Northwest Atlantic Fisheries Organization

Serial No. N4571 **NAFO SCR Doc. 01/182**

SCIENTIFIC COUNCIL MEETING – NOVEMBER 2001

Oceanographic Conditions on the Flemish Cap During the Spring of 2001

by

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Abstract

Oceanographic data from the spring of 2001 on the Flemish Cap are examined and compared to the long-term (1971-2000) average. The cold near-surface temperatures (0.5° to 2°C below normal) experienced over the Cap from 1993-1996 had warmed to 0.5°-1.5°C above normal by July of 1997, which increased further to 2°C above normal by the summer of 1999. Upper layer temperatures directly over the Flemish Cap during the spring of 2001 were generally below normal by up 0.5°C. Bottom temperatures over the Cap, which were generally below normal during the early to mid-1990s increased to 1°C above normal by 1999 but decreased to near-normal values during 2000 and 2001. Salinities over most of the upper water column during the spring of 2001 were saltier-than-normal (by 0.2-0.8). In the deeper water (generally below 100-m depth) and near bottom, salinities were generally about normal. In general the colder than normal temperatures experienced over the continental shelf and on the Flemish Cap from the late 1980s up to the mid-1990s moderated by the summer of 1996 and continued to warm until 1999. During the summer of 2000 and into the spring of 2001 the observations indicates a reversal in the recent warm trend in some areas of the water column with near normal temperatures in most areas. During most of the 1990s summer chlorophyll levels in the upper 100-m of the water column over the Cap were higher compared to the adjacent Grand Bank and during the spring of 2001 levels were generally lower over the Cap relative to the Grand Banks. Dissolved oxygen levels were about normal for the region with some super-saturation in the near surface layers. Both the measured currents and the geostrophic estimates, while showing considerable differences and variability between years, indicate a general anticyclonic circulation around the Flemish Cap.

1. *Introduction*

The Flemish Cap is an isolated bank located east of the Grand Banks of Newfoundland centered at about 47°N, 45°W with minimum water depths of 126-m (Fig. 1 top panel). To the west, the Flemish Pass with maximum water depths of about 1100 m separates the Cap from the Grand Bank. The water mass over the Flemish Cap is a mixture of Labrador Current and North Atlantic Current water, the general circulation of which is shown in Fig. 1 (bottom panel). Since the early-1970s the water masses over the Atlantic continental shelves have been dominated by three anomalous periods: early-1970s, mid-1980s and the early-1990s (Colbourne *et al*., 1994). During these periods strong positive winter North Atlantic Oscillation (NAO) index anomalies were mainly responsible for colder than normal air temperatures over the Northwest Atlantic resulting in increased ice cover and eventually colder and fresher than normal oceanographic conditions over the continental shelf of Atlantic Canada (Drinkwater, 1996). An examination of the time series of historical temperature data from the Flemish Cap indicated similar conditions existed on the Flemish Cap, however recent data indicates that conditions have returned to more normal conditions (Colbourne, 1999, 2000).

The monthly mean temperature and salinity along the standard Flemish Cap Section (Fig. 1) have been published by Keeley (1981) and includes observations from 1910 to 1980. Drinkwater and Trites (1986) published spatially averaged temperature and salinity from all available bottle data from 1910 to 1982 over the Flemish Cap area. Numerous reviews and studies of the physical oceanography around the Flemish Cap were conducted during the Flemish Cap Project of the late 1970s and early 1980s (Hays *et al*., 1978; Bailey, 1982; Akenhead, 1981). More recent reviews of oceanographic conditions in the region compared 1993 and 1995-2000 observations with the long-term mean and also presented time series of temperature and salinity anomalies at various depths around the Cap (Colbourne, 1993, 1995, 1996, 1997, 1998, 1999, 2000). Stein (1996) summarised the most recent studies of oceanographic conditions on the Flemish Cap. Additionally, Cervifio and Prego (1996), Garabana *et al*. (2000) and Lopez (2001) presented hydrographic conditions on the Flemish Cap in July from fisheries research surveys conducted by the European Union. This manuscript presents an update to these studies by including data up to the spring of 2001 and represents the ninth such review of oceanographic conditions on and around the Flemish Cap in support of the annual shrimp assessment for NAFO Div. 3M.

The report describes oceanographic conditions on the Flemish Cap during the spring of 2001 with a comparison to the long-term mean, based on all available historical data. The normal has been defined as the 30-year period from 1971-2000 in accordance with the convention of the World Meteorological Organization and recommendations of the NAFO Scientific Council. The observations presented here were made by Canada's Department of Fisheries and Oceans oceanographic survey during the spring of 2001. During these surveys oceanographic observations were made along the standard NAFO Flemish Cap transect at 47^{o}N latitude (Fig. 1 top panel). Physical oceanographic measurements included vertical profiles of temp erature, salinity, and chlorophyll and dissolved oxygen. No data were available for the summer of 2001.

2. *Average Temperature and Salinity*

The vertical distributions of the average temperature and salinity over the Flemish Cap along 47^o N for the period April 13 to May 11 (a one month time period spanning the survey time), based on all available historical data from 1971-2000 are shown in Fig. 2. These dates were chosen to span a one-month time period centred on the 20001 observations. No other attemp ts were made to adjust the mean for possible temporal biasing arising from variations in the number of observations within the time interval.

The average temperature for this time period, in the depth range of 0-200 m, ranges from 1^o to 3^{o}C on the Flemish Pass side of the Cap (Fig. 2, upper panel). Deeper water temperatures (200 m to bottom) in the Pass range from 3^o-4^{o}C. Over the cap and to the east of the Cap, temperatures on average range from 3^o to 4^{o}C from the surface to the bottom. The corresponding average surface salinities (Fig. 2, bottom panel) range from less than 33.5 in the Flemish Pass to about 34 over the Cap and eastward of the Cap. Near bottom over the Cap, in water depths of 150 to 300 m, salinities range from 34.5 to 34.75.

3. *2001 Temperature and Salinity*

The vertical temperature distribution during the spring of 2001 (Fig. 3, top panel) over the Flemish Cap, show temperatures ranging from about 3^o to 3.75^{o}C at 150-m depth to above 4^{o}C near the surface. Near-bottom temperatures over the Cap ranged from 3.5^o to 3.75^{o}C. The vertical distribution of temperature anomalies for the spring of 2001 referenced to the 1971-2000 normal is shown in Fig. 3 (bottom panel). During the spring of 2001 temperature anomalies on the Flemish Pass side of the Cap ranged from 0.5^o to 1.5^{o}C above normal in the depth range of 0-200 m. Directly over the Cap temperature were about 0.5^{o}C below normal and to the east of the Cap they were up to 1^{o}C above normal. Bottom layer temperatures at all surveyed depths were near normal.

The vertical distribution of salinities for the spring of 2001 (Fig. 4 top panel) show values ranging from less than 34.25 in the upper surface layers to 34.5 near bottom over the Cap in water depths of 150 m. Salinities in water depths greater than 150 m ranged from 34.5 to 34.8. The corresponding salinity anomalies during the spring of 2001 were slightly saltier than normal (by 0.2 to 0.8) to the west of the Cap in the surface layer and from 0.2 to 0.5 over the Cap. On the eastern side of the Cap salinities were slightly saltier than normal (0.2-0.3) in the upper layers. In the deeper water and near bottom over all areas, salinities were near normal.

4. *Long-Term Trends in Temperature and Salinity*

Similar to conditions on the Newfoundland Shelf the monthly temperature anomalies on the Flemish Cap (Fig. 5) are characterised by 3 major cold periods: most of the 1970s, mid-1980s and the late-1980s to the mid-1990s. The cold period beginning around 1971 continued until about 1977. From 1978 to 1984 temperature anomalies showed a high degree of variability in the upper water column with a tendency towards positive anomalies. By 1985 in the top 100 m of the water column negative temperature anomalies had returned. This cold period moderated briefly in 1987-88 but returned again by 1989 and continued until the mid-1990s. From 1995 to 1998 temperatures have moderated and remained above normal during the summer of 1999 in the depth range from 0 to 150 m. During 2000 and 2001 temperatures decreased significantly over 1999 values but remained near to slightly above normal over most of the water column.

The time series of salinity anomalies (Fig. 6) shows fresher-than-normal conditions from 1970 to 1976 and from 1983 to 1986 in the upper 100 m of the water column with peak amplitudes reaching 0.9 below normal. In general, the magnitude of the salinity anomalies decreases with increasing depth. The trend in salinity values during the early-1990s was mostly below normal up until 1995 at the surface to 100-m depth. From 1996 to 1998 salinities were generally above normal. During the summer of 1999 salinities were near the long-term average on the Flemish Cap but fell to slightly below normal by the summer of 2000 increasing again in 2001 to above normal values. In general, the temperature and salinity (except for the 1990s) anomalies are very similar to those at Station 27 and elsewhere on the continental shelf over similar depth ranges (Colbourne, 1998b).

5. *2001 Chlorophyll and Dissolved Oxygen*

The vertical distributions of dissolved oxygen and dissolved oxygen saturation for the spring of 2001 along the standard NAFO transect across the Grand Bank and the Flemish Cap are shown in Fig. 7. These data were collected in conjunction with the temperature and salinity data using a YSI type polarographic element dissolved oxygen sensor interfaced to a Seabird-9 CTD system. The oxygen sensor was factory calibrated at zero and air-saturated water oxygen levels and also field calibrated by taking water samples at standard depths. The oxygen levels of the samples were determined by semi-automated analytical chemistry using a modified Winkler titration technique. The sensor readings were then corrected by using a least-squares fit of the titration measurements to the electronic sensor measurements.

Over the Flemish Cap dissolved oxygen saturation levels during 2001 ranged from 100 to 105% from the surface to about 75-m depth (Fig. 7). Below 75-m depth, values ranged from 90 to 100%, except near bottom where values ranged from 80 to 90%. Overall, oxygen saturation values were very similar to the summer values during both 1999 and 2000 (Colbourne 2000). The super-saturated values in the top 50-m of the water column correspond to the high chlorophyll concentrations encountered over the Flemish Cap. These saturation levels are similar to that observed during most of the 1990s and are typical for this region.

The vertical distribution of relative chlorophyll concentrations for the spring of 2001 along the standard NAFO transect across the Grand Bank and the Flemish Cap is shown in Fig. 8. These data were collected in conjunction with the temperature and salinity data using a fluorometer interfaced to a Seabird-9 CTD system. No field calibrations were applied to the chlorophyll values presented here. The chlorophyll concentrations show relatively high values over the Flemish Cap and the adjacent Grand Bank during the spring of 2001, as expected. Maximum values were confined to the surface layer of about 75-m thick (Fig. 8). The higher chlorophyll values over the Flemish Cap appear to extend into mid summer and may indicate an extended offshore plankton bloom relative to the Newfoundland Shelf areas (Colbourne, 2000).

6. *Circulation*

The general circulation in the Flemish Cap region consists of the offshore branch of the Labrador Current, which flows through the Flemish Pass, more or less trapped to the Grand Bank side of the continental slope area and a jet that flows to the east, north of the Cap. To the south the Gulf Stream flows to the northeast merging with the Labrador Current to form the North Atlantic Current (Fig. 1 bottom panel). In the absence of strong wind forcing the circulation over the Flemish Cap is dominated by a topographically induced anticyclonic gyre over the central portion of the bank (Kudlo *et al.*, 1984, Ross 1981). The stability of this circulation pattern may influence the retention of ichthyoplankton on the bank and is probably a factor in determining the year-class strength of various fish species, such as cod, redfish and shrimp (Kudlo and Borovkov, 1977; Kudlo and Boytsov, 1979). This hypothesis however, has never been investigated in detail.

The anticyclonic motion of the water mass around the Flemish Cap was first described by Kudlo and Burmakin (1972), Kudlo and Borovkov (1975) and Kudlo *et al.* (1984) using geostrophic currents estimated from density measurements. The geostrophic currents perpendicular to the 47^{o} N transect calculated from the density data collected during the spring of 2001 are shown in Fig. 9. These estimates, which are referenced to 300-m, or the bottom, in water depths less than 300-m, shows some of the well-known features of the circulation. The strong baroclinic component of the offshore branch of the Labrador Current west of the Flemish Pass and the northward flowing water of the North Atlantic Current east of the Cap are evident. The estimates over the Cap itself show evidence of anticyclonic circulation, however, the northward component on the western side of the Cap appears much weaker than that observed during the summers of both 1999 and 2000 (Colbourne, 2000).

From 1993 to 2000 (except 1994) currents on the Flemish Cap during mid-July were measured with hull-mounted 150 kHz RDI acoustic Doppler current profilers (ADCPs) at a spatial resolution of 4 m vertically by approximately 1.5 km horizontally. Measurements were restricted to water depths less than 500 where bottom referencing was possible. The useful range of the 150 kHz ADCP for current measurements in this area is about 10 to 300 m depth. The circulation around the Flemish Cap is predominately anticyclonic in all surveys since 1993 with typical re-circulation times ranging from 50 to 70 days. Figure 10 shows a vertical cross-section of the north-south currents over the Flemish Cap during July of 2000 along 47^{o}N latitude. These measurements show a northward component ranging from 5 to 20 cm/s over the western portion of the Cap in the Flemish Pass area and over the Cap in water depths below 50-m depth. In the surface layer and east of the Cap currents were generally southward with speeds ranging from 5 to 20 cm/s. In general, the details of the circulation patterns measured with ADCPs differ significantly from the geostrophic estimates, thus showing the potential importance of wind driven and tidal currents on the Flemish Cap. Finally, both the measured currents and the geostrophic estimates while showing considerable variability between years, nevertheless show similar features in the overall circulation pattern confirming the existence of anticyclonic circulation around the Flemish Cap.

Acknowledgements

I thank C. Fitzpatrick, P. Stead, W. Bailey, C. Bromley, J. Craig and S. Kennedy of the oceanography section at the Canadian Northwest Atlantic Fisheries Centre for data collection and processing and for computer software support. I would also like to thank the captain and crew of the CCGS Teleost for field support and to the many scientists whom over the years have contributed to the national database.

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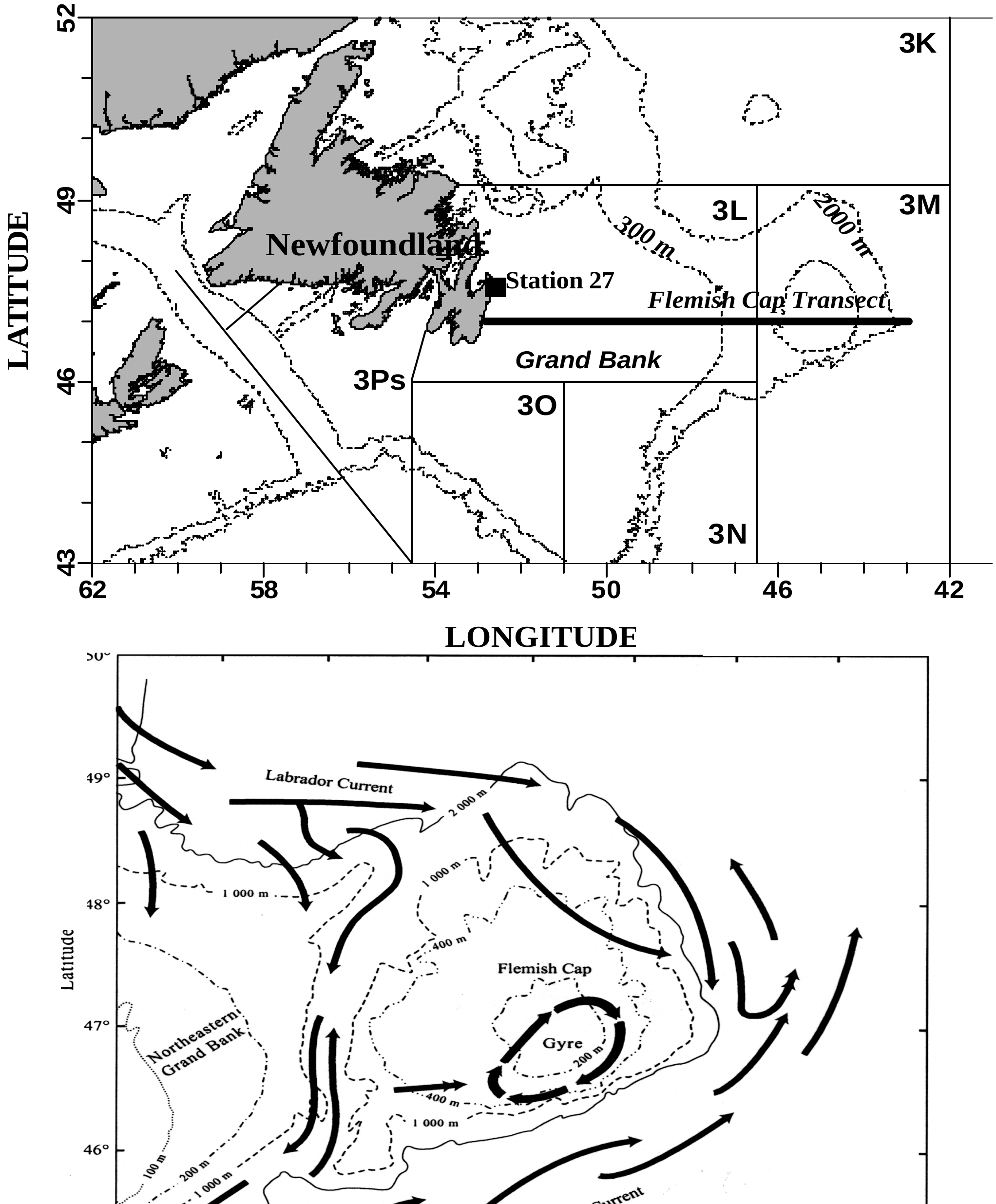


Fig. 1. Areal map of the Flemish Cap region in NAFO Division 3M showing the position of the standard Flemish Cap Transect (top panel) and the major circulation features around the Flemish Cap area (bottom panel).

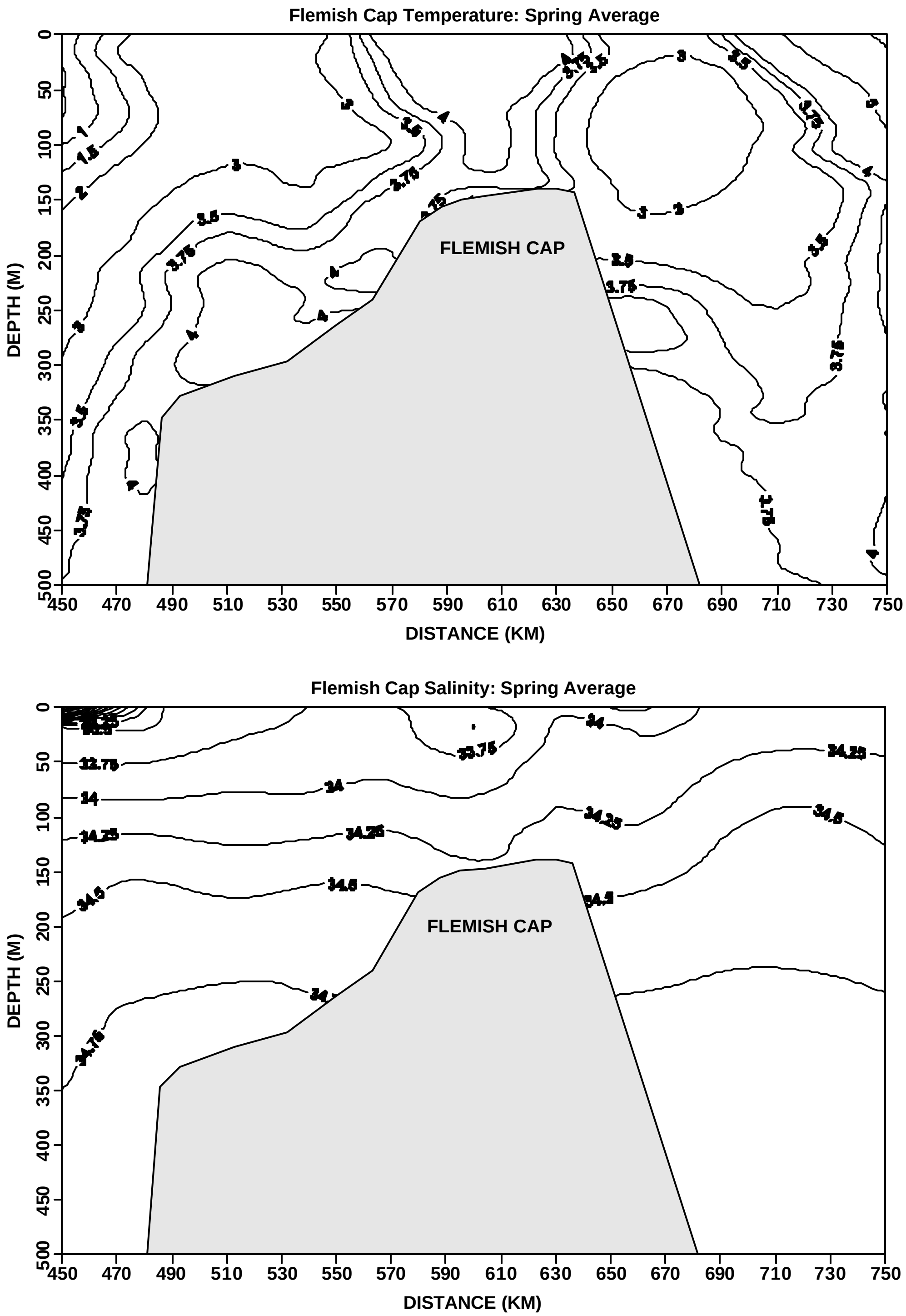
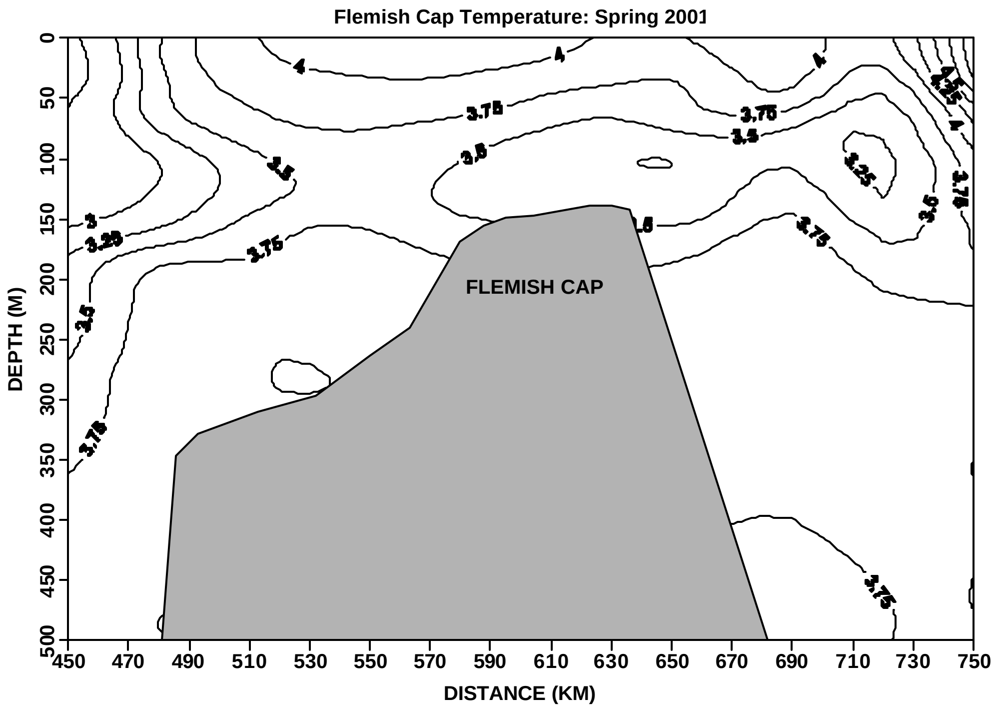


Fig. 2. Average spring temperature (in °C) and salinity on the Flemish Cap based on all data collected between 1971-2000.



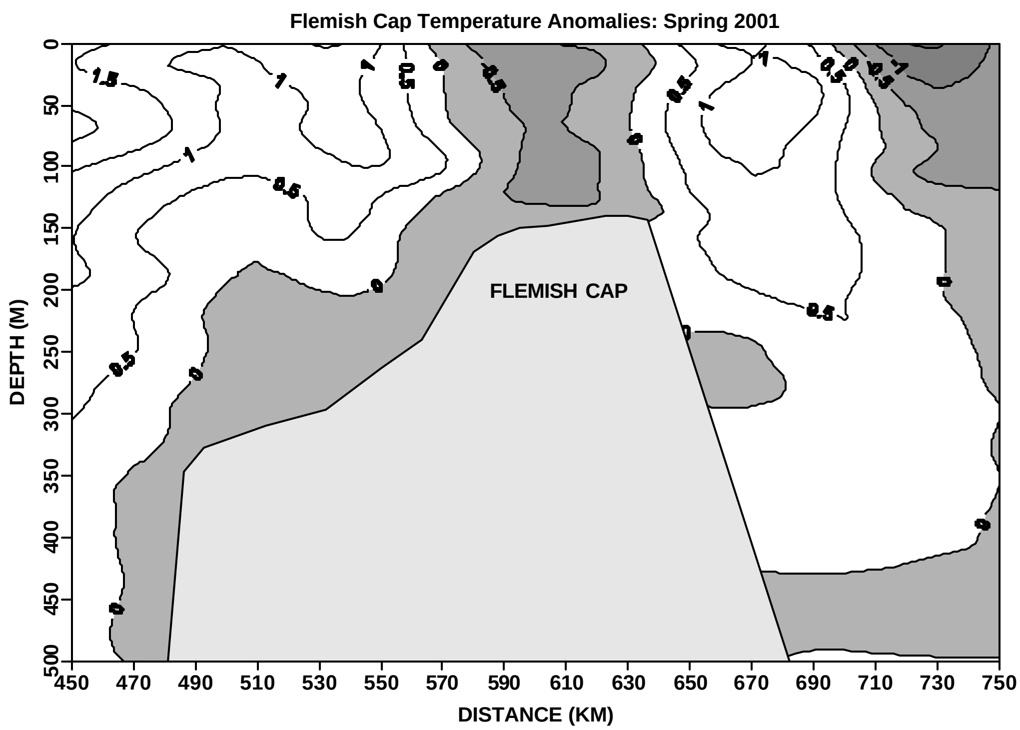


Fig. 3. The vertical distribution of temperature and temperature anomalies (in °C) over the Flemish Cap (along 47°N) for the spring of 2001. Negative anomalies are shaded.

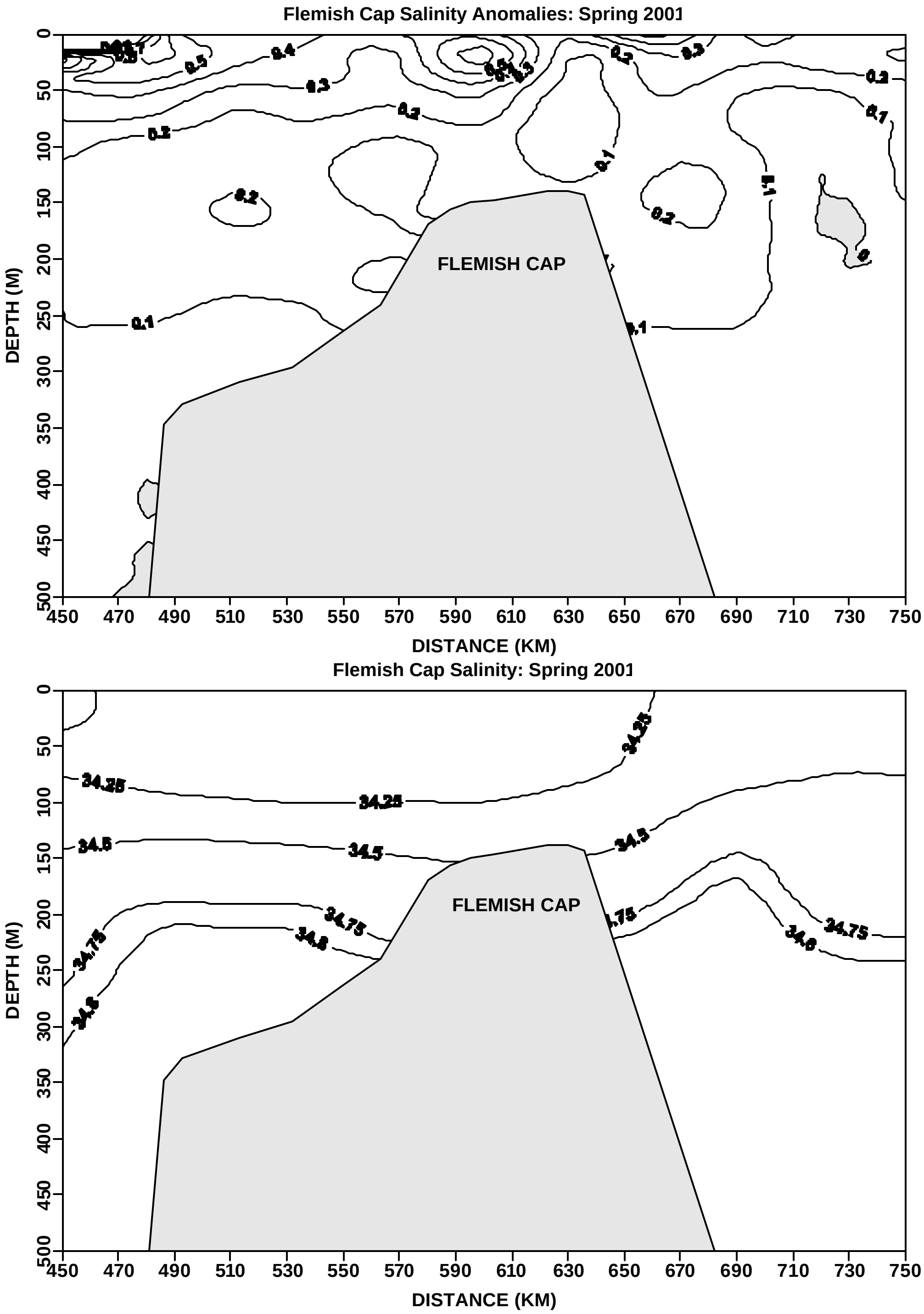


Fig. 4. The vertical distribution of salinity and salinity anomalies over the Flemish Cap (along 47° N) for the spring of 2001. Negative anomalies are shaded.

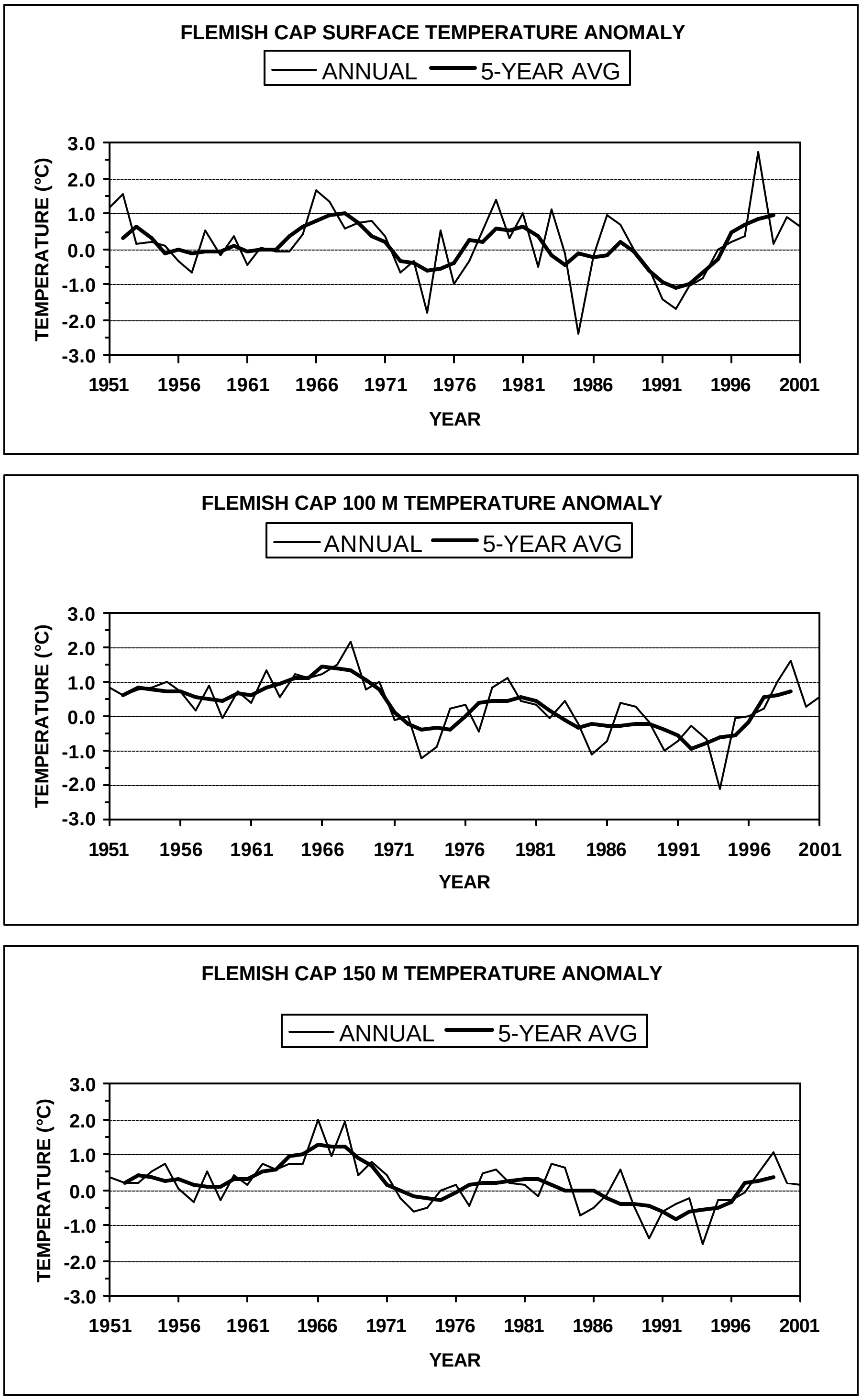


Fig. 5. Time series of annual temperature anomalies at standard depths of 0, 100 and 150 m on the Flemish Cap in NAFO Division 3M. The solid line represents a 5-year running mean.

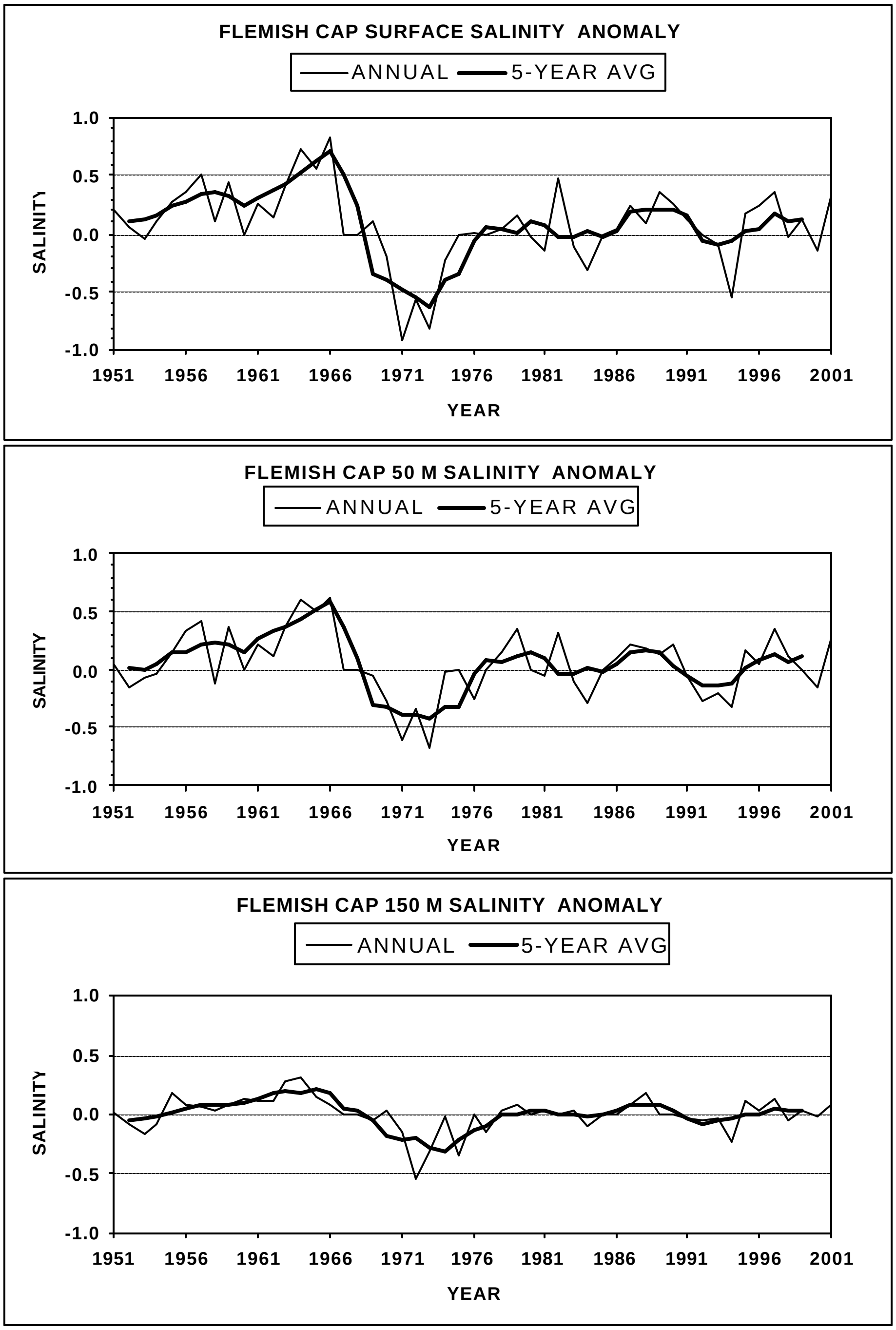


Fig. 6. Time series of annual salinity anomalies at standard depths of 0, 50 and 150 m on the Flemish Cap in NAFO Division 3M. The solid line represents a 5-year running average.

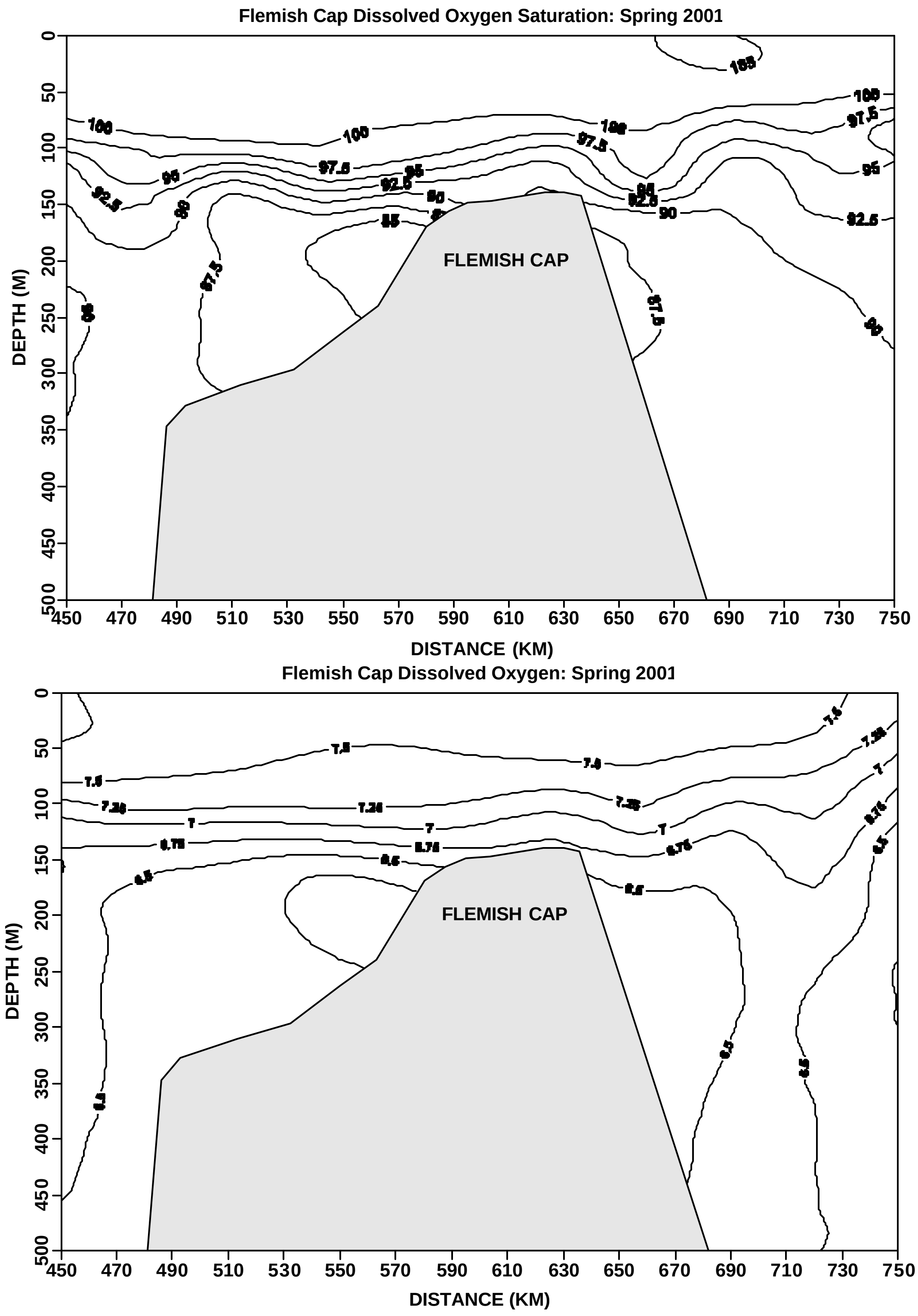


Fig. 7. The vertical distribution of dissolved oxygen and percent saturation along 47°N for the spring of 2001.

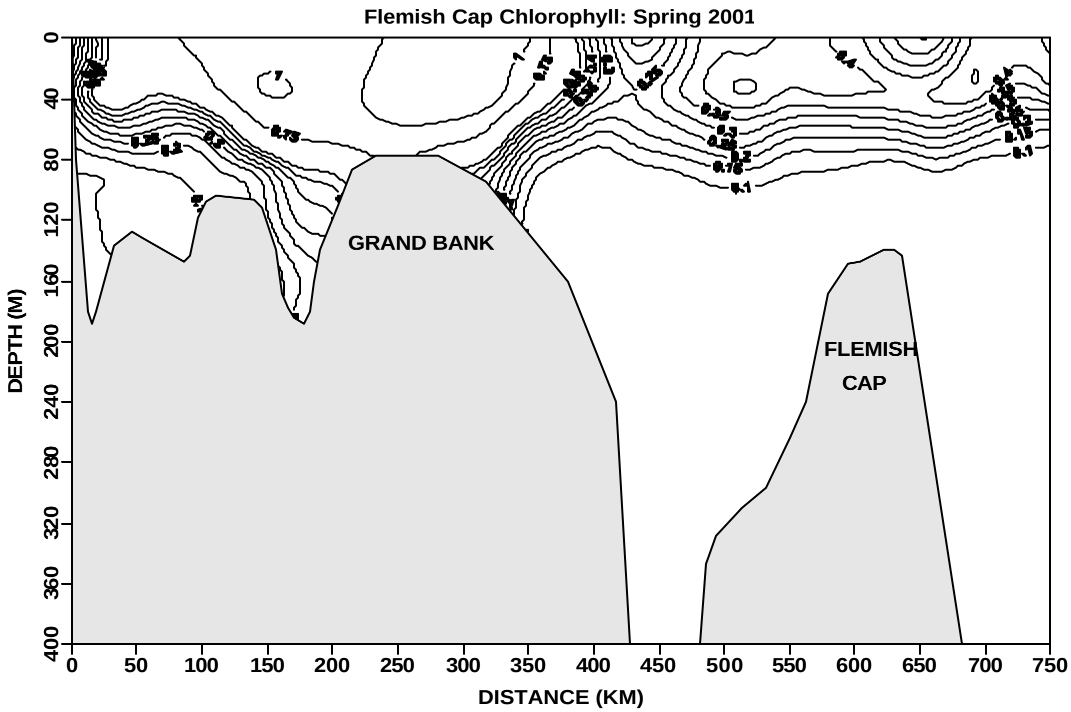


Fig. 8. The vertical distribution of chlorophyll concentrations (mg/l) along the 47°N transect for the spring of 2001.

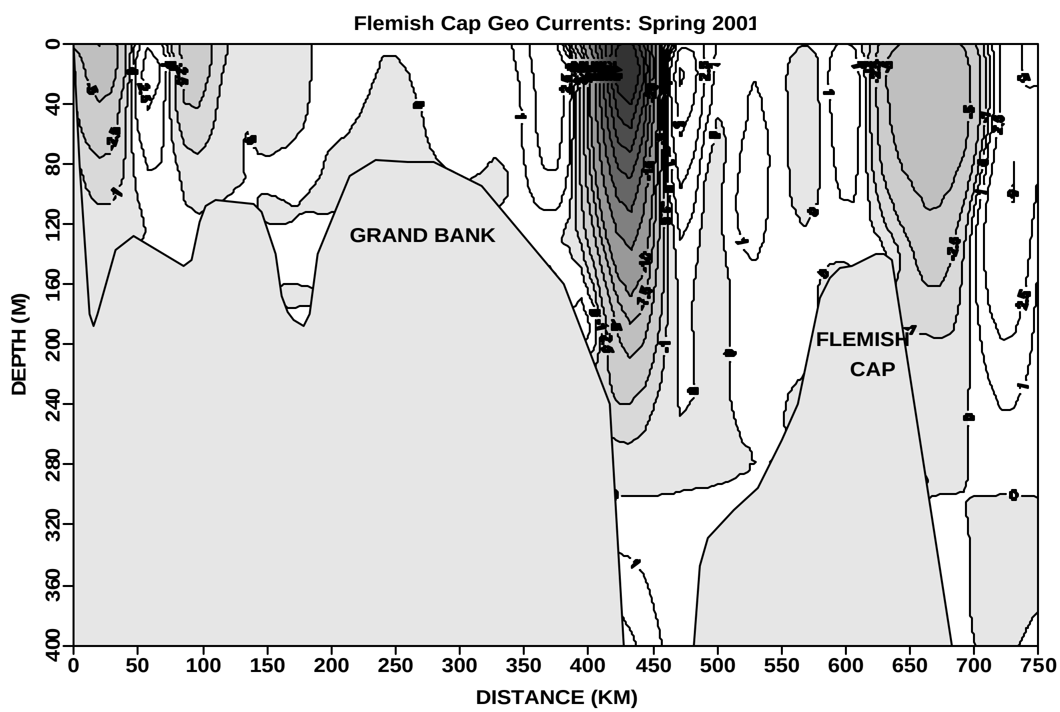


Fig. 9. The vertical distribution of the N-S geostrophic current field (in cm/s) over the Flemish Cap during the spring of 2001 calculated from the density data. Negative (shaded) currents are southward and positive are northward.

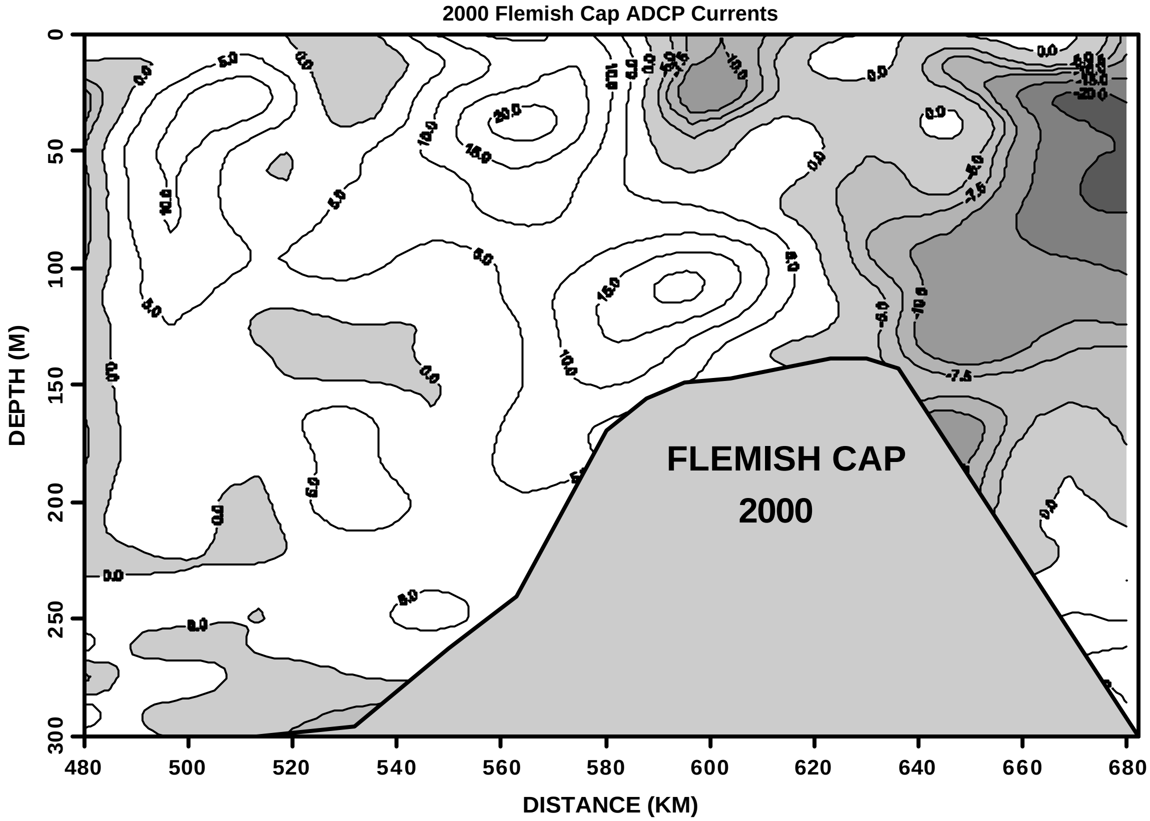


Fig. 10. A vertical cross-section of the N-S current field (in cm/s) over the Flemish Cap (along 47° N) during July of 2000 measured with a 150 kHz ADCP. Negative (shaded) currents are southward and positive are northward.