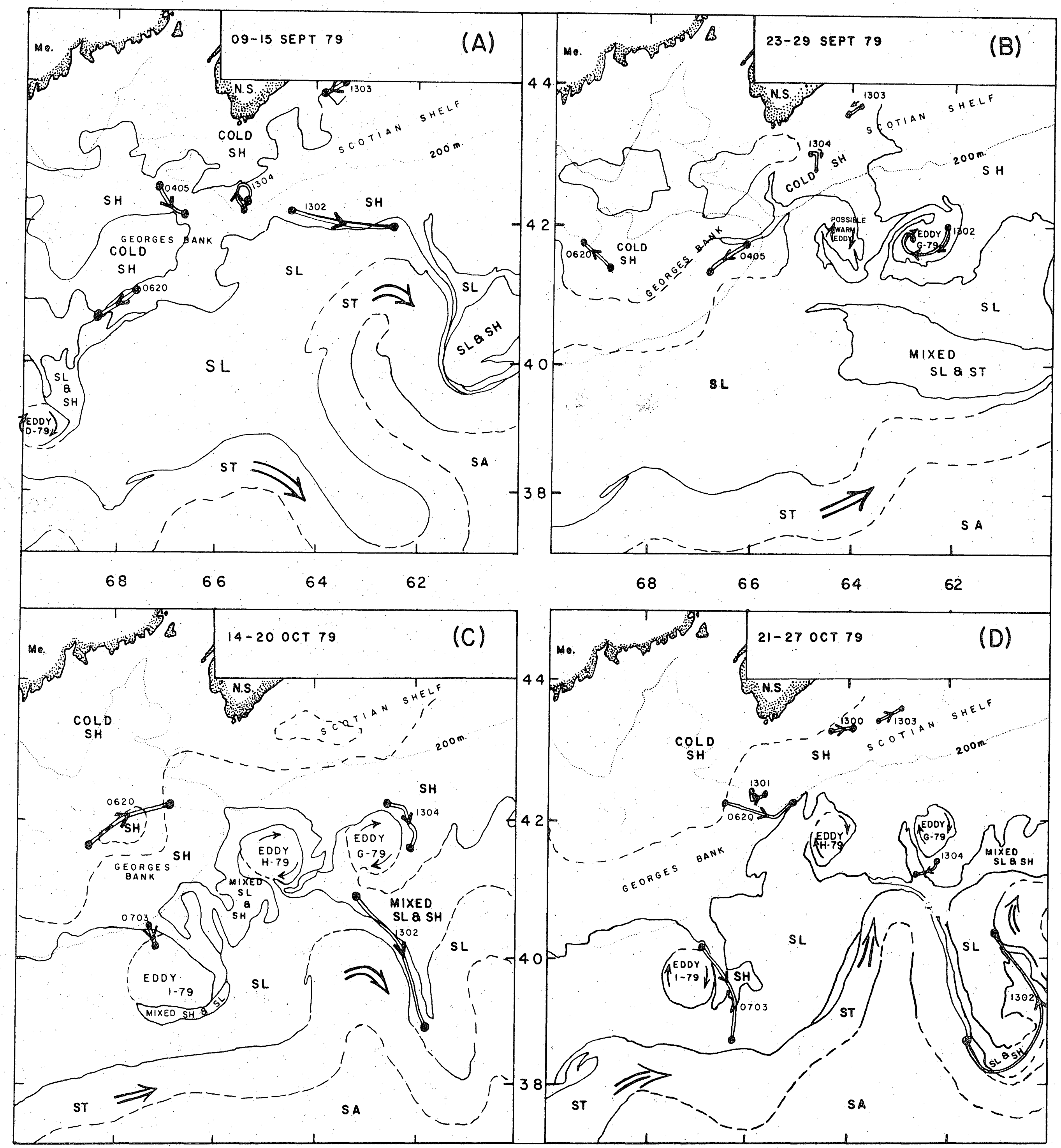


Figure 3 Maps showing surface thermal features for weekly periods as extracted from the U.S. Naval Oceanographic Experimental Ocean Frontal Analysis Charts: (A) 09-15 Sept 1979, (B) 23-29 Sept 1979, (C) 14-20 Oct 1979, and (D) 21-27 Oct 1979. Key for water types: SA = Sargasso, ST = Gulf Strea, SL = Slope Water, SH = Shelf water, and COLDSH = Cold Shelf water. Approximate trajectories of buoys for each 7 day period are also shown.

A B

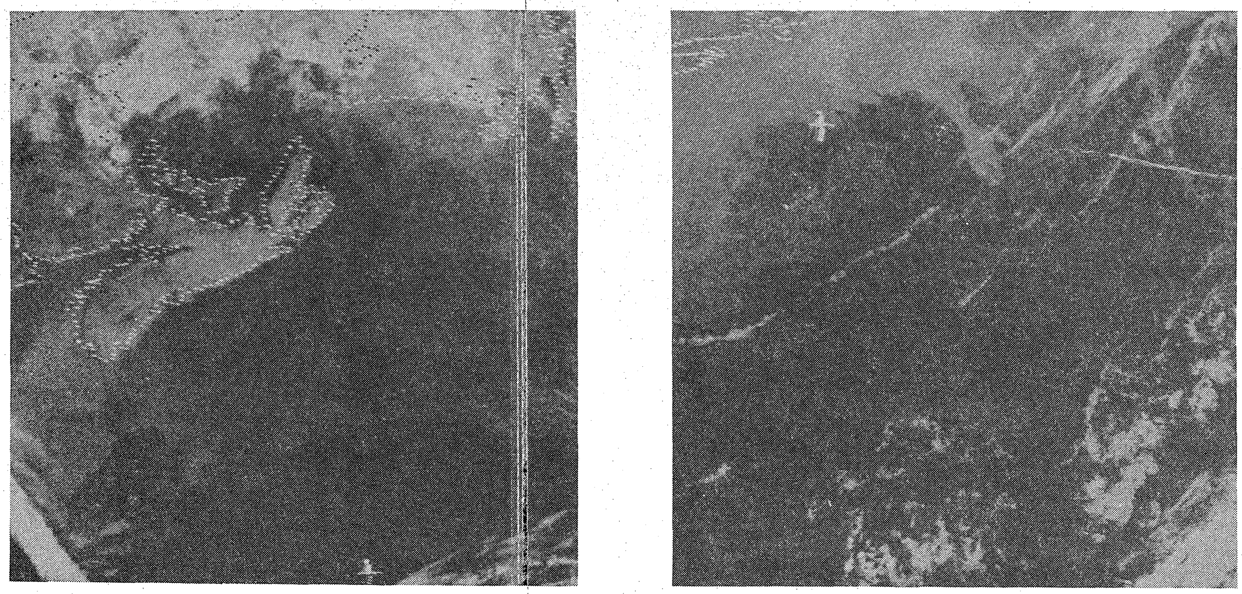

Figure 4 (A) TIROS N infrared picture taken 28 Sept 1979 showing Eddies G-79 and H-79 and the Cold Shelf water (lighest colour) extending from the Cape Sable area to the Eddies. (B) NIMBUS 6 - infrared picture taken 22 Oct 1979 showing large tongue of Georges Bank Shelf water extending southeastward along the eastern side of Eddy I-79.

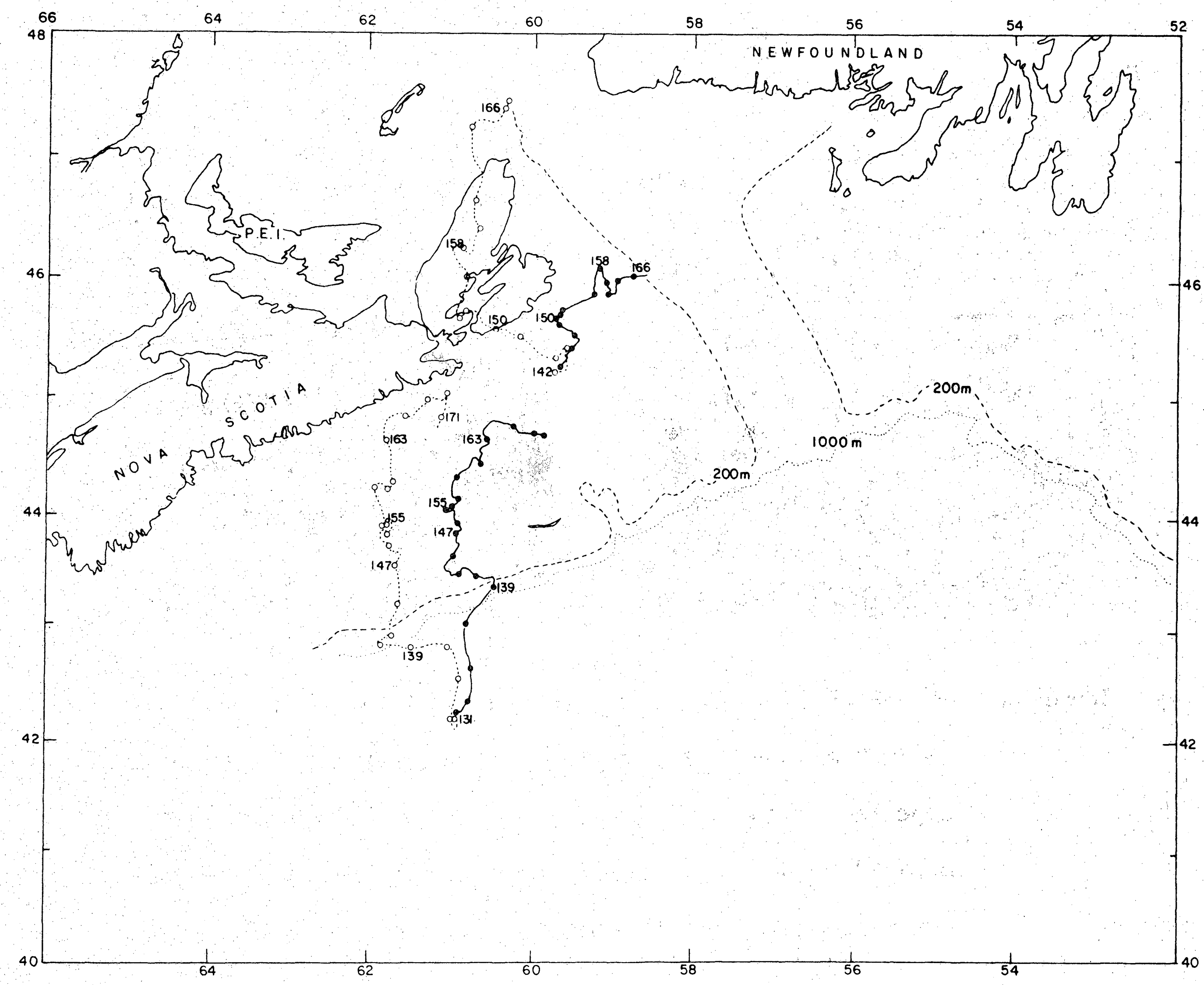


Figure 5 Buoy tracks (solid lines) for buoys released on 11 May (day 131) and 22 May 1979 (day 142). Dotted lines are the estimated wind drift trajectories for corresponding buoy drift period, using a 3% factor to simulate surface water drift.

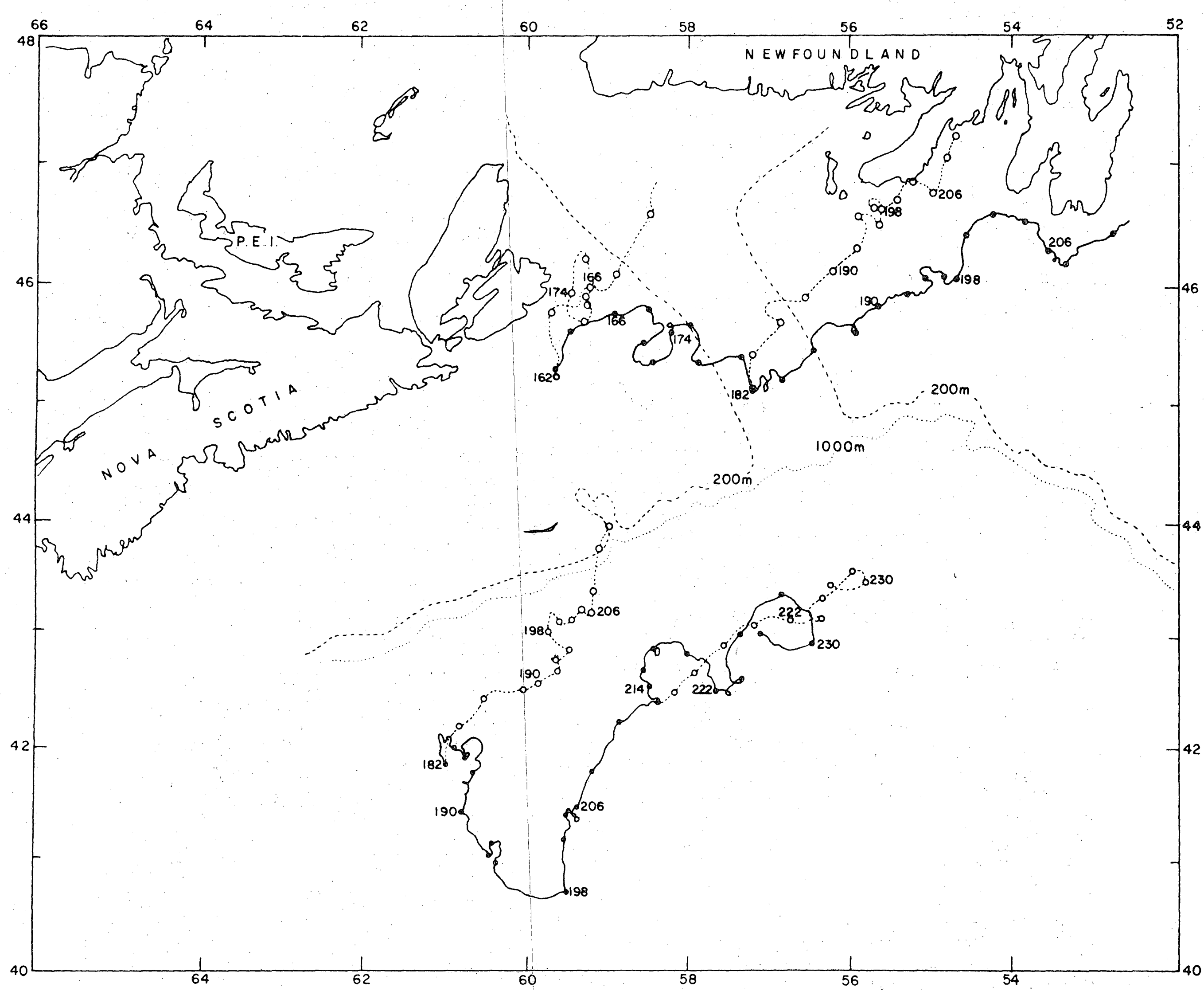


Figure 6 Buoy tracks (solid lines) for buoys released on 11 June (day 162) and 30 July 1979 (day 181). Dotted lines are the estimated drift trajectories for corresponding buoy drift period, using a 3% factor to simulate surface water drift.

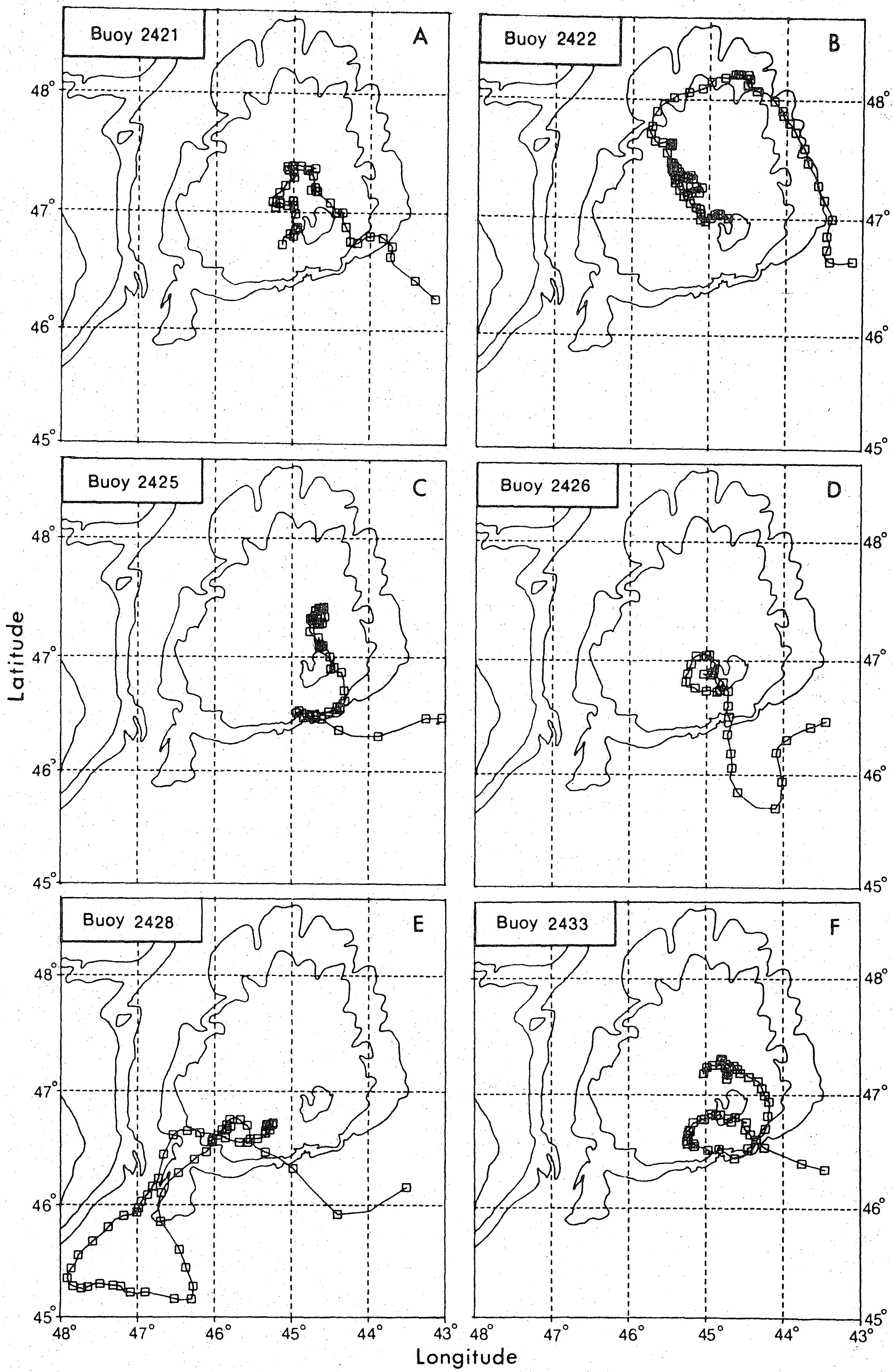


Figure 7 Drift tracks of six buoys released on Flemish Cap during 1979-80 with symbols plotted at 24-hour intervals.