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Oceanographic Conditions on the Flemish Cap in NAFO Division 3M During the Summer of 2002

by

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ABSTRACT

Oceanographic data from the summer of 2002 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 directly over the Flemish Cap during the spring of 2001 were generally below normal by up 0.5^{o}C which decreased further to 2^{o}C below normal during the summer of 2002. Intermediate depth temperatures over the Cap were generally above normal by up to 2^{o}C while bottom temperatures ranged from above normal over the shallowest water depths to near normal below 150 m depth, similar to that observed during 2000 and 2001. These values represent a decrease over the 1^{o}C above normal bottom temperatures in 1999. Salinities over most of the upper water column during the summer of 2002 were similar to the spring of 2001, generally saltier-than-normal (by 0.25-0.5). 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 the summer of 2002 most areas of the water column except for the near surface layer were either at or above normal. During 2002 and throughout 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. 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.

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 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. During the late 1990s however, the ocean climate in this region has returned to more normal like 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 1995-2001 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). 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) 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 2002 and represents the tenth such review of oceanographic conditions on and around the Flemish Cap in support of the annual shrimp assessment for NAFO Division 3M.

The report describes oceanographic variability on the Flemish Cap during the summer of 2002 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 observations presented here were made by Canada's Department of Fisheries and Oceans oceanographic survey during the summer of 2002. 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 temperature, salinity, chlorophyll, dissolved oxygen and ocean currents.

Average Temperature and Salinity

Vertical distributions of the temperature and salinity fields over the Flemish Cap along 47^o N averaged over the time period of June 30 to July 28 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 2002 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 7^o-8^{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 1^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 to bottom) in the Pass range from 3^o-4^{o}C. Bottom temperatures over the Cap and on the eastern slopes of the Cap 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.

2002 Temperature and Salinity

Surface temperatures over the Flemish Cap during the summer of 2002 (Fig. 3 top panel) ranged from about 8^o-9^{o}C, which were up to 2^{o}C below normal in most areas (Fig. 3 bottom panel). Near-bottom temperatures over the Cap ranged from 3.5^o-4^{o}C, which were slightly above normal on the shallowest regions of the Cap in water depths of approximately 150 m and near normal in water depths >200 m. Below the surface layer, intermediate waters were above normal by up to 2^{o}C across most of the region. Cold intermediate waters with temperatures <2^{o}C from the Newfoundland Shelf were present in the Flemish Pass during July of 2002.

The vertical distribution of salinities for the summer of 2002 (Fig. 4 top panel) show values ranging from <33.5 in the upper surface layers over the Flemish Pass to 34-34.5 over the Cap and regions to the east. Salinities near bottom over the Cap in water depths of 150 m were generally >34.5. Salinities in water depths >150 m ranged from 34.5-34.8. The corresponding salinity anomalies during the summer of 2002 were saltier-than-normal (by about 0.5) in the surface layer and by about 0.25 in water depths >75 m to the bottom over the Cap. In the deeper water >250 m salinities were near normal (Fig. 4 bottom panel).

Long-Term Trends in Temperature and Salinity

Similar to conditions on the Newfoundland Shelf the monthly temperature anomalies in the upper water column on the Flemish Cap (Fig. 5 left panels) 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 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. Data from the spring and summer of 2002 indicates a return to colder-than-normal conditions at the surface, while values at 100-150 m depth indicates a slight increase to above normal values.

The time series of 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 up until 1995 at the surface to 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. 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). 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, however the long-term trends generally show real features.

2002 Chlorophyll and Dissolved Oxygen

The vertical distribution of dissolved oxygen saturation for the summer of 2002 along the standard NAFO transect 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 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 a least-squares fit of the titration measurements to the electronic sensor measurements.

Over the Flemish Cap dissolved oxygen saturation levels during the summer of 2002 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%. Near bottom over the Flemish Cap values were generally <85% saturation. Overall, oxygen saturation values were very similar to the summer values observed during both 1999 and 2000 (Colbourne 2000). The super-saturated values in the top 50-m of the water column generally 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 summer of 2002 along the standard NAFO transect 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 but somewhat higher over the Flemish Cap compared to the adjacent Grand Bank. 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).

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 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. The geostrophic currents perpendicular to the 47^{o} N section calculated from the density data collected during the summer of 2000 and 2002 are shown in Figs. 8 and 10. These estimates, which are referenced to 300-m, or the bottom, in water depths less than 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, particularly during 2000. The northward component on the western side of the Cap during 2002 appears much weaker than that observed during the summers of both 1999 and 2000 (Colbourne 2000).

Throughout most of the 1990s and up to 2002 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 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 2000 and 2002 along 47^{o} N latitude from the ADCP measurements are displayed in Figs. 9 and 11. 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

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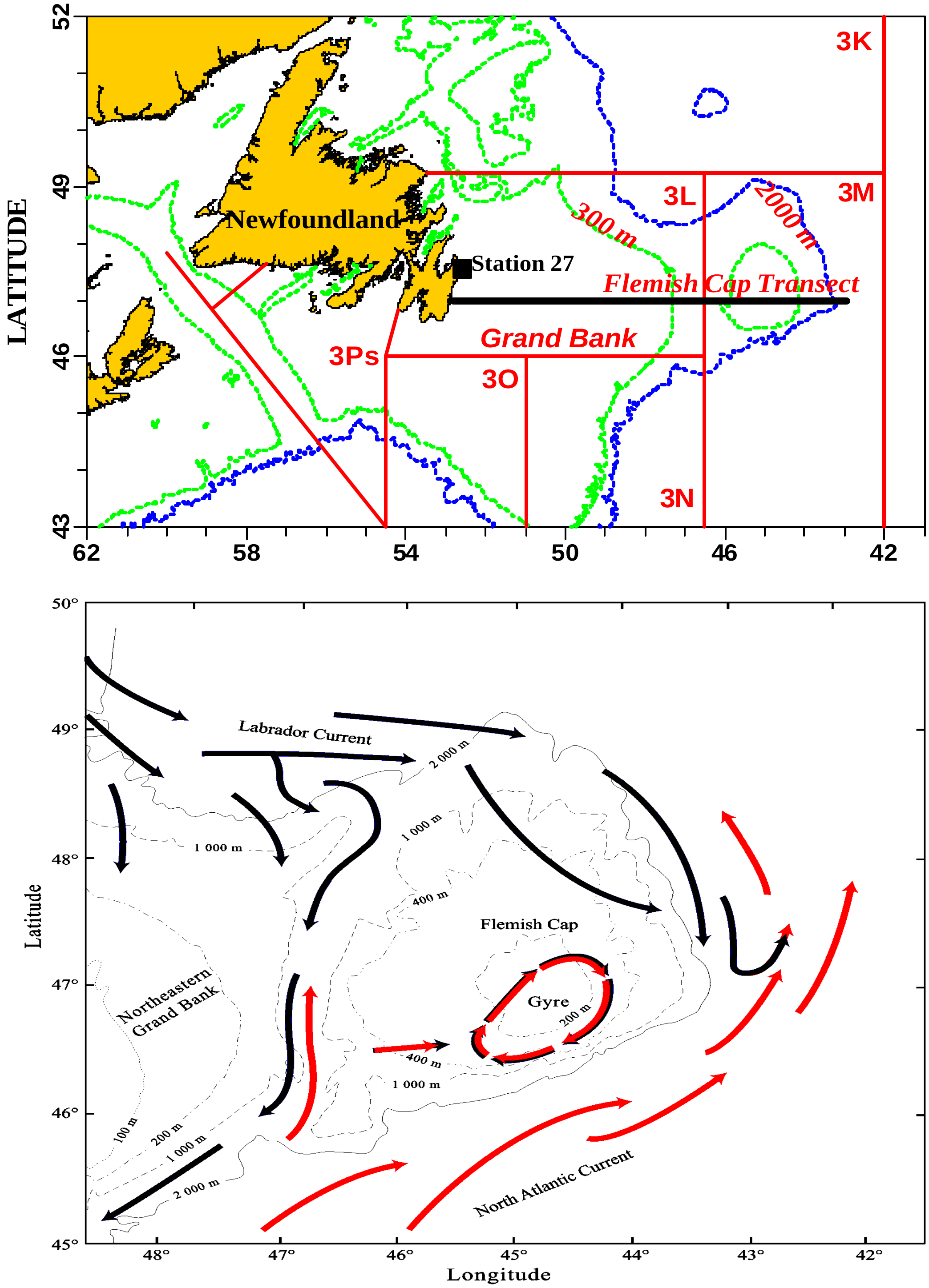

Fig. 1. Areal map showing the standard Flemish Cap section in NAFO Subarea 3 and the Flemish Cap region in NAFO Division 3M (top panel) and the major circulation features around the Flemish Cap area (bottom panel).

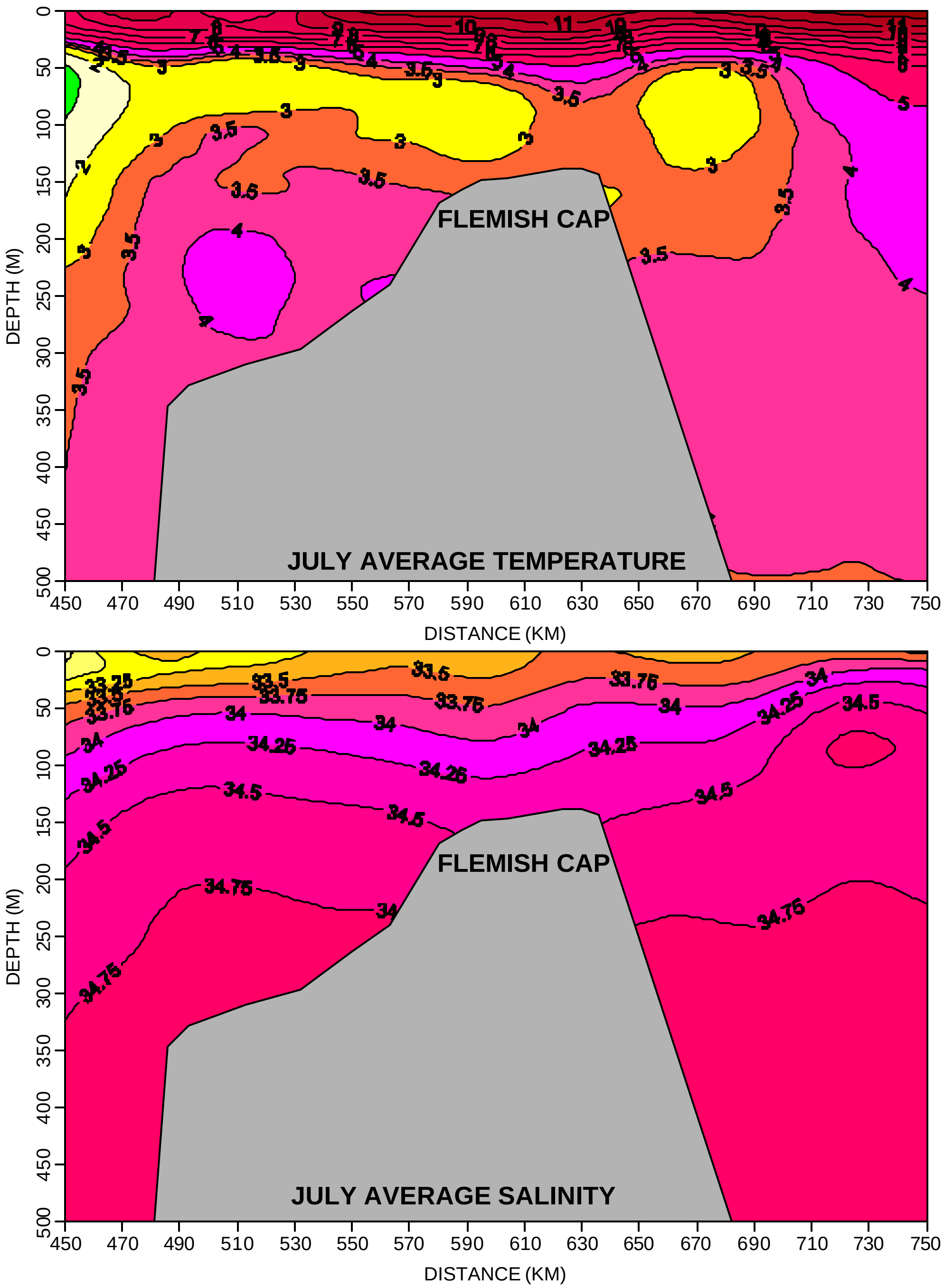

Fig. 2. Average July temperature (in °C) and salinity on the Flemish Cap based on all data collected between 1971-2000.

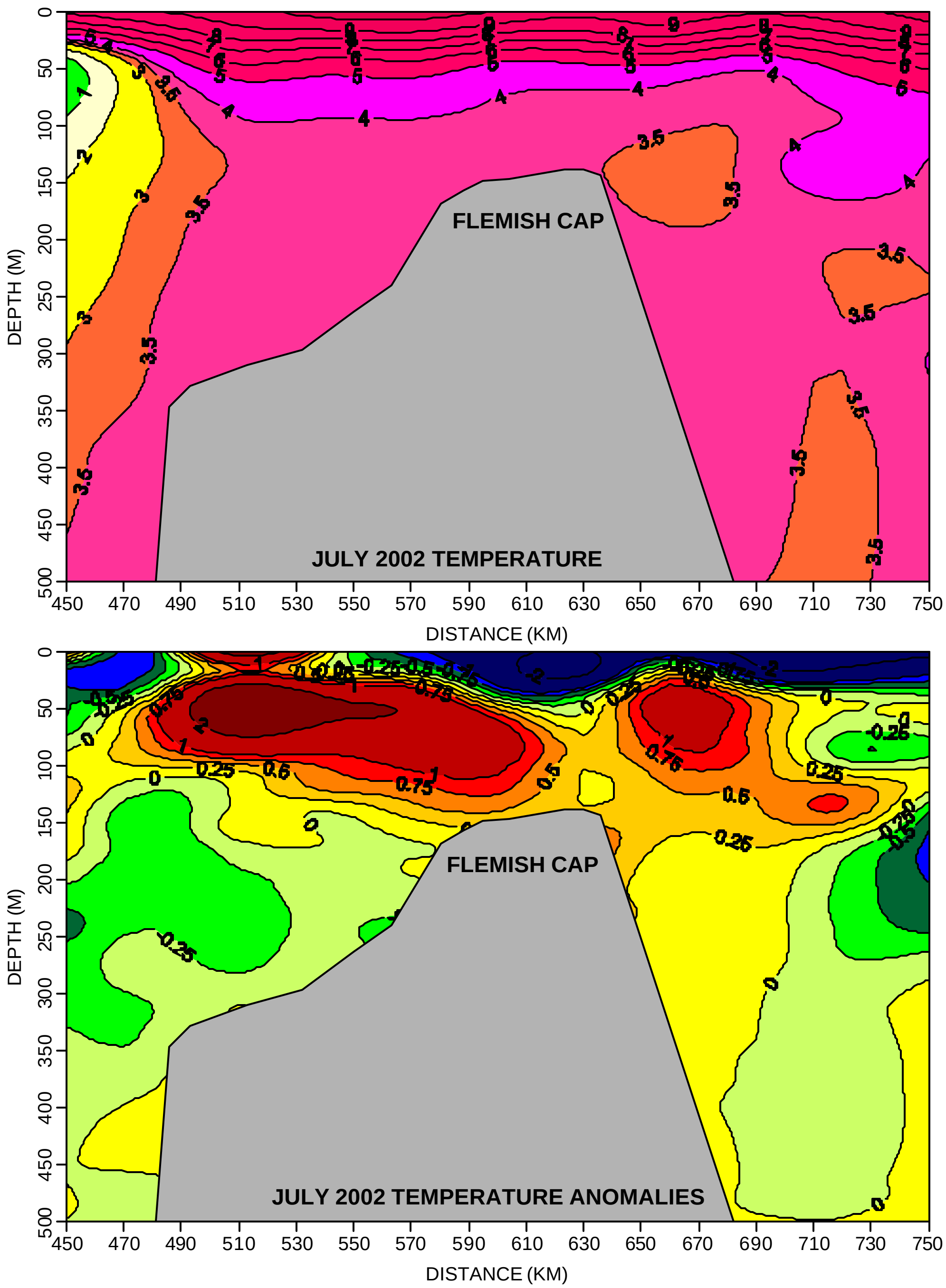

Fig. 3. The vertical distribution of temperature and temperature anomalies (in °C) over the Flemish Cap (along 47°N) for the summer of 2002.

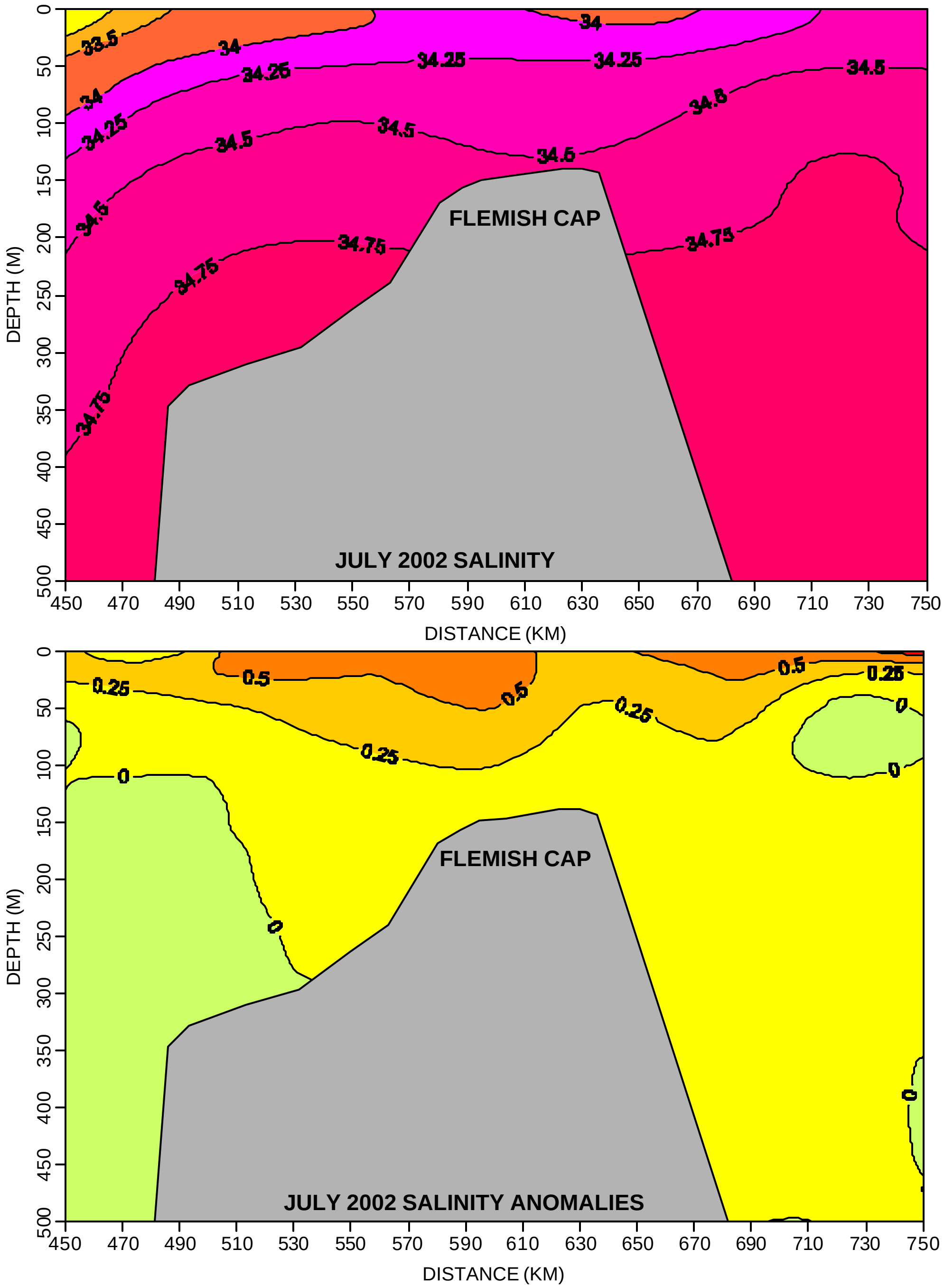

Fig. 4. The vertical distribution of salinity and salinity anomalies over the Flemish Cap (along 47° N) for the summer of 2002.

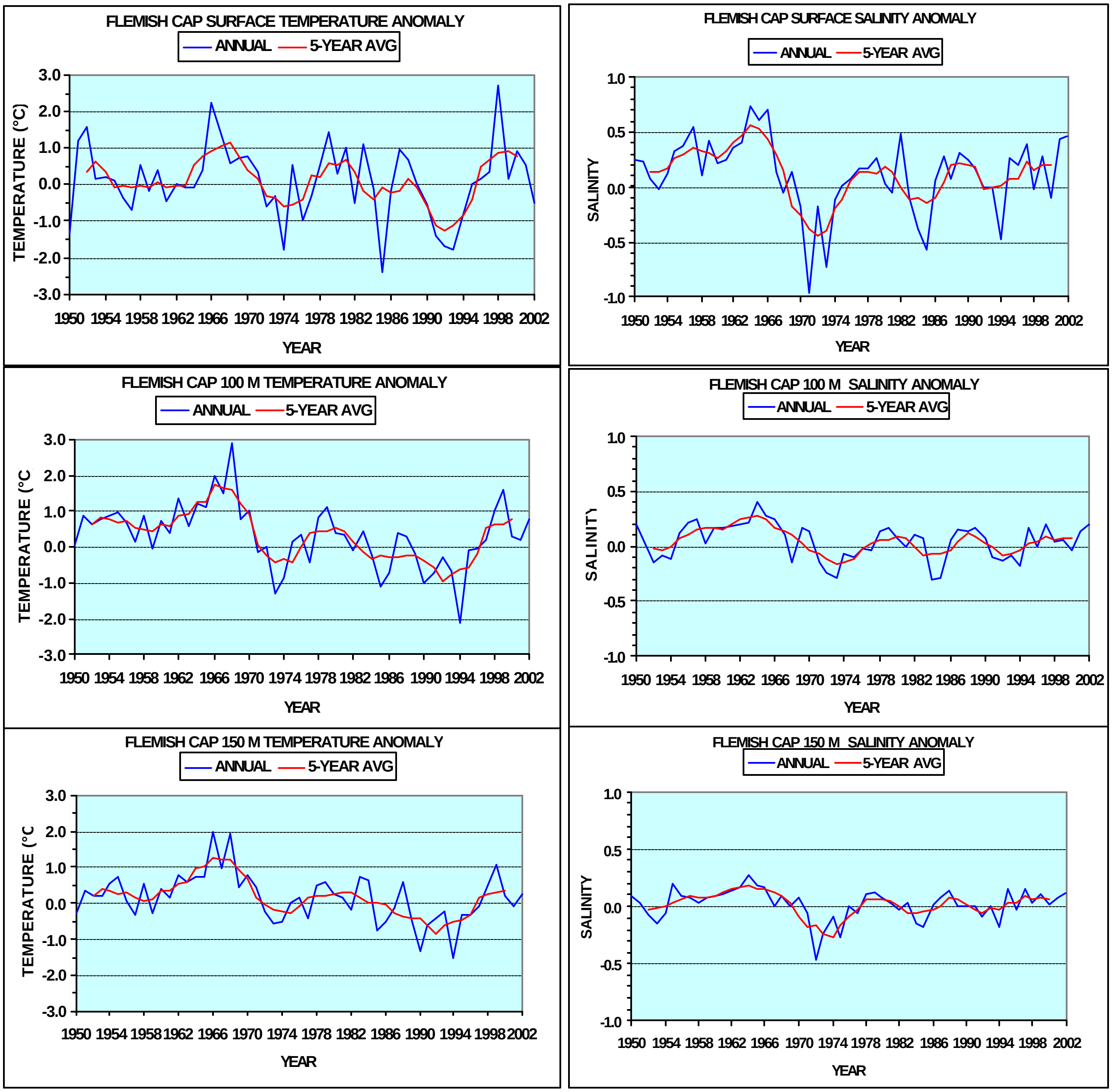

Fig. 5. Annual temperature and salinity anomalies at standard depths on the Flemish Cap in NAFO Division 3M. The solid line represents a 5-year running mean.

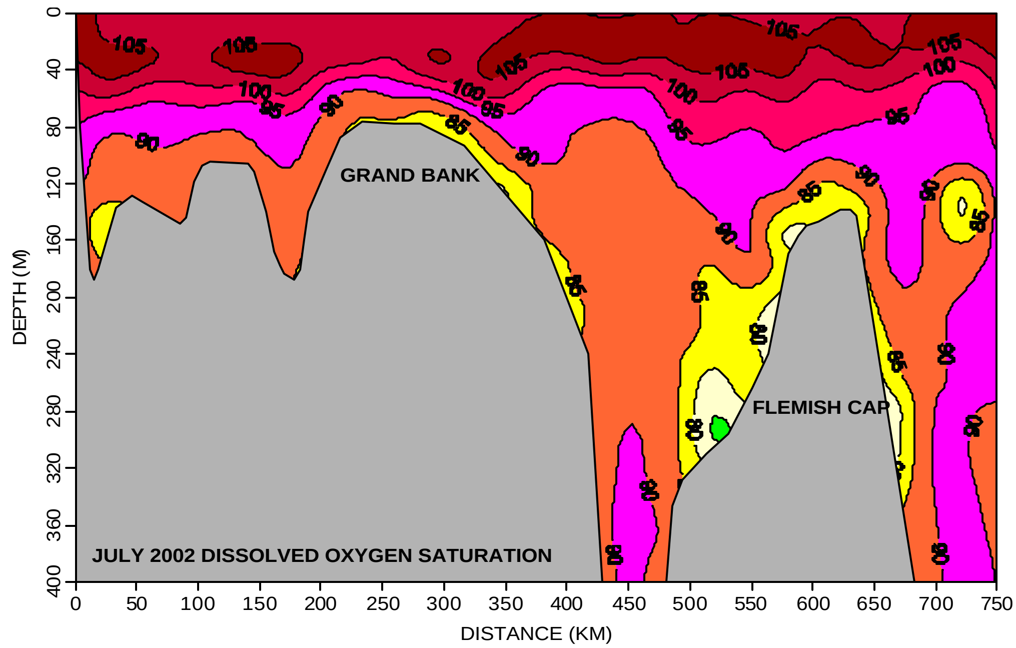

Fig. 6. The vertical distribution of dissolved oxygen percent saturation along 47°N for the summer of 2002.

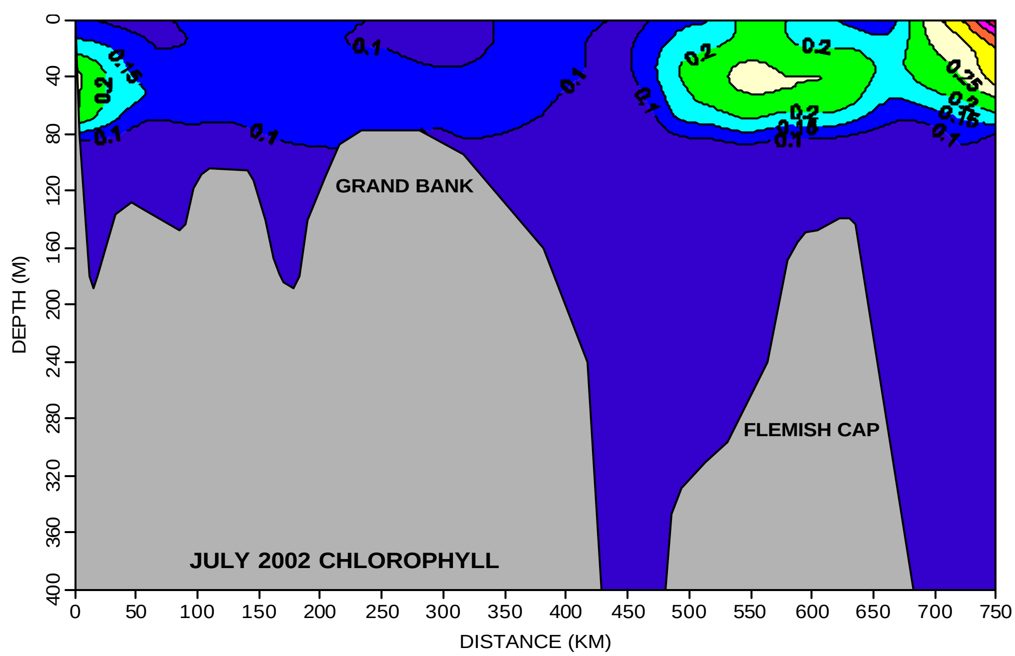

Fig. 7. The vertical distribution of chlorophyll concentrations (mg/l) along the 47°N transect for the summer of 2002.

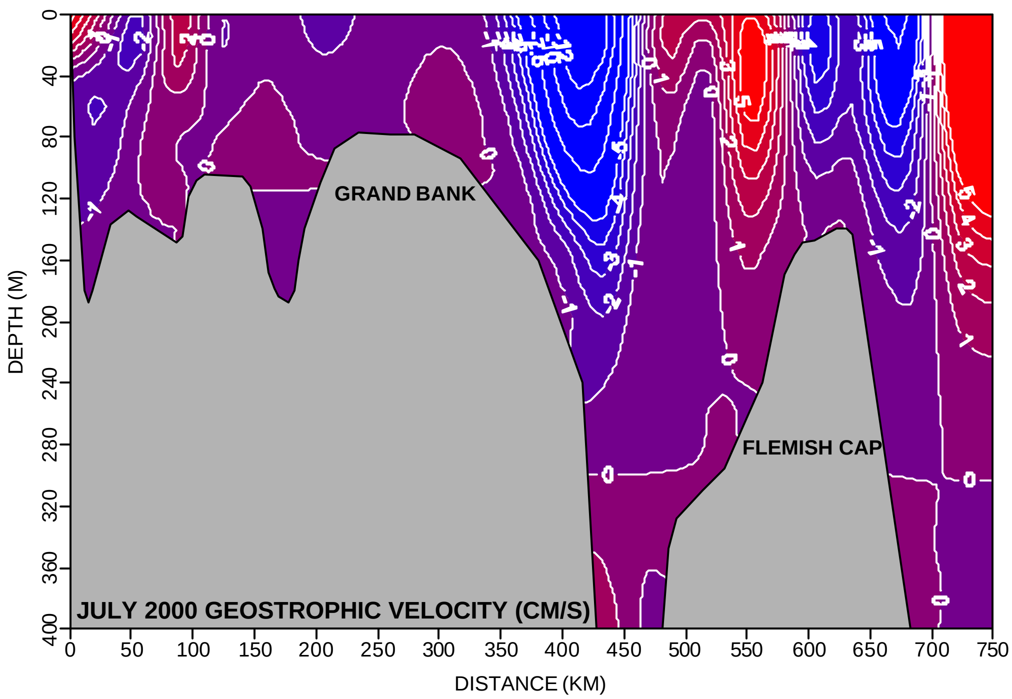

Fig. 8. The vertical distribution of the N-S geostrophic current field (in cm/s) over the Flemish Cap during the summer of 2000 estimated from the density data. Negative currents (blue) are southward and positive currents (red) are northward.

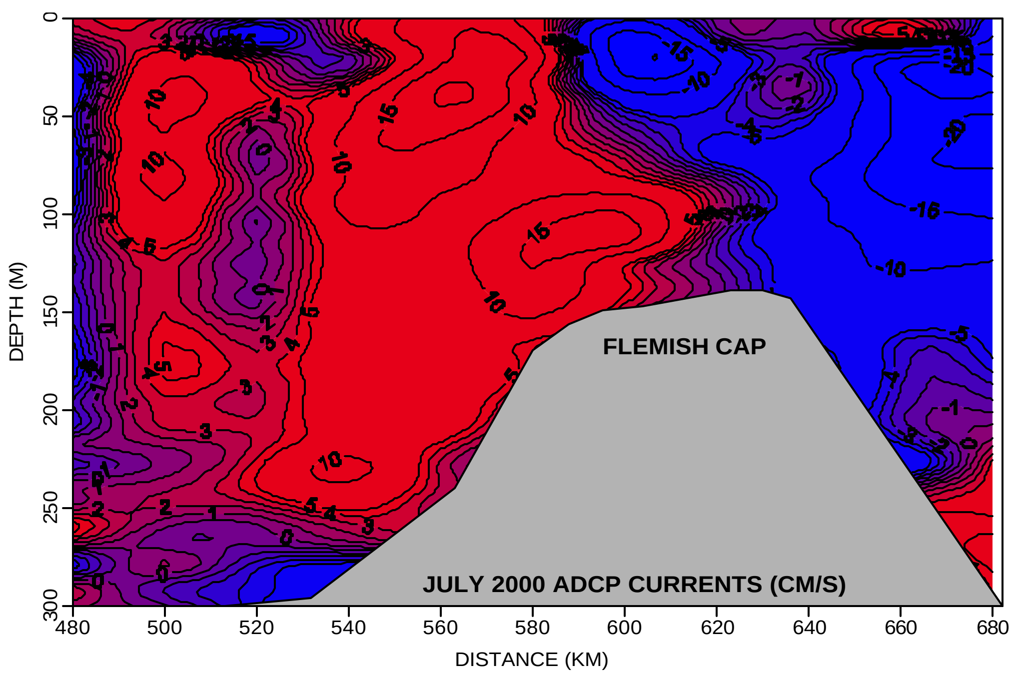

Fig. 9. A vertical cross-section of the N-S current field (in cm/s) over the Flemish Cap (along 47° N) during July of 2000 measured with a 150 kHz ADCP. Negative currents (blue) are southward and positive currents (red) are northward.

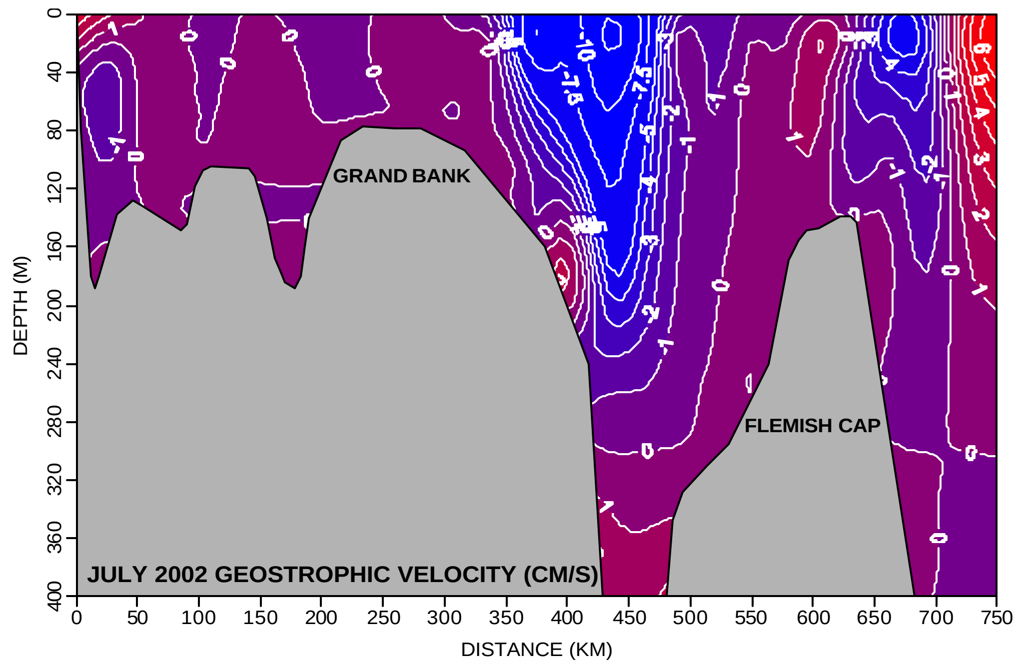

Fig. 10. The vertical distribution of the N-S geostrophic current field (in cm/s) over the Flemish Cap during the summer of 2002 estimated from the density data. Negative currents (blue) are southward and positive currents (red) are northward.

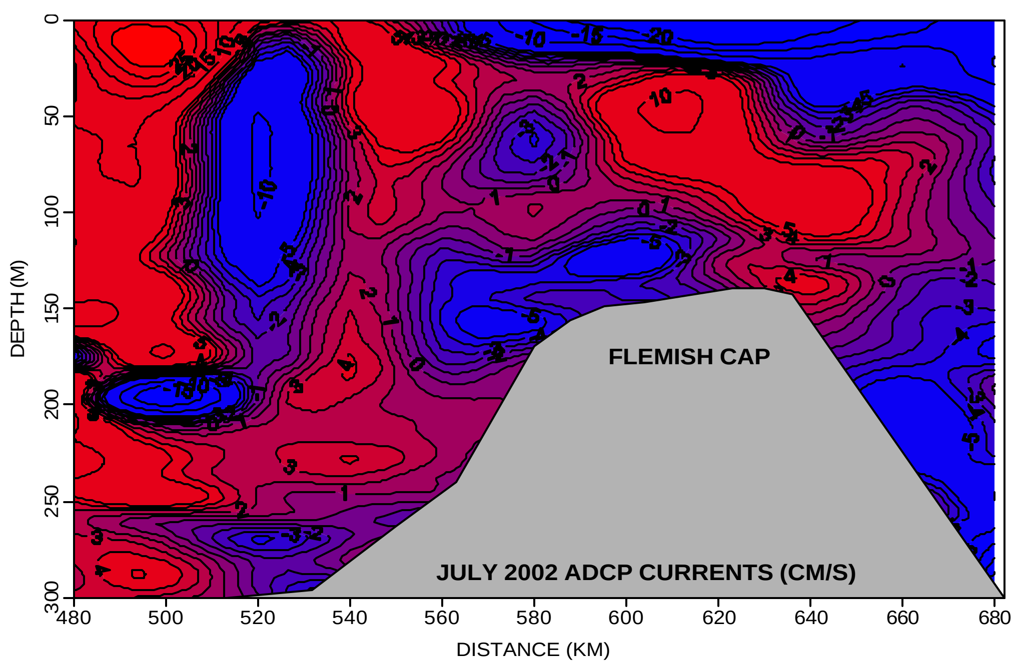

Fig. 11. A vertical cross-section of the N-S current field (in cm/s) over the Flemish Cap (along 47° N) during the summer of 2002 measured with a 150 kHz ADCP. Negative currents (blue) are southward and positive currents (red) are northward.