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An Application of Satellites and Remote Sensing to Studies of Surface Circulation off Eastern Canada

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Abstract

The application of satellite technology both through tracking drifting buoys and providing infrared imagery of the sea surface is proving extremely valuable in developing a better understanding of oceanographic processes. The provision of near real-time data is also of added value in operational applications such as tracking oil slicks or in fisheries studies such as tracking near-surface concentrations of fish larvae.

Introduction

Several projects supported by the Bedford Institute of Oceanography utilized satellite-tracked drifting buoys during 1979 and 1980. As part of a comprehensive oceanographic study off the southwestern Scotian Shelf, six drogued buoys were released between August 1979 and January 1980 and their movements compared with sea-surface features derived from satellite infrared data and produced as weekly maps by the US Naval Oceanographic Office. In conjunction with an oil-monitoring program subsequent to the breakup of a tanker in March 1979 in Cabot Strait, undrogued buoys were released during May–August 1979 on the eastern Scotian Shelf and in an area about 180 km south of Sable Island. These buoys were designed to track the residual movement of the surface water, thereby simulating as closely as possible the movement of any bunker-C oil present in the area. As part of the NAFO Flemish Cap Experiment, six drogued buoys were released on Flemish Cap between June 1979 and May 1980 in order to shed more light on the circulation and resident time of water in the area. Some of the results of these projects are described in this paper, in order to demonstrate the valuable role that remote-sensing technology can play in studying physical oceanographic processes in the NAFO area.

Buoys and Data

The buoys, manufactured by Hermes Electronics, Dartmouth, Nova Scotia, Canada, were fitted with Handar transmitters and operated within the TIROS-ARGOS satellite system. The buoys employed off southwestern Nova Scotia and on Flemish Cap were each fitted with a 2 m x 8 m windowshade-type drogue centered at a depth of about 6 m (Fig. 1). The buoys used during the oil-monitoring program were modified and released without drogues in order to closely simulate the movement of water in the upper few centimeters of the water column. All of the buoys were fitted with surface temperature sensors and some had a sensor to detect if 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, 7–10 buoy positions were obtained daily. The buoys were designed to function for at least 12 months. Generally they transmitted beyond that period, provided they had not drifted ashore or were recovered.

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 transmitted positions with labelling at 5-day intervals. For the Flemish Cap project, the arithmetic mean of all positions and temperatures were calculated over 12-hour intervals. For the oil-monitoring project on the eastern Scotian Shelf, buoy trajectories were plotted using all positions, symbols at 2-day intervals at 1200 hr (GMT) were added by linear interpolation, and surface winds were estimated at six offshore sites from pressure maps (Lawrence and Galbraith, 1980) with spatial interpolation at each 6-hour time step.

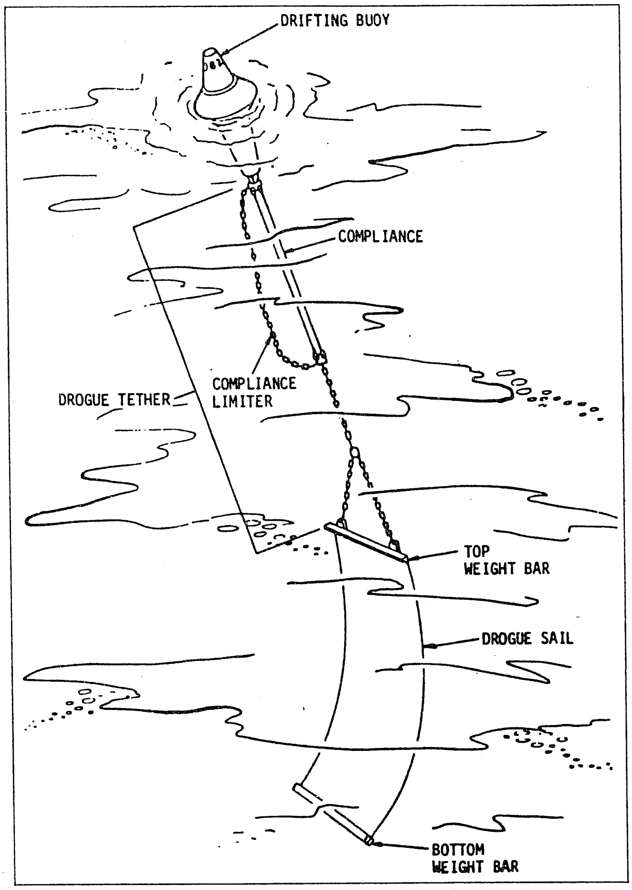

Fig. 1. Schematic diagram of a drogued drifting buoy.

Results and Discussion

Southwestern Nova Scotia project

The location of three buoys released in August 1979 and subsequent drift until mid-December for two of them are shown in Fig. 2. Buoy 1302, released on Browns Bank, left the shelf about a month later and was caught in an eddy for the following month before being ejected into the Gulf Stream and carried eastward. During the same period, Buoy 1303 moved slowly and erratically east-northeastward and eventually grounded on Sable Island in mid-December. Buoy 1304 (track not shown) remained on the shelf for about two months before leaving and looping around the eddy which buoy 1302 had been in earlier. It then moved 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 frontal analysis maps produced weekly by the U. S. Navy Oceanographic Office are particularly instructive. These maps are constructed from available satellite infrared imagery and sea-surface temperature observations by ships. Extracts of four of these maps, with plotted buoy trajectories for the corresponding weeks, are shown in

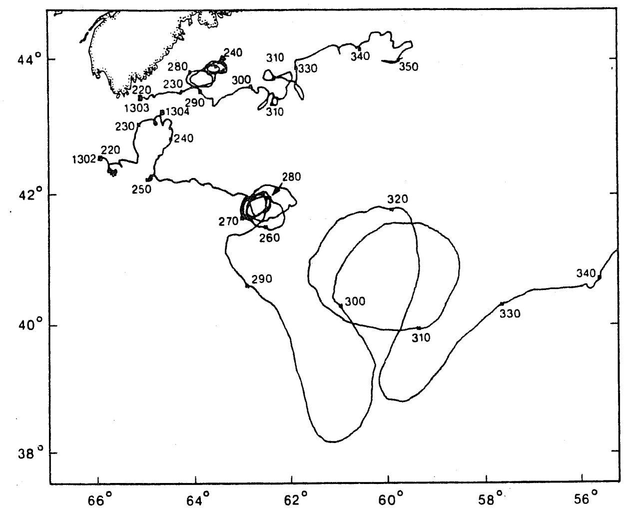

Fig. 2. Locations of two buoys (1302 and 1303) released on the southwestern Scotian Shelf on 8 August 1979 (day 220) and their trajectories until mid-December.

Fig. 3. In Fig. 3A, buoy 1302 had just left the Scotian Shelf and moved rapidly eastward. This movement evidently was responding to a large Gulf Stream meander which appeared to be entraining shelf water. In the following week, the buoy moved in a complete circle, indicating that a Gulf Stream eddy had formed. It was not until the subsequent week that the eddy was identified as G-79 (Fig. 3B) and the buoy had nearly completed another circuit. 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 and 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 clouds, the TIROS-N infrared picture of 28 September 1979 is particularly striking (Fig. 4A). While the coldest shelf water present is evident just south of Cape Sable, cold water clearly extended all the way from the Nova Scotia coastline to eddies G and H. Of interest also was the penetration of Slope Water into the Northeast Channel between Georges Bank and Browns Bank and onto both banks. By 7 October, buoy 1304 had moved off the shelf under the influence of eddies G and H, which were nearly stationary geographically. On 11 October, buoy 1302, which had made five circuits of eddy G in the preceding 28 days (Fig. 2), left the eddy and moved rapidly (1 knot) southeastward during 14–20 October very close to the northern edge of the Gulf Stream. Meanwhile, buoy 1304, which commenced to circle eddy G, did not become trapped by this eddy but rather moved westward (Fig. 3D) and subsequently made one circuit of eddy H.

During 21–27 October, eddies H and I had a major effect on the surface waters of Georges Bank. Buoy 0620, which had been expected to move southward and southwestward along the eastern part of Georges Bank, actually moved eastward off the bank, evidently

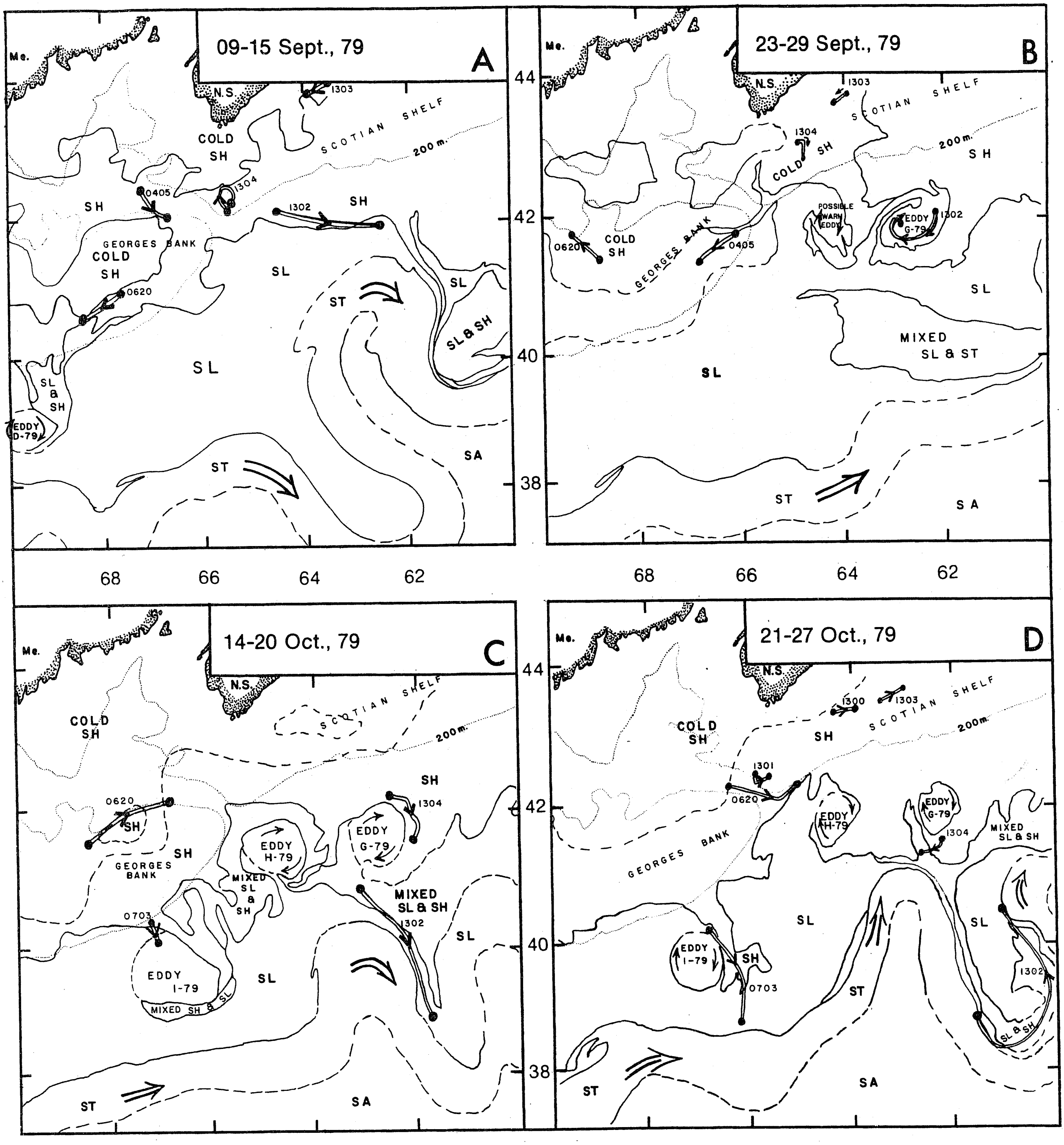

Fig. 3. Maps showing surface thermal features for weekly periods in 1979, extracted from the U. S. Naval Oceanographic Experimental Ocean Frontal Analysis Charts. **A**, 9-15 September. **B**, 23-29 September. **C**, 14-20 October. **D**, 21-27 October. (Key for water types: SA = Sargasso Sea; ST = Gulf Stream; SL = Slope Water; SH = shelf water; COLDSH = cold shelf water. Approximate trajectories of buoys for each 7-day period are also shown.)

under the influence of eddy H. Interestingly, buoy 1301, located less than 35 km to the north of buoy 0620, was apparently not under the influence of eddy H, as it continued a slow clockwise motion on the bank (Fig. 3D). Eddy I produced an even greater effect on Georges Bank water, as buoy 0703 moved rapidly southward passing the eddy on its eastern side. A NIMBUS-6 infrared picture on 22 October (Fig. 4B) clearly shows a large tongue of Georges Bank water extending seaward on the western side of eddy I.

The presence of an eddy near the edge of the shelf does not in itself imply that there will be significant excursions of water either onto or off the shelf, nor does the buoy data or the infrared thermal patterns indicate how deep a water layer is involved in these

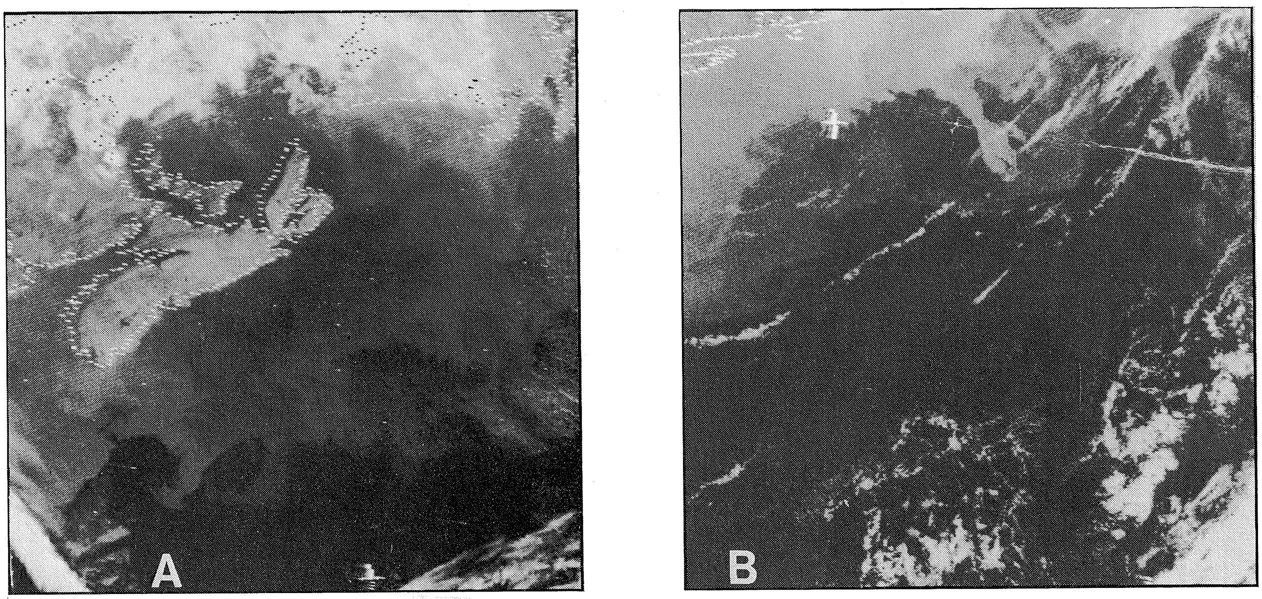

Fig. 4. Satellite infrared images. **A**, TIROS-N picture on 28 September 1979 showing eddies G-79 and H-79 and the cold shelf water (light color) extending from the southern tip of Nova Scotia to the eddies. **B**, NIMBUS-6 picture on 22 October 1979 showing a large tongue of Georges Bank shelf water extending southeastward along the eastern side of eddy I-79.

offshore excursions. However, a current meter moored near the edge of the Scotian Shelf in August 1976 revealed major offshore excursions at least to a depth of 50 m when eddy Q was present off the shelf (Smith, 1979). From the thermal maps, it appears that eddies tend to extract surface water from the shelf more frequently than they inject slope water onto the shelf. However, the reverse may be the case at greater depths, because Slope Water is known to invade the deeper channels of the shelf, but it has yet to be determined if eddies play a dominant role in forcing these shoreward incursions.

Oil-monitoring studies

Inshore. Five buoys were deployed southeast of Cape Breton Island in May–August 1979. The movements of two of these buoys released about 65 km from the coast on 22 May (day 142) and on 11 June (day 162) are shown in Fig. 5. Since wind is known to produce surface drift at a speed of about 3% of the wind, the 3% wind trajectories are also shown. The buoy released on day 142 moved northeastward, whereas the wind trajectory initially moved westward and then northward (Fig. 5A). This indicated that there was a strong non-wind induced underlying flow to the southeast. The buoy released on day 162 (Fig. 5B) also moved northeastward initially and then continued eastward passing Cape Race, Newfoundland, by day 210. Buoy motion appeared to be mainly determined by the underlying current during the period from day 166 to day 182. After day 182, only a slight rotation of the wind vectors (20°–25° clockwise) was enough to give good agreement between buoy and wind tracks.

Offshore. To monitor possible oil slick movement in 1979, buoys were deployed on 11 May (day 131), 26 May (day 146), 1 July (day 182) and 31 August (day 243) at the site (42°N, 61°W) where part of a tanker was sunk in 4,000 m. The first buoy (day 131) moved northward in good agreement with the rotated (20° clockwise) wind trajectory, the effect of the underlying current being evident only during a few days as the buoy crossed the edge of the shelf (Fig. 5A). The second buoy (day 146, not shown) stayed over deep water, moved slightly northward under the influence of light winds and a southward current. The third buoy (day 182) moved generally eastward, exhibiting a major southward excursion loop and several minor ones northward (Fig. 5B). These currents are related to the Gulf Stream. Frontal analysis maps of the U. S. Navy Oceanographic Office showed the development of a strong Gulf Stream loop during days 168–174 which had moved eastward to the longitude of the buoy by days 182–188. In response, the shelf-Slope Water boundary showed a very significant offshore movement. The surface water temperature, measured by the buoy, decreased from 17° to less than 15°C for 2 days. For day 198–232, the wind and buoy trajectories have a similar resultant direction.

Two buoys (not shown) released on 31 August (day 243), one about 35 km southeast of Cape Breton Island and the other at the offshore site, were left in the

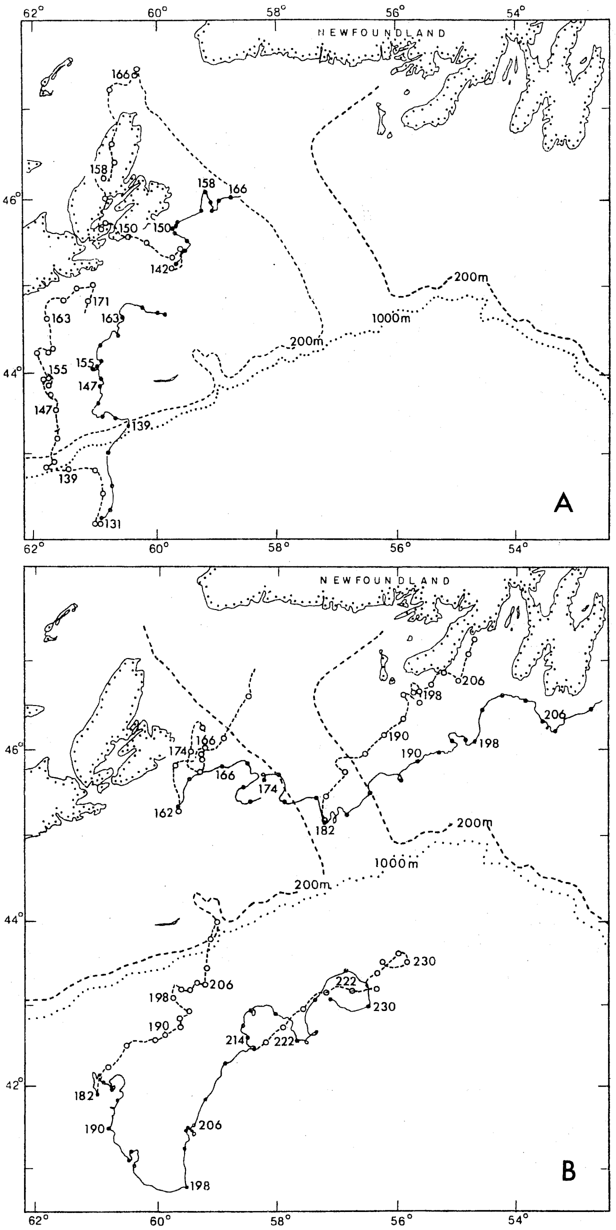

Fig. 5. Drift tracks (solid lines) for buoys released on the Scotian Shelf. **A**, on 11 May 1979 (day 132). **B**, on 22 May (day 142) and 1 July 1979 (day 182). (Dotted lines are estimated wind drift trajectories for corresponding buoy drift periods using a 3% factor to simulate surface water drift.)

water until they eventually drifted eastward out of the area of interest. The buoy deployed off Cape Breton Island moved eastward to the Laurentian Channel and then southward to the edge shelf where currents held it nearly stationary (days 274–287) before it continued southward (days 287–293) over deep water. Over deep water, both buoys followed the wind drift until about day 320 when they both appeared to encounter currents at the southwest edge of the Grand Bank. Both were subsequently moved as far south as 42° N before resuming an easterly course and passing the tail of the Grand Bank.

Flemish Cap project

The drift tracks for six buoys released on Flemish Cap are shown in Fig. 6. Buoys 2421 and 2426 were released in January 1979 and described a very slow clockwise track around the shallowest part of the bank 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 showed a very sluggish trajectory to the northwest until reaching the 400 m isobath, where it speeded up and proceded clockwise around the northern and eastern parts of the bank before being caught in the North Atlantic Current. There does not appear to have been any significant response to strong meteorological influences during its period of 72 days in the vicinity of Flemish Cap. Buoy 2425 described a very slow motion from the center to the southwestern edge of the bank, moving westward at first before being caught in the North Atlantic Current.

Buoy 2428 was deployed in early July 1979. After several days of very slow motion, it moved westward and came under the influence of the southward-flowing Labrador Current, following which it moved eastward and northward to the Flemish Cap in the region of mixed Labrador Current and North Atlantic Current water. It then moved eastward across the southern part of the bank and was carried away by the North Atlantic Current. Buoy 2433, deployed in late May 1980, described a clockwise motion around the shallow area before exiting into the North Atlantic Current.

The six trajectories shown in Fig. 6 represent residence periods in the vicinity of Flemish Cap of 32–72 days with an average of 50 days. The buoy speeds observed over the Flemish Cap were consistently less than 10 cm/sec., whereas speeds in the North Atlantic Curent were higher than 200 cm/sec. Although each drifter track was unique, the composite results confirmed the existence of a very sluggish, anticyclonic circulation around the shallower part of the bank. This is further confirmed by data from three moored current meters during the first half of 1979 (Ross, MS 1980). Noteworthy is the fact that all buoys exited from the bank in the southeastern quadrant and were advected from the region by the North Atlantic Current. Buoys

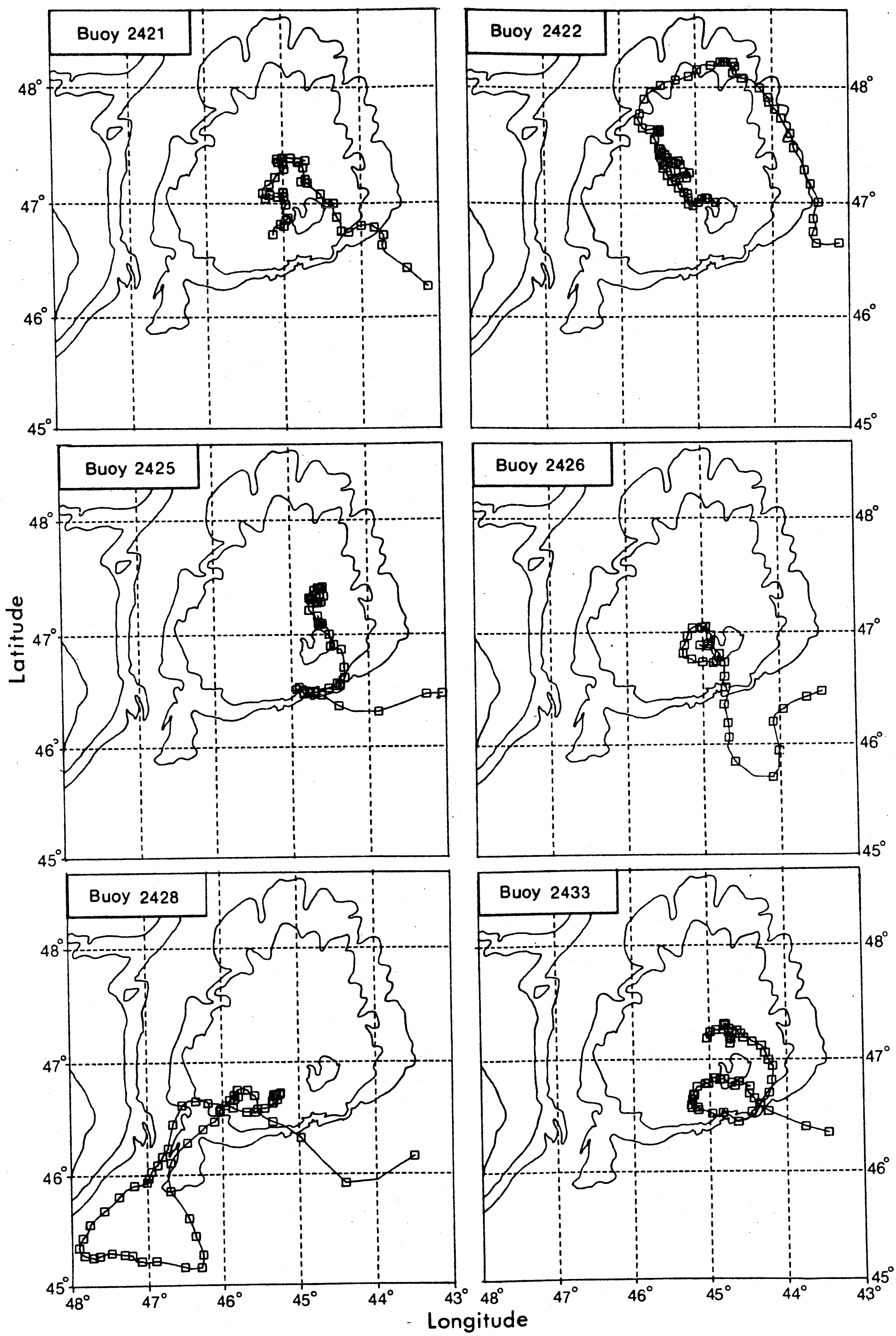

Fig. 6. Drift tracks of six buoys on Flemish Cap during 1979-80 with symbols plotted at 24-hour intervals (from Ross, 1981).

drifting near the center to the bank appear to have been influenced by meteorological forces but it is difficult to predict individual tracks from a simple analysis of winds.

Acknowledgements

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References

LAWRENCE, D., and P. GALBRAITH. 1980. A simple oil spill trajectory model for the Scotian Shelf using single and multi-point wind fields. *In* Scientific Studies during the Kurdistan Tanker Incident: Proceedings of a Workshop (ed. J. H. Vandermeulen). Bedford Institute of Oceanography, Report Series BI-R-80-3: 17–32.

ROSS, C. K. MS 1980. Moored current meter data from Flemish Cap, January–July 1979. *NAFO SCR Doc.*, No. 128, Serial No. N200.

1981. Drift of satellite-tracked buoys on Flemish Cap, 1979–80. *NAFO Sci. Coun. Studies*, **1**: 47–50.

SMITH, P. C. 1979. A proposal to study the circulation off Cape Sable, Nova Scotia. Bedford Institute of Oceanography, Report Series BI-R-79-5, 107 p.