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Oceanographic Conditions on the Flemish Cap in NAFO Division 3M during the Summer of 2003

by

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ABSTRACT

Oceanographic data from the summer of 2003 on the Flemish Cap are examined and compared to the long-term (1971-2000) average. The cold near-surface temperatures (0.5^o to 2^{o}C below normal) experienced over the Cap from 1993-1996 had warmed to 0.5^o-1.5^{o}C above normal by July of 1997, which increased further to 2^{o}C above normal by the summer of 1999. Upper layer temperatures over the Flemish Cap during the spring of 2001 and the summer of 2002 generally showed a downward trend with temperatures decreasing to below normal values. During the summer of 2003, temperatures directly over the Cap were highly variable while adjacent areas showed significant positive anomalies. Near bottom temperatures over the Cap were generally around 3.5^{o}C, which was below normal in some areas particularly on the western side of the Cap. Salinities over most of the upper water column during the summer of 2002 and 2003 were generally saltier-than-normal (0.25-1.0). In the deeper water (>100-m depth) salinities were 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 indicate a reversal in the recent warm trend in some areas of the water column with near normal temperatures in most areas. During the summers of 2002 and 2003 most areas of the water column experienced highly variably conditions with near-surface values below normal in 2002 and above normal in 2003. During 2003 and throughout most of the 1990s summer chlorophyll levels in the upper 100 of the water column over the Cap were higher compared to the adjacent Grand Bank. Dissolved oxygen levels were about normal for the region with super-saturated values in the near surface layers reaching 105%. Both the measured currents and the geostrophic estimates, while showing considerable differences and variability between years, confirm the existence of a general anticyclonic circulation around the Flemish Cap during the summer.

1. **Introduction**

The Flemish Cap is an isolated bank located east of the Grand Bank of Newfoundland centred at about 47^{o}N, 45^{o}W with minimum water depths of 126 m (Fig. 1, top panel). To the west, the Flemish Pass with maximum water depths of about 1 100 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 anomalously cold 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. During the mid-1990s however, the ocean climate in this region returned to more normal like conditions and by the late-1990s ocean temperatures in many areas reached record highs (Colbourne, 1999, 2000, 2003).

Keeley (1981) published monthly mean temperature and salinity data from 1910-1980 along the standard Flemish Cap Section (Fig. 1). Drinkwater and Trites (1986) published spatially averaged temperature and salinity from all available bottle data from 1 910 to 1 982 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 1995-2002 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, 1998a, 1998b, 1999, 2000, 2001, 2002). Stein (1996) summarised the most recent studies of oceanographic conditions on the Flemish Cap. Additionally, Cervifio and Prego (1996), Garabana *et al*. (2000), Lopez (2001) and Cabanas (2002, 2003) have 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 summer of 2003 and represents the eleventh such review of oceanographic conditions on and around the Flemish Cap in support of the annual shrimp assessment for NAFO Div. 3M.

This report describes oceanographic variability on the Flemish Cap during the summer of 2003 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. The 2003 observations were made by Canada's Department of Fisheries and Oceans oceanographic survey during the summer of 2003. During these surveys oceanographic observations were made along the standard NAFO Flemish Cap section at 47^{o} N latitude (Fig. 1, top panel). Physical oceanographic measurements included vertical profiles of temperature, salinity, chlorophyll, dissolved oxygen and ocean currents.

1. Average Temperature and Salinity

Vertical distributions of the temperature and salinity fields over the Flemish Cap along 47^{o} N averaged over the period of July 9 to August 6 based on all available historical data from 1971-2000 are shown in Fig. 2. These dates were chosen to span a one-month period centred on the 2003 observations. No other attempts were made to adjust the mean for possible temporal biasing arising from variations in the number of observations within the time interval.

The average surface temperature for this time period ranges from 9^{o}-10^{o}C on the Flemish Pass side of the Cap, to 10^{o} -11^{o}C over the Cap and to the east of the Cap (Fig. 2, upper panel). In the depth range of 50-150 m temperatures range from 2^{o}-3^{o}C on the Flemish Pass side of the Cap to 3^{o}-4^{o}C over the Cap and 3^{o}-6 ^{o}C to the east of the Cap. Deeper water temperatures (>200 m) in the Pass range from 3^{o}-4^{o}C. Bottom temperatures over the Cap and on the eastern slopes of the Cap generally range from 3.5^{o} to 4^{o}C. The corresponding average surface salinities (Fig. 2, bottom panel) range from less than 33.25 in the Flemish Pass to about 33.5-33.75 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. In general, cold sub-surface and relatively fresh surface water from the Newfoundland Shelf normally influences the water mass characteristics over most of the Flemish Cap.

2. **2003 Temperature and Salinity**

Surface temperatures over the Flemish Cap during the summer of 2003 (Fig. 3, top panel) ranged from about 10^{o}-12^{o}C, which were generally above normal in most areas, by up to 3^{o}C on the Flemish Pass side of the Cap and by up to 4^{o}C to the east of the Cap (Fig. 3, bottom panel). Near-bottom temperatures over the Cap were generally around 3.5^{o}C, which was below normal, particularly on the western side of the Cap in the range of 200-300 m. Below the surface layer, intermediate depth waters were above normal across most of the region, except for directly over the Cap where they were variable. The edge of the cold intermediate waters with temperatures <2^{o}C from the

Newfoundland Shelf were present in the Flemish Pass during July of 2003. The most significant anomaly observed during the summer 2003 survey was the very warm water associated with the North Atlantic Current to the east of the Cap. This circulation feature appeared to lie much further to the east resulting in temperatures near 15^{o}C at the surface and values >10^{o}C at 300 m depth. As a result temperature anomalies in this region were as high as 8^o-9^{o}C above normal.

Surface salinities observed during the summer of 2003 (Fig. 4, top panel) show values ranging from <34 over the Flemish Pass to between 34.25-34.5 over the Cap. Salinities near bottom over the Cap in water depths around 150 m were generally >34.5 and >34.75 below 250 m depth. In general these values were above the long-term mean in the upper 100-m of the water column by up to 1 unit in some areas. Near bottom values in water depths of 150-500 m were near the long-term mean. Again the most significant anomaly observed in the salinity field during the summer 2003 survey was the saltier water associated with the North Atlantic Current to the east of the Cap. Salinities in this area were >35.5, resulting in salinity anomalies as high as 1.25 above the long-term mean (Fig. 4, bottom panel).

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

The time series of annual temperature anomalies in the upper water column on the Flemish Cap (Fig. 5, left panels) are characterised by three major cold periods and two warm periods. Colder-than-normal temperatures occurred during most of the 1970s, mid-1980s and the late-1980s to the mid-1990s, with warmer-than-normal conditions during most of the 1960s and late-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 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 normal at 150 m and slightly above normal at shallower depths. Near surface temperatures during 2003 were above normal, an increase over the below normal values observed in 2002. Temperatures at 100-m depth during both 2002 and 2003 were about the same, slightly above normal, while near-bottom temperature (150 m) increased slightly during 2003. In general, these conditions are very similar to those observed on the Newfoundland Shelf during the same period (Colbourne and Foote, 2000).

The time series of annual salinity anomalies (Fig. 5, right panels) show fresher-than-normal conditions during the mid-1970s and mid-1980s 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 until 1995 from the surface to about 100-m depth. From 1996 to 1998 salinities were generally above normal. During 1999-2000 salinities were near the long-term average on the Flemish Cap but increased to above normal during 2001-2002. Upper layer salinities during 2003 increased to some of the highest values observed in the time series. In general, temperature anomalies are very similar to those at Station 27 and elsewhere on the continental shelf over similar depth ranges (Colbourne, 1998b). It should be noted however, that unlike the time series of anomalies from fixed points (e.g. Station 27), these anomalies are based on data collected over a larger geographical area and therefore may exhibit variability due to spatial differences in the monthly estimates. In addition, the annual values may be based on only a few monthly estimates for the year. Therefore caution should be used when interpreting short time scale features of these series. The long-term trends however, generally show real features.

5. **2003 Chlorophyll and Dissolved Oxygen**

The vertical distribution of dissolved oxygen saturation during the summer of 2003 along the standard NAFO section across the Grand Bank and the Flemish Cap is shown in Fig. 6. These data were collected in conjunction with the temperature and salinity data using a SBE-43 type polarographic element dissolved oxygen sensor interfaced to a Seabird-911 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 least-squares fit (slope 0.98, intercept 0.12) of the titration measurements to the electronic sensor measurements. Over the Flemish Cap dissolved oxygen saturation levels during the summer of 2003 ranged from 100-105% from the surface to about 40-m depth (Fig. 6). From 50-100 m depth, saturation values decreased from 100% to 90% and near bottom values were generally around 90% saturation. In general oxygen levels observed along this section 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 summer of 2003 across the Grand Bank and the Flemish Cap is shown in Fig. 7. These data were collected in conjunction with the temperature and salinity data using a fluorometer interfaced to a Seabird-911 CTD system. No field calibrations were applied to the chlorophyll values presented here. The chlorophyll concentrations were generally low over the Grand Bank but somewhat higher over the Flemish Cap. Maximum chlorophyll values over the Cap were confined to the surface layer of about 75-m thick (Fig. 7). 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 vicinity of the Flemish Cap consists of the offshore branch of the Labrador Current which flows through the Flemish Pass on the Grand Bank side of the continental slope and a jet that flows to the east, north of the Cap, which then flows southward. 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 (mainly summer) 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 and invertebrate species, such as cod, redfish and shrimp (Kudlo and Borovkov, 1977; Kudlo and Boytsov, 1979).

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. Gil *et al.* (2002) and Colbourne and Foote (2000) provided additional analysis based on more recent data. The geostrophic currents perpendicular to the 47^{o}N section calculated from the density data collected during the summer of 2002 and 2003 are shown in Fig. 8 and 10. These estimates, which are referenced to 300 m, or the bottom, in water depths <300 m, show 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 current estimates over the Cap itself show evidence of anticyclonic circulation with northward flowing water to the west and southward flow on eastern side of the Cap. The northward component on the western side of the Cap during 2002 however appears much weaker than that observed during the summers of 1999, 2000 and 2003 (Colbourne, 2000).

During most oceanographic surveys of the 1990s and up to 2003 ocean currents around the Flemish Cap area 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 <500 m where bottom referencing was possible. The useful range of the ADCP current measurements during these surveys was about 10 to 300-m depth. The circulation around the Flemish Cap determined from these measurements was predominately anticyclonic in all surveys since 1993, with typical re-circulation times ranging from 50 to 70 days. Vertical cross-sections of the north-south currents over the Flemish Cap during July of 2002 and 2003 along 47^{o}N latitude from the ADCP measurements are displayed in Fig. 9 and 11. These measurements show a northward component with speeds 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 >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. 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 during the summer.

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References

AKENHEAD, S. 1981. Local sea-surface temperature and salinity on the Flemish Cap. *NAFO SCR Doc*., 87/66, Ser. No. N426, 20 p.

BAILEY, W.B. 1982. A time-series of sea-surface temperature on the Flemish Cap, 1962-81. *NAFO SCR Doc*., 82/4, Ser. No. N489, 7 p.

CABANAS, J. M. 2002. Hydrographic conditions on the Flemish Cap in July 2001. *NAFO SCR Doc*., 02/25, Ser. No. N4631, 10 p.

CABANAS, J. M. 2003. Hydrographic conditions on the Flemish Cap in July 2002. *NAFO SCR Doc*., 03/32, Ser. No. N4848, 9 p.

CERVIFIO, S. and R. PREGO. 1996. Hydrographic conditions on the Flemish Cap in July 1996. *NAFO SCR Doc*., 97/17, Ser. No. N2847, 13 p.

COLBOURNE, E.B. S. NARAYANAN, and S. PRINSENBERG. 1994. Climate change and environment conditions in the Northwest Atlantic during the period 1970-1993. *ICES Mar. Sci. Symp*., **198**: 311-322.

COLBOURNE, E. B., and K. D. FOOTE. 2000. Variability of the stratification and circulation on the Flemish Cap.during the decades of the 1950s-1990s. *J. Northw. Atl. Fish Sci*., **26**: 103-122.

COLBOURNE, E. B. 1993. Oceanographic conditions on the Flemish Cap during the summer of 1993, with comparisons to the long-term average. *NAFO SCR Doc*., 93/107, Ser. No. N2300, 36 p.

COLBOURNE, E. B. 1995. Oceanographic conditions on the Flemish Cap during the summer 1995, with comparisons to the 1961-1990 average. *NAFO SCR Doc*., 95/102, Ser. No. N2625, 12 p.

COLBOURNE, E. B. 1996. Oceanographic conditions on the Flemish Cap during the summer 1996, with comparisons to the previous year and the 1961-1990 average. *NAFO SCR Doc*., 96/87, Ser. No. N2770, 12 p.

COLBOURNE, E. B. 1997. Oceanographic conditions on the Flemish Cap during the summer 1997, with comparisons to the previous year and the 1961-1990 average. *NAFO SCR Doc*., 97/84, Ser. No. N2930, 15 p.

COLBOURNE, E. B. 1998a. Oceanographic conditions on the Flemish Cap during the summer 1998, with comparisons to the previous year and the 1961-1990 Average. *NAFO SCR Doc*., 98/86, Ser. No. N3087, 16 p.

COLBOURNE, E. B. and K. D. FOOTE. 1998b. Oceanographic variability on the Flemish Cap. *NAFO SCR Doc*., 98/35, Ser. No. N3022, 56 p.

COLBOURNE, E. B. 1999. Oceanographic conditions on the Flemish Cap during the summer 1999, with comparisons to the previous year and the 1961-1990 average. *NAFO SCR Doc*. 99/101, Ser. No. N4180, 18 p.

COLBOURNE, E. B. 2000. Oceanographic conditions on the Flemish Cap during the summer 2000, with comparisons to the previous year and the 1961-1990 average. *NAFO SCR Doc*., 00/73, Ser. No. N4330, 19 p.

COLBOURNE, E. B. 2001. Oceanographic conditions on the Flemish Cap during the spring of 2001, with comparisons to the previous year and the 1971-2000 average. *NAFO SCR Doc*., 01/, Ser. No. N4330, 19 p.

COLBOURNE, E. B. 2002. Oceanographic conditions on the Flemish Cap in NAFO Division 3M during the summer of 2002. *NAFO SCR Doc*., 02/152, Ser. No. N4781, 14 p.

COLBOURNE, E. B. 2003. Physical Oceanographic Conditions on the Newfoundland and Labrador Shelves during 2002. *Canadian Science Advisory Secretariat Research Doc*., 2003/23, 56 p.

DRINKWATER, K. F. and R. W. TRITES. 1986. Monthly means of temperature and salinity in the Grand Banks region. *Can. Tech. Rep. Fish. Aquat. Sci*., **1450**: iv+111 p.

DRINKWATER, K. F. 1996. Climate and oceanographic variability in the Northwest Atlantic during the 1980s and early-1990s. *J. Northw. Atl. Fish. Sci*., **18**: 77-97.

GARABANA, D., J. GIL and R. SANCHEZ. 2000. Hydrographic conditions on the Flemish Cap in July 1999 and comparison with those observed in previous years. *NAFO SCR Doc*., 00/08, Ser. No. N4227, 13 p.

GIL, J., R. SÁNCHEZ, S. CERVIÑO and D. GARABANA. 2002. Geostrophic Circulation and Heat Flux across the Flemish Cap, 1988-2000. *NAFO SCR Doc*. 02/37, Ser. No. N4648, 26 p.

HAYS, R. M., D.G. MOUNTAIN and T.C. WOLFORD. 1978. Physical oceanography and the abiotic influence on cod recruitment in the Flemish Cap region. *ICNAF Res. Doc*., 77/54, Ser. No. 5107, 33 p.

KEELEY, J.R. 1981. Mean conditions of potential temperature and salinity along the standard Flemish Cap Section. *Mar. Environ. Data Serv. Tech. Rep*., No. **9**: 148 pp.

KUDLO, B.P. V.A. BOROVKOV and N.G. SAPRONETSKAYA. 1984. Water circulation patterns on the Flemish Cap from observations in 1977-82. *NAFO Sci. Coun. Studies*, **7**: 27-37.

KUDLO, B.P. and V.V. BURMAKIN. 1972. Water circulation in the South Labrador and Newfoundland areas in 1970-71. *ICNAF Redbook,* **1972** (iii): 22-33.

KUDLO, B.P. and V. A. BOROVKOV. 1975. Circulation of waters in the ICNAF area in 1973-1974. *ICNAF Res. Doc*., No. 79, Serial No. 3506, 12 p.

KUDLO, B.P. and V.A. BOROVKOV. 1977. Hydrological regime of the Labrador Current and reproduction of commercial fishes. Syezd Sovetskikh Okeanologov, Tezisy Dokladov, Moskva vyp. ii: 33-134.

KUDLO, B.P. and V. D. BOYTSOV. 1979. The effect of water dynamics on year-class strength of cod on Flemish Cap. *ICNAF Sel. Papers,* **5**: 7-9.

LOPEZ, SANTIAGO CERVINO, 2001. Hydrographic conditions on the Flemish Cap in July 2000. *NAFO SCR Doc*., 01/24, Ser. No. N4395, 10 p.

ROSS, C.K. 1981. Drift of satellite-tracked buoys on the Flemish Cap, 1970-80. *NAFO Sci. Coun. Studies*, **1**: 47-50.

STEIN, M. 1996. Flemish Cap **-** A review on Research Activities with Focus on Oceanographic Conditions. *NAFO Sci. Coun. Studies*, **25**:1-24.

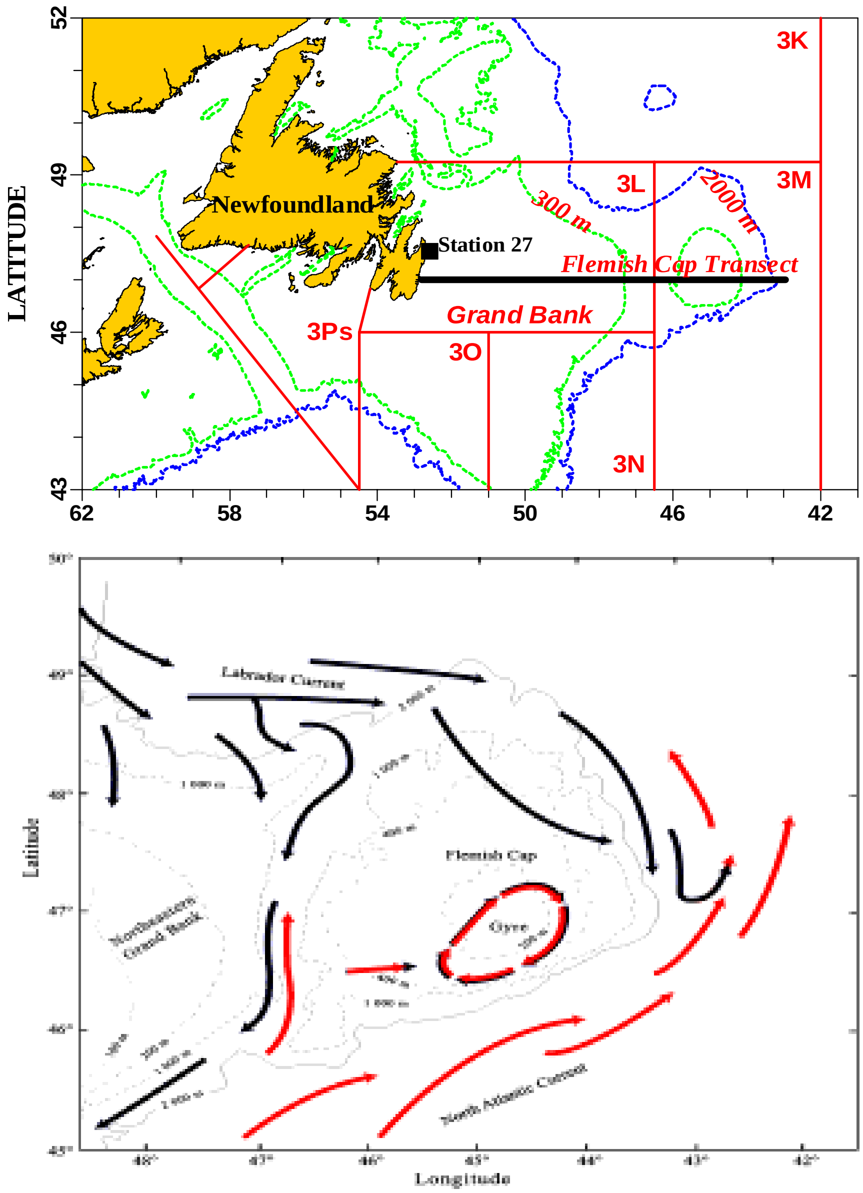

Fig. 1. Areal map showing the standard Flemish Cap section in NAFO Sub-area 3 and the Flemish Cap region in NAFO Div. 3M (top panel) and the major circulation features around the Flemish Cap area (bottom panel).

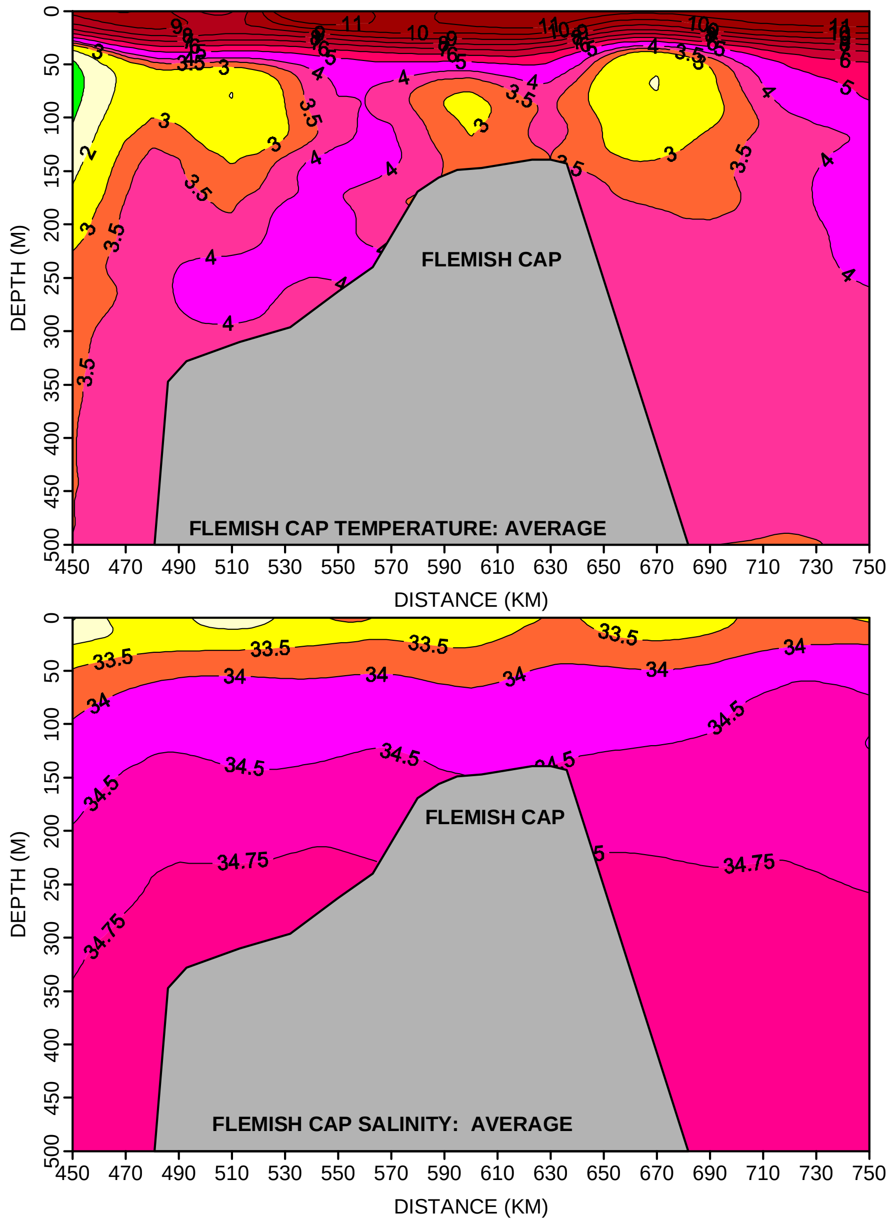

Fig. 2. Average temperature (in ^{o}C) and salinity on the Flemish Cap based on all data collected between July 9 to August 6 for the years 1971-2000.

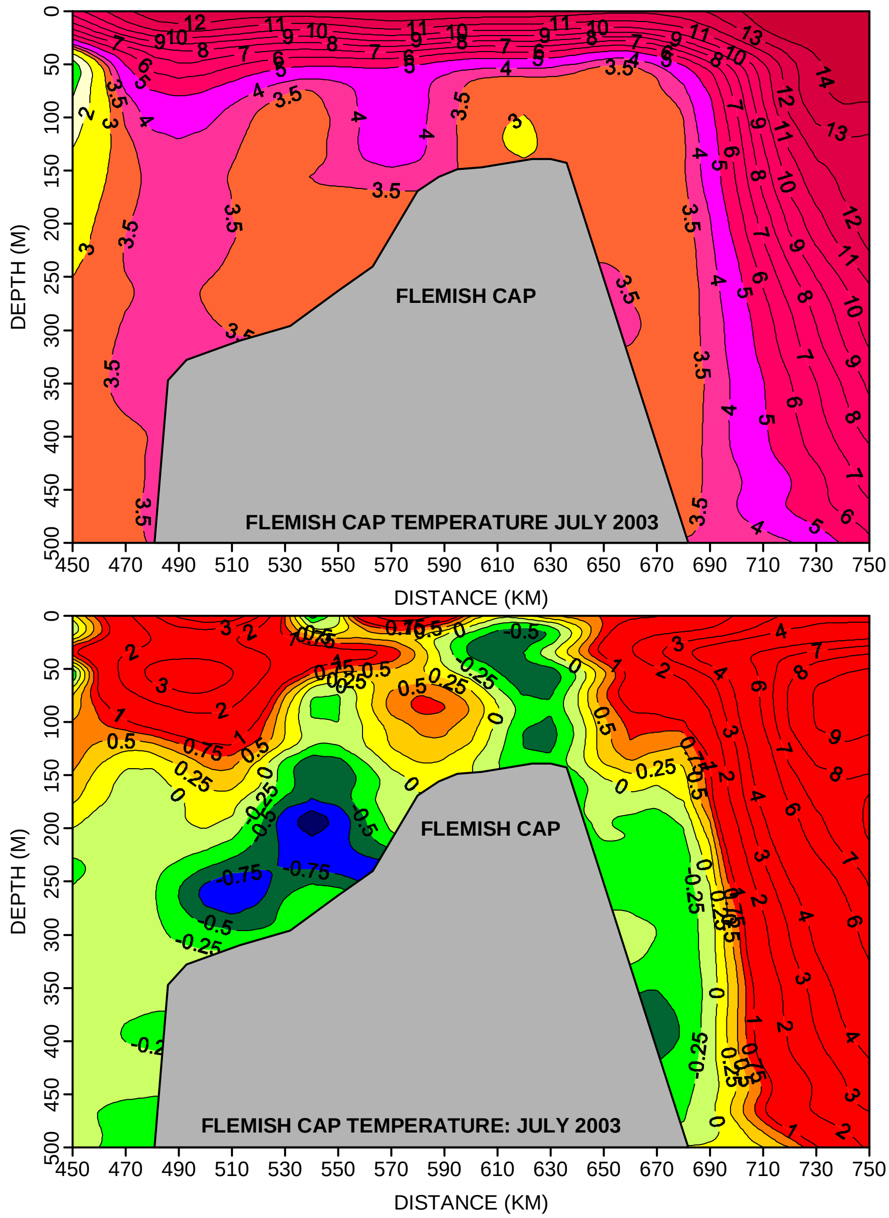

Fig. 3. The vertical distribution of temperature and temperature anomalies (in °C) over the Flemish Cap (along 47°N) for the summer of 2003.

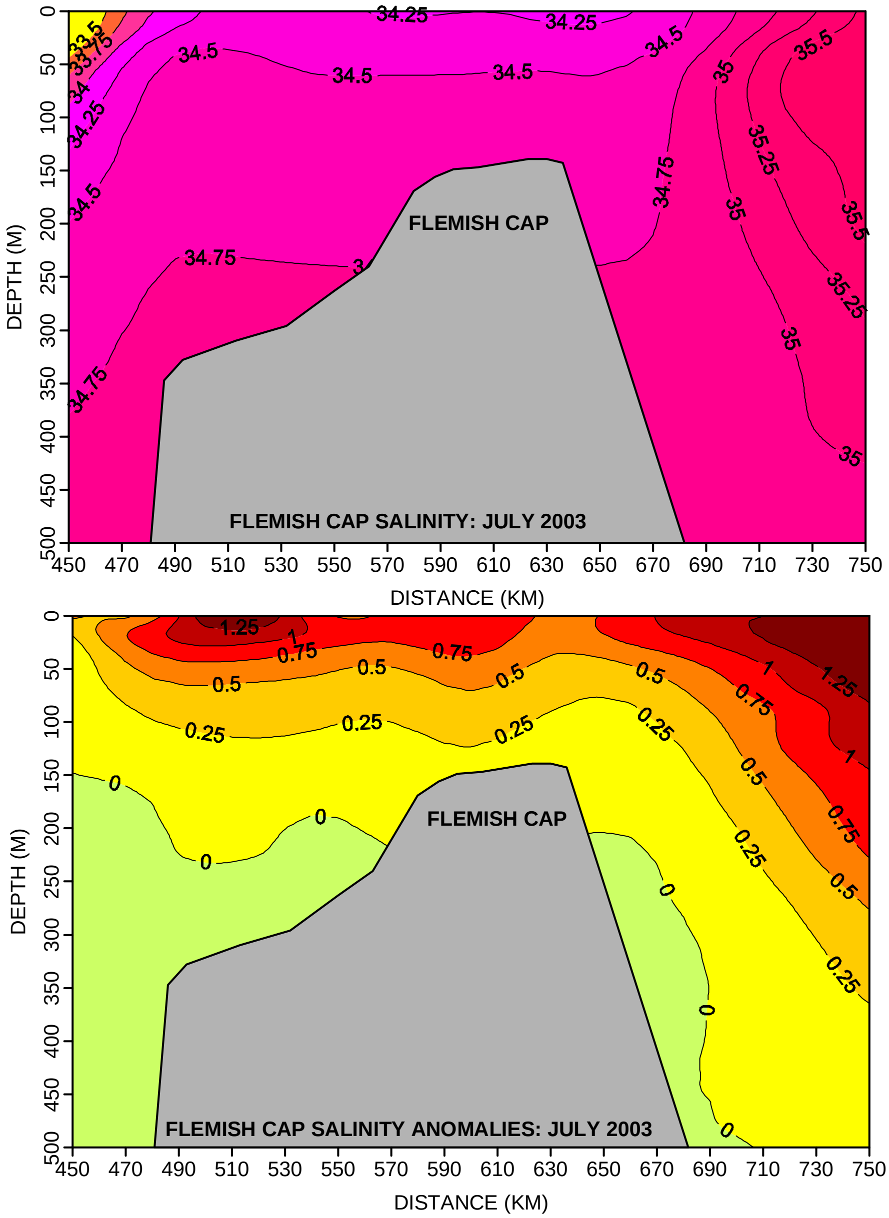

Fig. 4. The vertical distribution of salinity and salinity anomalies over the Flemish Cap (along 47°N) for the summer of 2003.

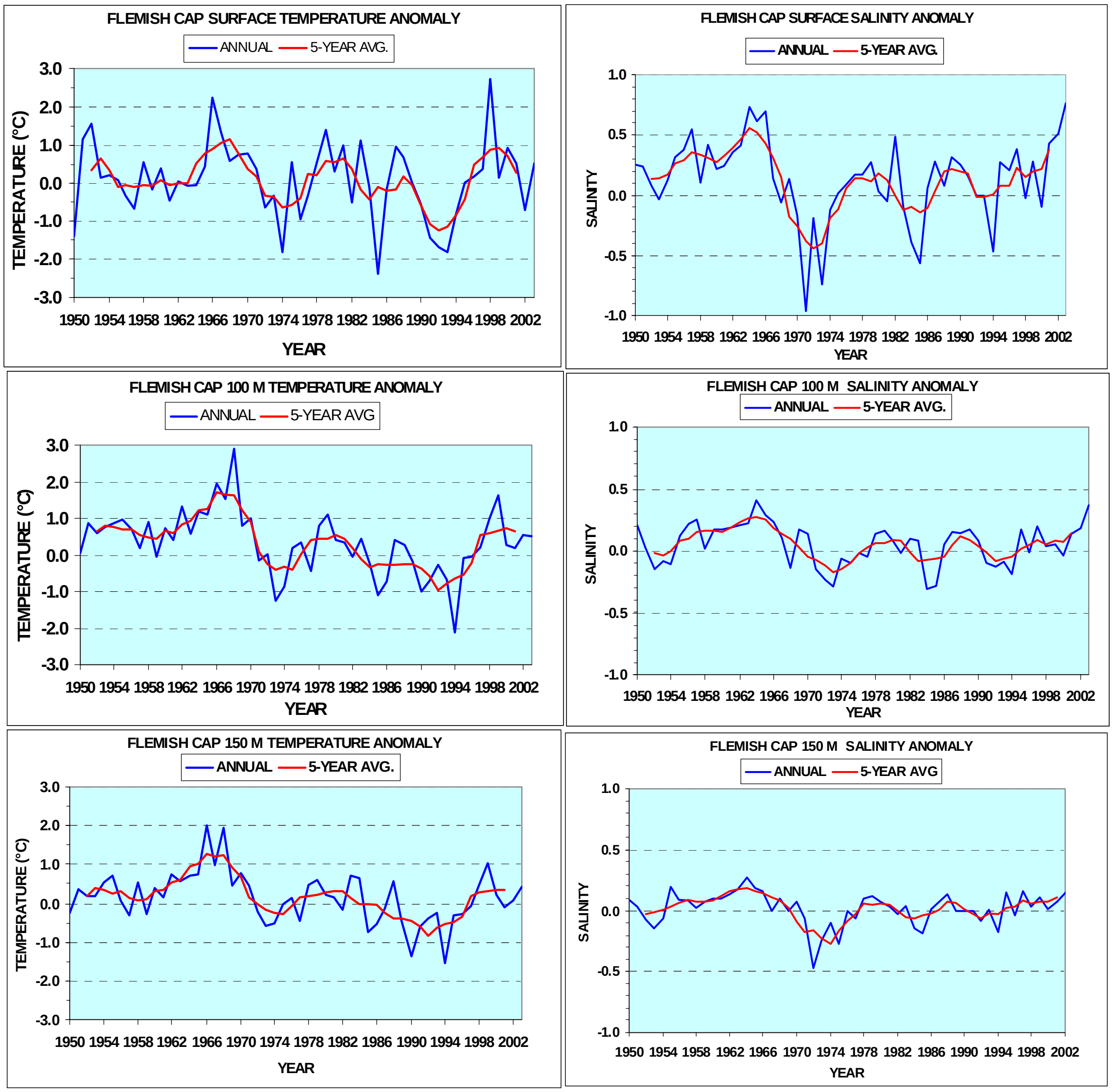

Fig. 5. Annual temperature and salinity anomalies at standard depths on the Flemish Cap in NAFO Div. 3M. The solid line represents a 5-year running mean.

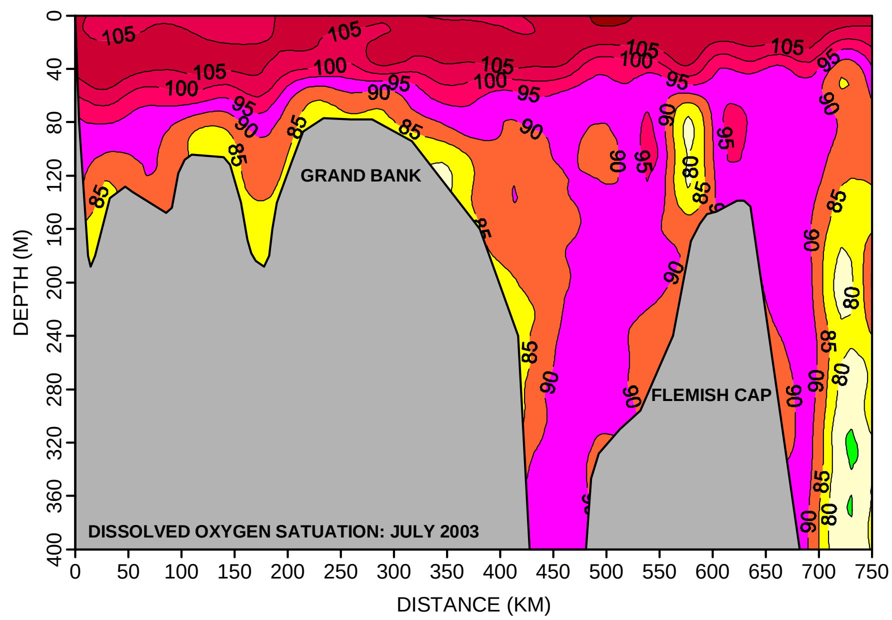

Fig. 6. The vertical distribution of dissolved oxygen percent saturation along 47°N for the summer of 2003.

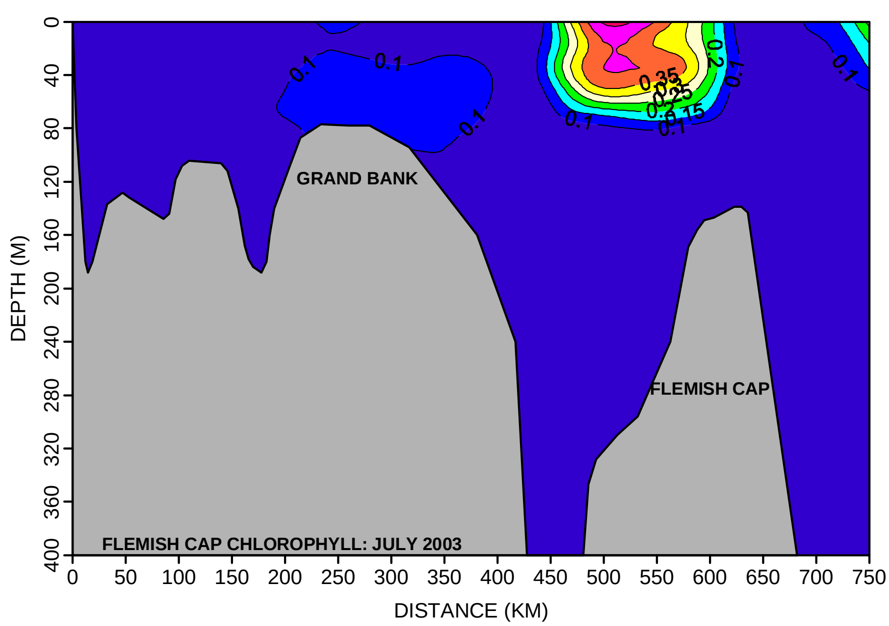

Fig. 7. The vertical distribution of chlorophyll concentrations (mg/l) along the 47°N transect for the summer of 2003.

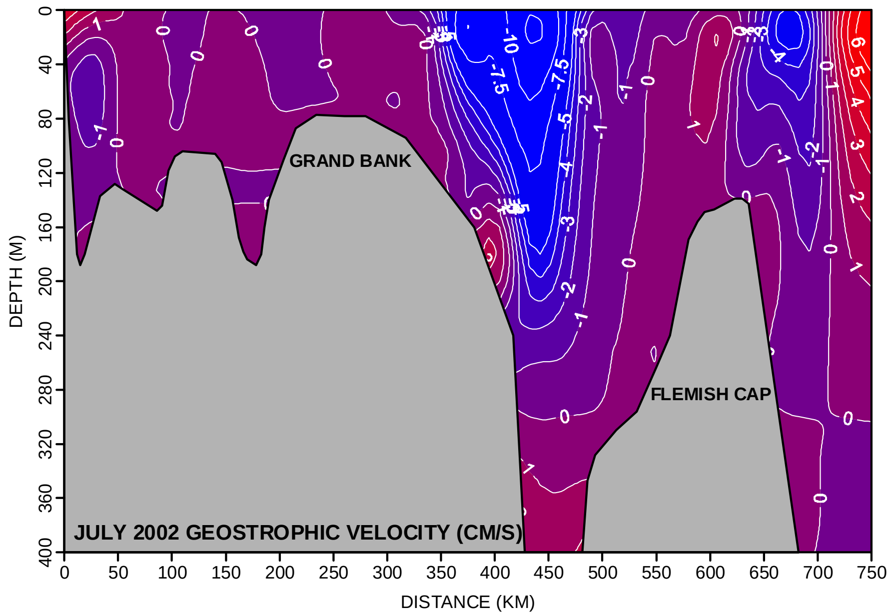

Fig. 8. The vertical distribution of the N-S geostrophic current field (in cm/s) over the Flemish Cap during the summer of 2002 estimated from the density data. Negative currents (blue) are southward and positive currents (red) are northward.

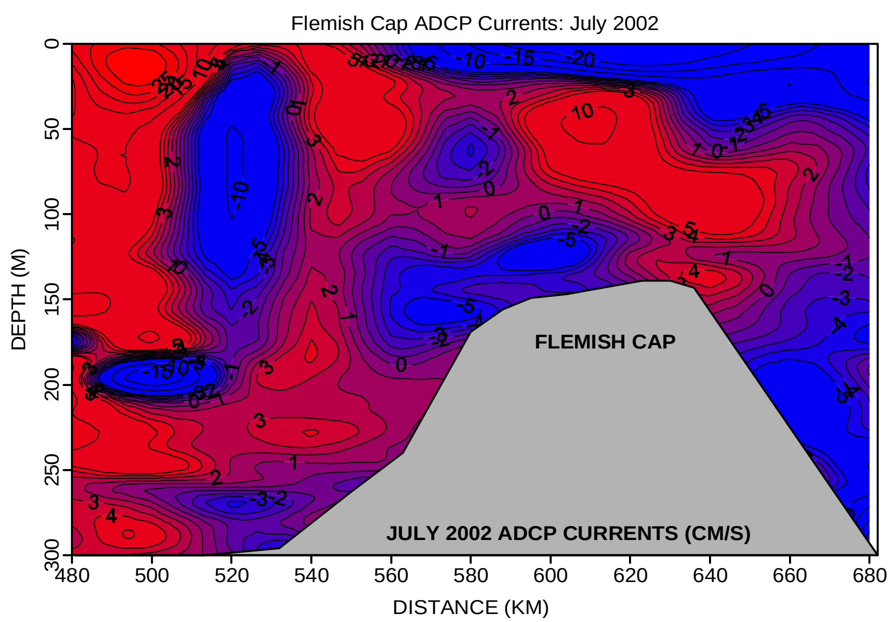

Fig. 9. A vertical cross-section of the N-S current field (in cm/s) over the Flemish Cap (along 47°N) during July of 2002 measured with a 150 kHz ADCP. Negative currents (blue) are southward and positive currents (red) are northward.

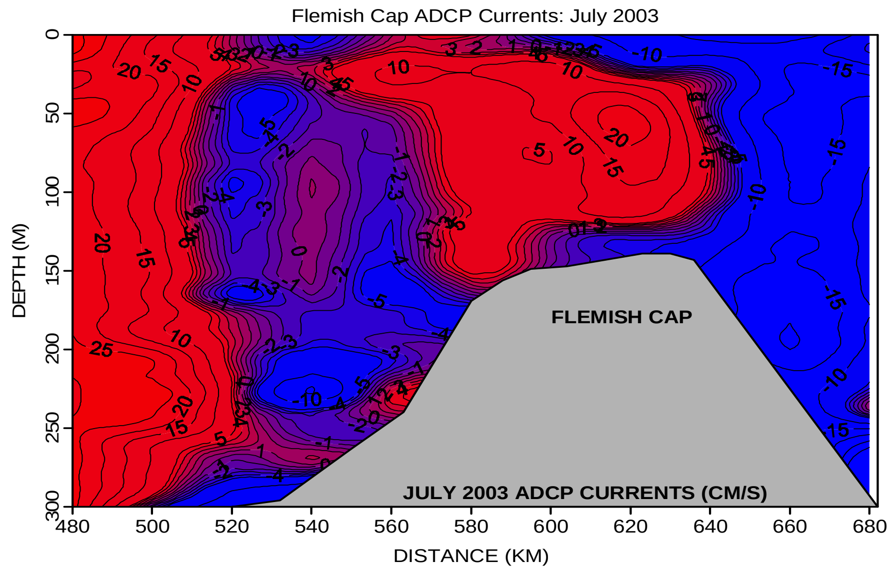

Fig. 10. The vertical distribution of the N-S geostrophic current field (in cm/s) over the Flemish Cap during the summer of 2003 estimated from the density data. Negative currents (blue) are southward and positive currents (red) are northward.

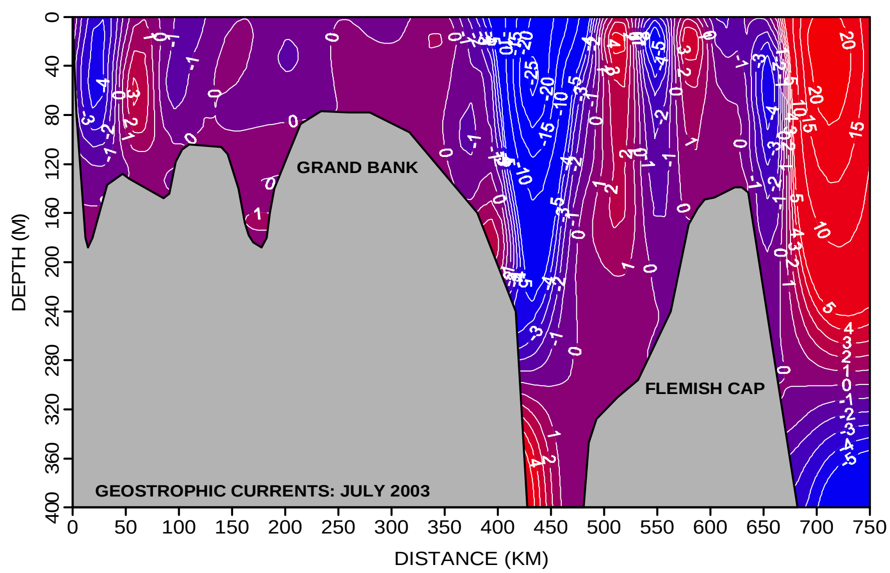

Fig. 11. A vertical cross-section of the N-S current field (in cm/s) over the Flemish Cap (along 47^{o}N) during the summer of 2003 measured with a 150 kHz ADCP. Negative currents (blue) are southward and positive currents (red) are northward.