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New Local-scale Hydrographic Observation on Flemish Cap in July 1996

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Abstract

The research cruise "FC96" was made on the Flemish Cap area on board the RV *Cornide de Saavedra* from 28 June to 14 July 1996. The survey consisted of a series of 121 random bottom trawls over Flemish Cap inside the boundaries of the 732 m isobath. A CTD station was established either at the beginning or at the end of each trawl for a total of 116 stations.

Three different water masses were detected. Two of them are already known: (a) Labrador Current waters, spreading around the Bank; (b) Central Cap seawater, the solar heated Labrador waters retained over the Cap. These waters made an anti-cyclonic gyre of 4–12 cm per sec. Both water masses tended to become stable at 200 m depth, with temperatures about 3.5°C and salinities about 34.85 psu.

A third water mass which had not been previously described on Flemish Cap was the Slope Water, found in the southwest area of the Cap between 200–300 m, where it occupied two separate areas with temperatures higher than 4.5°C and salinities higher than 34.90 psu. These intrusions of Slope Water on the Flemish Cap seemed to affect the distribution of some fish species. In particular, they coincided with the breaking of continuity in the geographic distribution of some demersal species, like the redfish *Sebastes marinus* and *S. fasciatus*.

Key words: CTD, Flemish Cap, geostrophic currents, slope water, water masses,

Introduction

The hydrographic characteristics of the Flemish Cap area are conditioned by two factors, namely, the local topography of the area, and the water current patterns.

Topographically, the Flemish Cap is an underwater plateau whose upper part reaches 125 m near 47°N–45°W (Fig. 1). It then spreads out to a depth of about 720 m, with a diameter of about 200 km. It is a relatively isolated Bank, separated from the continental shelf by a pass (about 1 100 m deep) known as the Flemish Pass.

In the context of water currents, the Labrador Current dominates the general system on Flemish Cap. The offshore branch of the Labrador Current flows southward along the Northeast Atlantic slope and it forks northwest of the Flemish Cap: the main branch continues across the Flemish Pass while a lateral branch goes around the Flemish Cap by the north. South from the Grand Banks, the Gulf Stream flows northeastward along the 4 000 m isobath of the continental shelf, and it continues flowing northward as the North Atlantic Current, then surrounding the Flemish Cap from the East.

The northeastward moving component is particularly significant to the hydrography of the Flemish Cap area. According to Hayes *et al.*, (MS 1977), a water mass lying between the Labrador Current and North Atlantic Current is originated south of Flemish Cap by the mixing of both these currents.

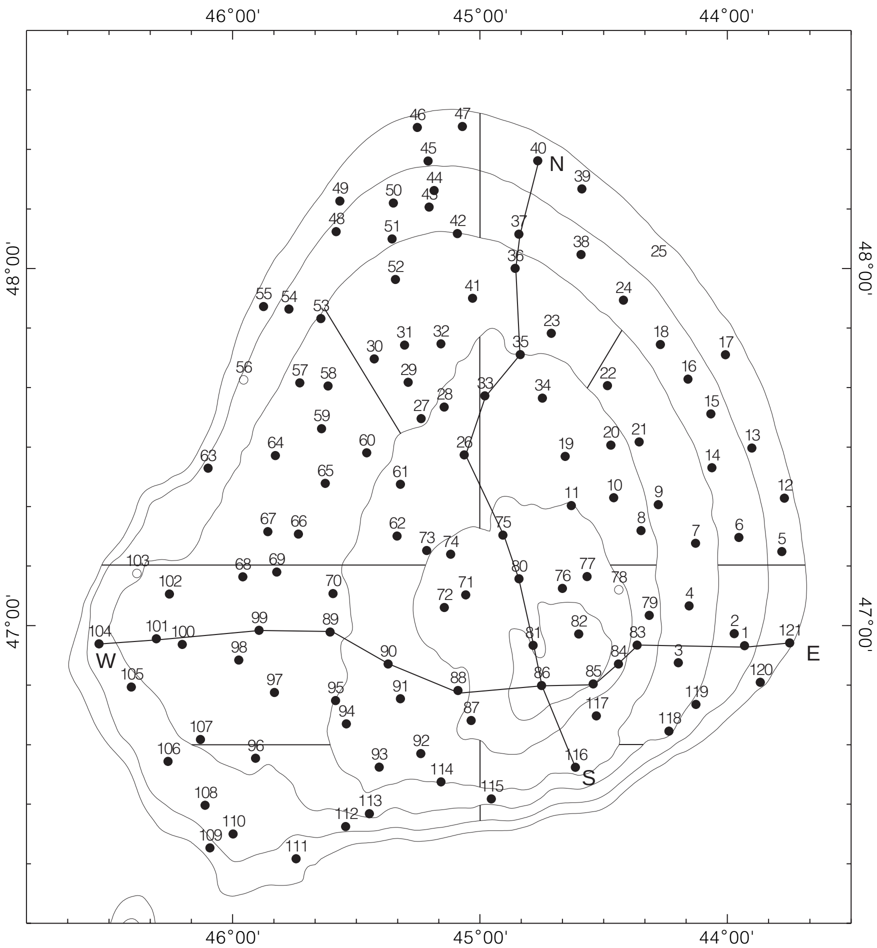

Fig. 1. Location of CTD stations and N–S and E–W sections established on Flemish Cap for July 1996 survey.

This adjacent deeper offshore water is known as Slope Water (Loder, 1991; Drinkwater, 1993). It is warmer and saltier than water on the continental shelves off eastern Canada.

Several authors have discussed the influence of such a general system of currents on the thermohaline properties of Flemish Cap. Here, the typical movement of water is an anti-cyclonic gyre, which has been described by analyses of geostrophic circulation (Kudlo and Burmakin, 1972; Kudlo and Borovkov, MS 1975; Kudlo *et al.*, 1984). Ross (MS 1980) has also reinforced this idea using moored current metre data and drift buoys (Ross, 1981). More recently, Colbourne (MS 1993; MS 1995; MS 1996) has described the circulation on the Flemish Cap using an acoustic Doppler Current Profiler, confirming the existence of a general anti-cyclonic motion. Many oceanographic surveys have been carried out in this area in recent years. Stein (1996) has presented a resumé of the results of these works.

The Flemish Cap is situated in international waters regulated by NAFO (in Div. 3M). The hydrographic information about this area is very useful to understand the reasons of its richness. Following Kudlo *et al*. (1984), the stability of the gyre is one of the main factors regulating the retention of ichthyoplankton within the Flemish Cap ecosystem; the destruction of the gyre by the action of winds results in the transport of eggs and larvae away from the bank. On the contrary, De Cárdenas and Gil (1994) affirm that the breaking of the gyre can interrupt the incoming larvae.

The aim of this article is to describe the hydrographic conditions on the Flemish Cap during the summer of 1996, as well as to analyze the influence of the main water masses and currents and their possible relationships to the Flemish Cap fishery.

Materials and Methods

The research cruise "FC96" was made on the Flemish Cap area on board of RV *Cornide de Saavedra*. The survey consisted of a series of 121 random bottom trawls over Flemish Cap inside the boundaries of the 732 m isobath. The first trawl occurred on 28 June and the last one on 14 July 1996. A CTD station was established either at the beginning or at the end of each trawl, so that a total of 116 stations were established by the end of the survey (Fig. 1).

The CTD used was of the type Sea-Bird, SBE 19. It was dropped at a speed of 1 m per sec to take 2 samples per second down to a depth limit of 410 m. Before the cruise, its calibration had been checked against seawater samples in which salinity had been measured in an Autosal salinometer. The collected data were processed using the CTD software (Seasoft 4.2). Depth, temperature, conductivity, salinity and density data were measured or calculated at each station. Later, all data which were obviously considered to be wrong, were removed. Water density and salinity were measured using a low pass filter, and all variables were finally promediate, metre by metre, to get a proper data base which would later allow a correct processing of the results. All contour maps were made from a grid traced with a linear variogram, according to kriging method (Anon., 1995), using Surfer software.

Results

Two transects were outlined on a chart of the Flemish Cap showing the distribution of stations. One north to south (N–S) transect placed next to the 45°N meridian, consisting of 11 stations, was established from 2 July to 13 July 1996 (Fig. 1). The other spread from west to east (W–E), next to the 47°N parallel, also consisting of 11 stations, was established from 9 July to 14 July 1996 (Fig. 1).

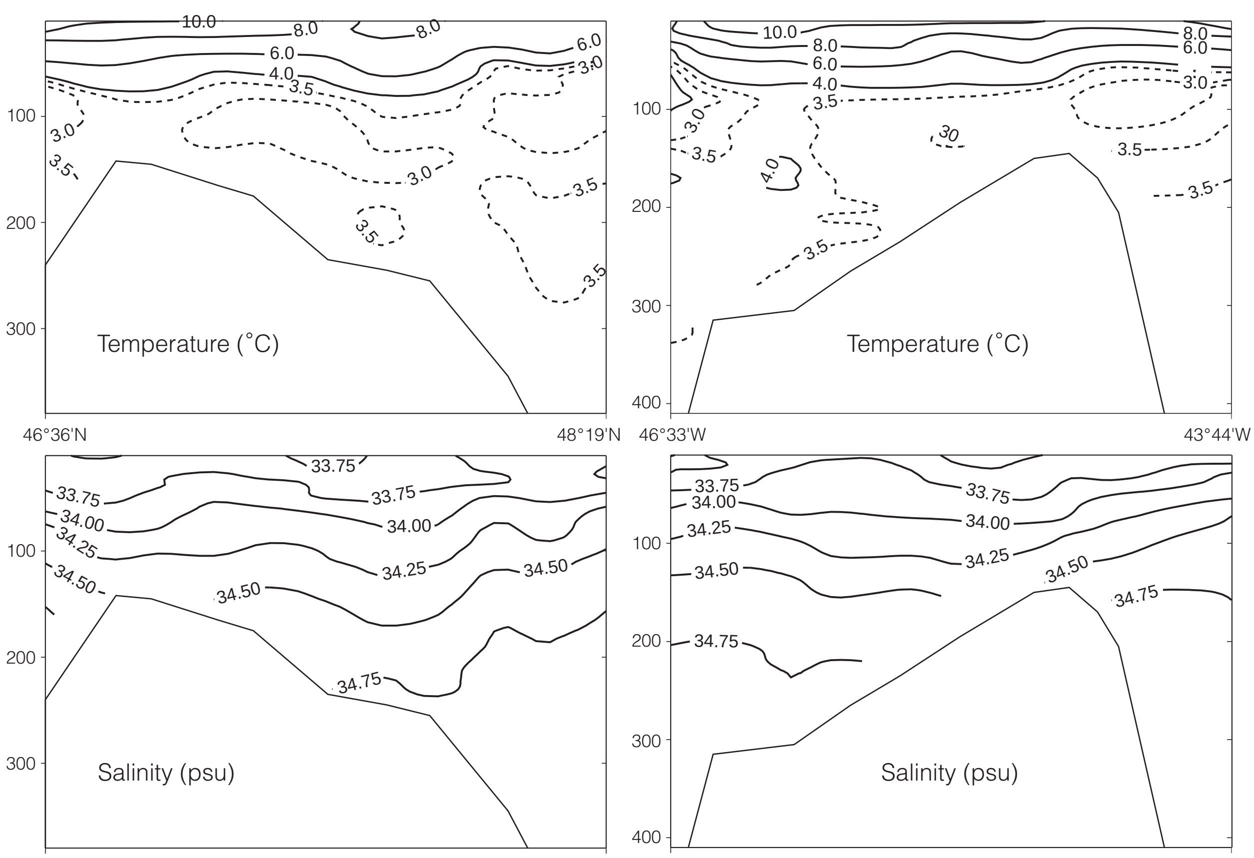

Fig. 2. Map showing isohaline and isoterm contours versus depth in the N–S and W–E sections of Flemish Cap.

The aim was to obtain some results that could later be compared to those previously provided by other authors. Recorded salinity and temperature values against depth are shown in Fig. 2. The vertical profiles on the W–E transect shows values ranging from 5°C at 50 m, and 10°C near the surface. Temperature minima appeared at a depth of about 100 m, ranging from 2.5°C at the western edge to 3.5°C on the plateau of the Cap, and 3°C at the eastern edge. In the deeper areas between 100 m and the bottom, the temperature appeared stable at about 3.5°C. Values above 4°C were registered in the western area, between 150 and 200 m. This was the only significant difference to data taken by Colbourne (MS 1996) on the standard 47°N transect during the same season of the year (Fig. 2). Along this transect, salinity ranged from 33.50 psu near the surface to slightly higher than 34.75 psu at the bottom. No significant variations on longitude were observed (Fig. 2).

In the southern area of the N–S transect, the temperature of the upper layer ranged from 6°C at 50 m to 10.5°C near the surface. In the northern area, it ranged from 3°C to 7.5°C. Temperature minima, almost reaching 3°C, appeared at depth of about 100 m. Temperature became stable near the bottom, being about 3.5°C (Fig. 2). Along the same transect, salinity values ranged from 33.50 psu at the surface and 34.75 psu at the bottom (Fig. 2).

Two temperature and salinity diagrams are displayed in Fig. 3: one shows all stations with values taken each 10 m and includes three standard stations with their respective depths. The other one serves as a criterion to define water masses found near the Grand Banks (Hayes *et al.*, MS 1977). In general, it shows the water mass characteristics of the Labrador Current, however, it also presents some significant differences. The map in Fig. 4 shows these differences according to the water domains found on the Flemish Cap.

Density distribution charts were established for all stations. The results in Fig. 5 show the distribution of density at several depths (10, 50, 100 and 200 m). At the 10 m depths it was observed that density increased northwards from 25.6 up to 26.6. The density gradient was very abrupt at the eastern and western edges, while it was much broader on

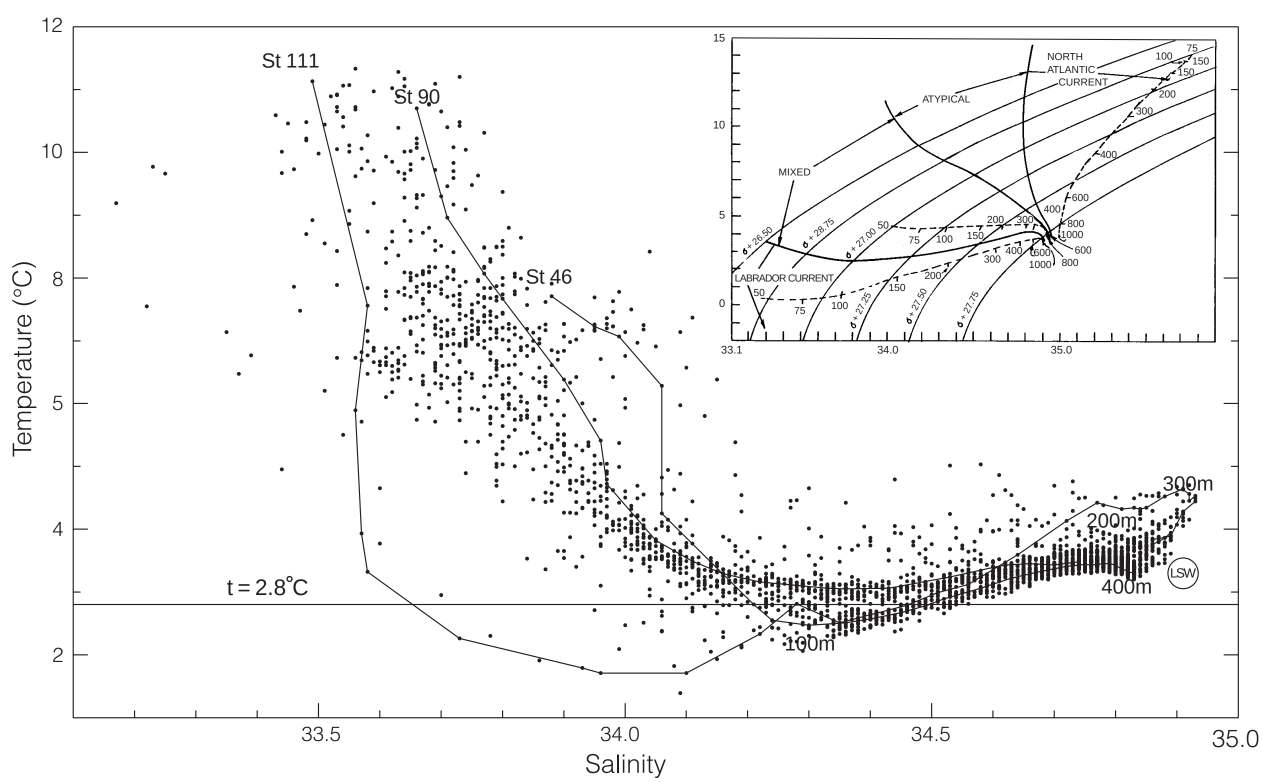

Fig. 3. Map of all survey stations showing temperature and salinity values at each 10 m depth. Stations 46, 90 and 111 show the three T–S types. LSW is the Labrador Sea Water. In the upper right corner are the T–S water masses of NW Atlantic zone (Hayes *et al.*, 1997).

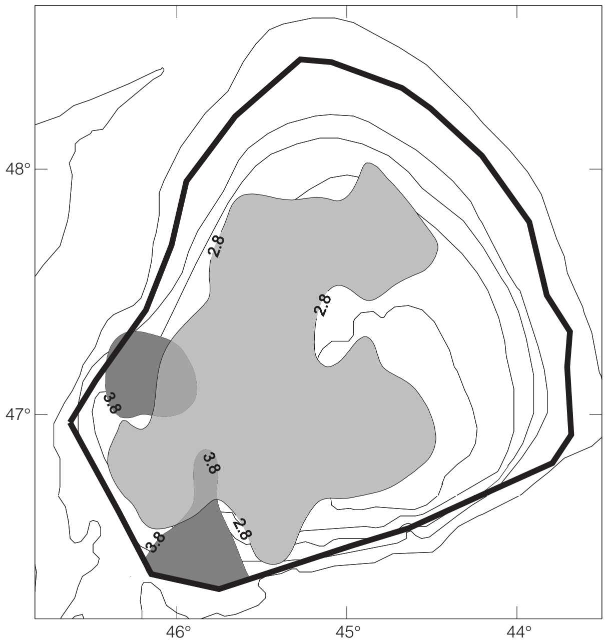

Fig. 4. Temperature isolines (°C) showing the water mass distribution on Flemish Cap: inner water (light grey), peripheral water (blank area) and Slope Water (dark grey).

the plateau. At 50 m, the gradient was observed from the centre of the Flemish Cap towards the periphery showing density values ranging from 26.5 to 27.2. At 200 m, the density was very homogeneous all over the area (from 27.60 to 27.65). In general, it was observed that density decreased near the surface from north to south and that in lower layers there was a density gradient which increased from the center to the periphery. This gradient decreased with depth, being almost negligible at 200 m. This permits, according to Kudlo *et al*. (1984), to construct the geostrophic circulation of sea surface (10 m deep) relative to the 200 m level. This circulation was calculated using the Helland-Hansen (1934) method, and Fig. 6 shows the pattern on Flemish Cap which confirms the existence of a clock-wise gyre during the survey.

Discussion

Three different water masses were observed at the local-scale on Flemish Cap during the July 1996 survey.

The first water mass corresponded to the stations showing temperature minima, values lower than 2.8°C (example: Station 46 in Fig. 3) and it spread around the Cap (Fig. 2 and 4). This peripheral seawater showed the typical features of the Labrador Current waters, as defined by Hayes *et al*. MS (1977). This water mass flows through the Flemish Cap area without being retained by any anti-cyclonic gyre, so it preserves its Labrador Current features.

The second water mass corresponded to the stations showing temperature maxima , values higher than 2.8°C (example: Station 90 in Fig. 3). It appeared on the central area and it was represented by stations with minimum temperature values above 2.8°C (Fig. 2 and 4). Both water masses tended to become stable at the 200 m depth (Fig. 5), with temperatures about 3.5°C and salinities about 34.85 psu.

These water mass distributions are in good agreement with Akenhead (1986), and the central water mass which originated due to solar heating was entrained and retained over the Flemish Cap. The slow anti-cyclonic motion typical of the area favors this retention, as well as it concentrates the water over the central area and causes its sinking down. The water surface warms up and then sinks, thus transmitting the heat to the bottom. In the summer of 1996 the results of this process were evident at a depth of about 100 m (Fig. 3), where the contrast with the peripheral water was more marked.

In general, the water found on the Flemish Cap shares the features of the offshore branch of Labrador Current. However, there were some stations showing temperature values higher than 4.5°C and salinity values higher than 34.90 psu. This phenomenon suggests there was a third water mass below 200 m (example: Station 111 in Fig.3). It was found on the southwestern area of the Cap, where it occupied two separate areas (Fig. 2 and 4). The features were similar to those of the Slope Water, and it has not been well described in previous studies about Flemish Cap. In the opinion of Akenhead (1986), the Flemish Cap waters proceed exclusively from Labrador Current, whereas North Atlantic Current has not been described to have any influence on the area. Nevertheless, Colbourne (MS 1996), who analyzed the 47°N transect, had already considered that the water heating offshore of the Cap is due to the influence of the North Atlantic Current. Thus, such a water mass might not have exclusively originated from the Labrador Current. Previously, Keeley

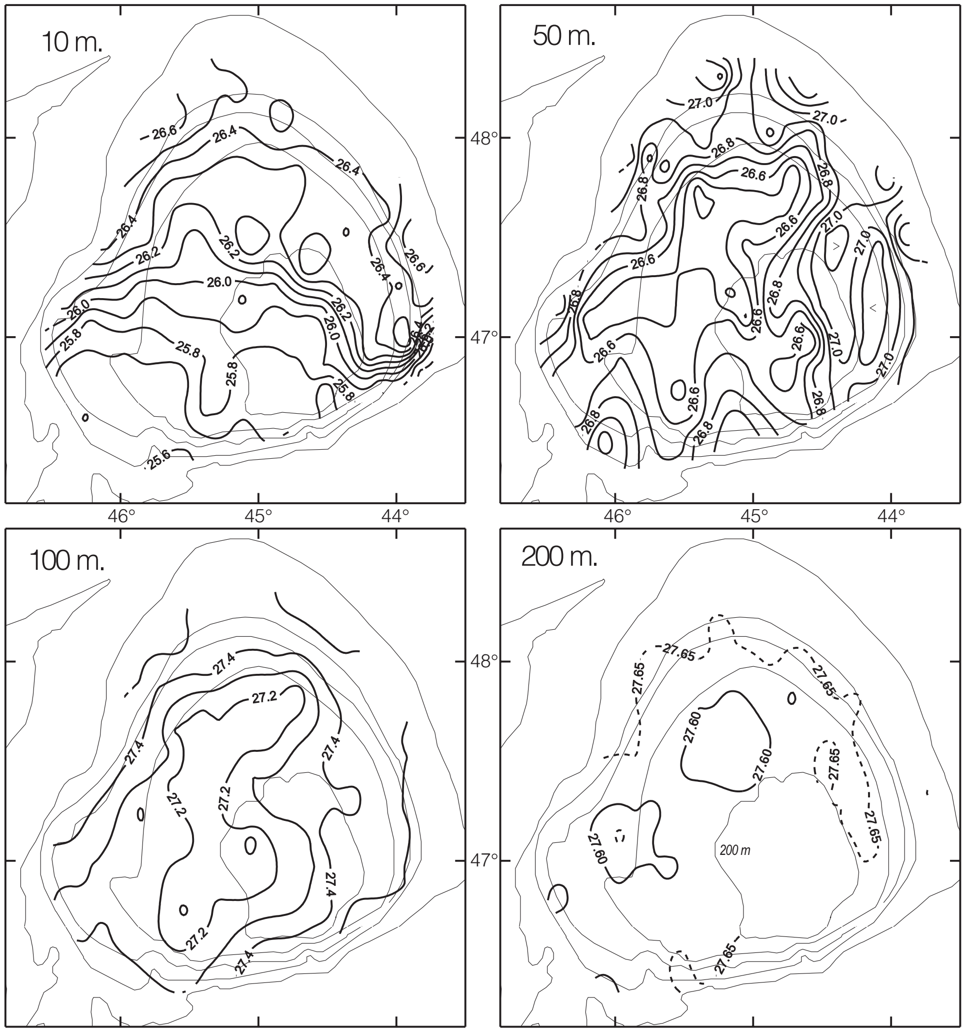

Fig. 5. Isopicnal maps at 10, 50, 100 and 200 m depths on Flemish Cap (July 1996).

(1982), using the method of clusters analysis, identified some local differences among the thermohaline characteristics, depending on the water input provided by each current. One of these areas, on the western side of the Cap, might stand as the melting pot where all different waters get mixed. This indeed coincides with the area where the presence of Slope Water was observed in the present study in July 1996.

This Slope Water originates from North Atlantic Current (NAC), which flows northwards along the eastern boundaries of the Grand Bank while it keeps in contact with Labrador Current (LC) along the 4 000 m batimetric contour. This NAC-LC interface is a complex system of meanders, extrusions and eddies that change rapidly in time and space (Krauss *et al*., 1987). Heywood *et al*. (1994) also described the presence of a vigorous eddy field, especially in deep water, which follows the 4 000 m contour. According to Drinkwater (1996), exchange between shelf and offshore waters is a continuous process with enhanced mixing in the southern area of NAFO (in NAFO SA 4+5), due to the presence of Gulf Stream rings which interact strongly with shelf waters.

In consequence, deeper water (200–300 m) on the southwestern area of the Flemish Cap reveals itself as an atypical water mass on the Flemish Cap, different from any of the previous ones. As it was the case of the central water mass, it cannot be explained by heating processes. Firstly, it must be taken into account that each water mass occupies a different position along the water column: the central warm water mass appears more clearly over the 100 m level, whereas south-eastern warm water mass appears at a deeper level, between 200–300 m. Secondly, the thermohaline properties in Figure 3 shows how Station 111 reaches temperature and salinity values similar to those of North Atlantic Current at about 300 m deep, while these values coincide with those of the Labrador Current at upper and deeper levels.

A similar situation in a different area was described by Loder (1991) in the South of the Grand Banks. It was described how the slope water coming into the Southeast Shoal, which is an elevated terrain, gives rise to a counter-clockwise gyre and to the subsequent water column heating derived from seasonal heat input. He affirms that the high temperatures observed near the bottom can not be explained in terms of convection from surface, and that the slope water plays an important role in this heating. A similar process can be observed on Flemish Cap, with heat inputs from the surface and from outside the bank. The heat input from slope water and the influence of global heating on the Flemish Cap, is still to be quantified. However, the distribution of some biological species on the Cap area during July 1996 could have been affected by the Slope Water (Fig. 7). In particular it appears to coincide with the break in continuity of distribution of the redfish, *Sebastes marinus* and *S. fasciatus*.

Conclusions

1. Generally, the hydrographic characteristics registered during the summer of 1996 correspond with those expected for the local-scale: a clockwise gyre and a water sharing of Labrador Current, which warms up over the Flemish Cap (Fig. 6). This typical situation on the Cap is complemented with the presence of another water mass which is warmer and saltier caused by the Slope Water (Fig. 4). Observations are commented on here for the first time.

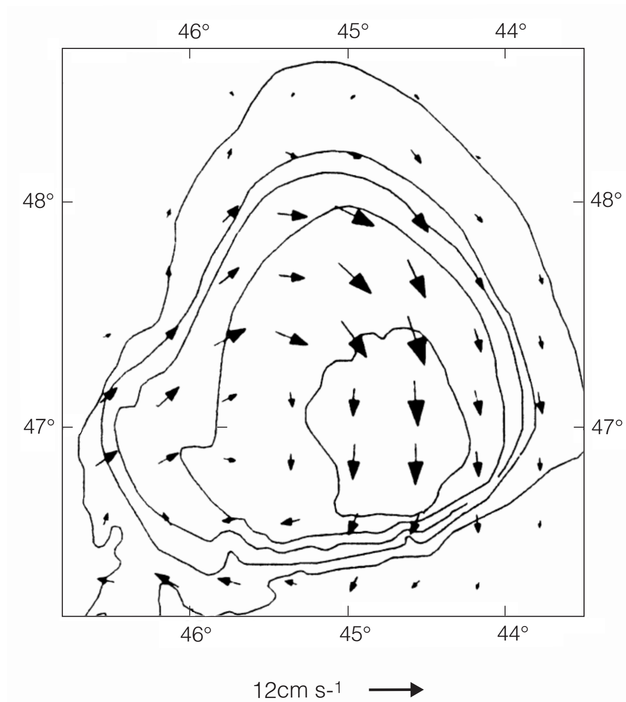

Fig. 6. Geostrophic circulation pattern on Flemish Cap in July 1996, relative to the 200 m depth level.

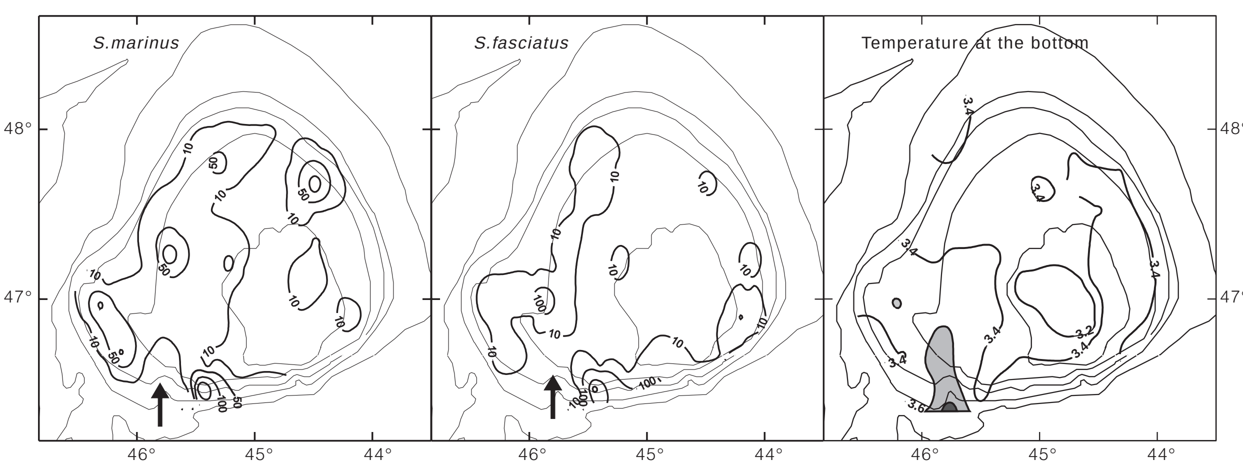

Fig. 7. Isotherms map (°C) at the sea bottom and distribution (in kg) of two species of redfish, *Sebastes marinus* and *S. fasciatus*. The arrow indicates the area where the warm water coincides with the absence of these species.

This water mass proceeds from North Atlantic Current, shifts northwards and then reaches the Cap, which also might collaborate with the heating of its waters.

2. The intrusions of Slope Water on the Flemish Cap seem to affect the distribution of some biological species over the area (Fig. 7). The intrusion of this water, which may reach a temperature of 3.6–3.8°C at the bottom, coincides with the breaking of continuity in the geographic distribution of some demersal species, like the redfish *Sebastes marinus* and *S. fasciatus*. This condition appears not to have been considered on the Flemish Cap until now.

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