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Oceanographic Conditions on the Flemish Cap during the Summer of 1999, with Comparisons to the Previous Year and the 1961-1990 Average

by

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ABSTRACT

Oceanographic data from the summer of 1999 on the Flemish Cap are examined and compared to the long-term (1961-1990) average and to conditions during the summer of 1998. The cold near-surface temperatures (0.5 to 2°C below normal) experienced over the Cap during 1993, 1995 and 1996 had warmed to 0.5 to 1.5°C above normal in July of 1997 and increased to 2°C above normal by the summer of 1998 and 1999. Bottom temperatures over the Cap were slightly below normal during 1997, up to 0.5°C above normal during 1998 and up to 1°C above normal during 1999. Upper layer (top 100-m) salinities were slightly above the long-term mean (by 0.2-0.4 PSU) during both 1998 and 1999, otherwise 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 1995 moderated by the summer of 1996 and continued above normal up to July of 1999. As in previous years, summer chlorophyll levels in the upper 100-m of the water column over the Cap were higher compared to the adjacent Grand Bank and dissolved oxygen levels were about normal for the region. 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. 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. 1a. 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 and salinity 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 1998a).

The monthly mean temperature and salinity along the standard Flemish Cap Section 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 1995-1998 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). Stein (1996), summarized the most recent studies of oceanographic conditions on the Flemish Cap. Additionally, Cervifio and Prego (1996) presented hydrographic conditions on the Flemish Cap in July of 1996 from a fisheries research survey conducted by the European Union. This manuscript presents an update to these studies by including data up to the summer of 1999 and represents the seventh such review of summer oceanographic conditions on the Flemish Cap in support of the annual Shrimp assessment for NAFO Division 3M.

The report describes oceanographic conditions on the Flemish Cap during the summer of 1999 with a comparison to 1998 conditions and to the long-term mean, based on all available historical data. The normal has been defined as the 30-year period from 1961-1990 in accordance with the convention of the World Meteorological Organization and recommendations of the NAFO Scientific Council. The 1998 and 1999 observations were made by the Department of Fisheries and Oceans on oceanographic surveys in mid-July of each year. During these surveys oceanographic observations were made along the standard NAFO Flemish Cap transect at 47^o N latitude (Fig. 1b). Measurements included vertical profiles of currents, temperature, salinity, and chlorophyll and dissolved oxygen.

2. Average Temperature and Salinity

The vertical distributions (depth versus horizontal distance from the Avalon Peninsula of Newfoundland) of the average temperature and salinity over the Flemish Cap along 47^o N for the period July 3 to August 2, based on all available historical data from 1961-1990 are shown in Fig. 2. These dates were chosen to span a one-month time period centered on the 1999 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 temperature for this time period (Fig. 2, upper panel) ranges from 4 to 5^{o}C at 50-m depth to above 10^{o}C near the surface. In deeper water (50-m to the bottom) temperatures range from 2 to 4^{o}C in the Flemish Pass area, in the offshore branch of the Labrador Current, and from 3.5 to 6^{o}C offshore of the Cap, where the influence of the Gulf Stream is evident. The corresponding average surface salinities (Fig. 2, bottom panel) range from about 33 psu in the Flemish Pass to about 33.5 psu over the Cap. Near bottom over the Cap in water depths of 150 to 300-m salinities range from 34.5 to 34.75 psu. In water depths greater than 300 m, salinities range from 34.75 to 34.85 psu.

3. 1998 and 1999 Temperature

The vertical temperature distribution in July of 1999 (Fig. 3, bottom panel) along the standard NAFO transect shows temperatures ranging from about 5 to 6^{o}C at 50-m depth to above 12^{o}C near the surface, similar to1998 values (Fig. 3, upper panel). In the depth range of 50-100 m temperatures ranged from 4 to 5^{o}C, except offshore of the Cap where they were between 3 to 3.5^{o}C. In the depth range of 100-m to the bottom over the Cap temperatures were about 4^{o}C, somewhat warmer than the 1997 and 1998 values.

The vertical distribution of temperature anomalies for 1998 and 1999 over the Flemish Cap referenced to the 1961-1990 normal is shown in Fig. 4. A temporal adjustment of these calculations was made by restricting the historical data in the time period of July 3 to August 2 for the 1999 anomalies. An examination of the historical data distribution for that time period shows that only about 17% of the profiles were collected before July 18, the mid-point of the 1999 observations, with a median date of July 27. The annual temperature cycle over the Flemish Cap indicates that the temperature normally changes by approximately 0.5^{o}C during the time period from July 18 to 27 in the near surface layers (0 to 20 m) and about 0.1^{o}C at 50-m depth. This indicates that in near surface zone, where the annual cycle is the strongest, the temperature anomalies may be biased low, assuming normal atmospheric heat flux.

During 1999, surface layer temperature anomalies (Fig. 4 bottom panel) ranged from 1 to 1.5^{o}C above normal on the Flemish Pass side of the cap and from 1 to 2^{o}C above normal over the Cap and on the eastern side. These values were very similar to the 1998 values (Fig. 4 top panel). Below the surface layer in the Flemish Pass temperatures were 0.5 to 1^{o}C above normal, warmer than the 1998 values. Bottom temperatures on the cap were up to 1^{o}C above normal, an increase of about 0.5^{o}C over 1998 values. The positive surface anomalies over the Flemish Cap during 1997 to 1999 are in contrast to the generally negative anomalies experienced during July of 1993, 1995 and 1996.

Long-Term Trends

Similar to the Newfoundland Shelf the monthly temperature anomalies on the Flemish Cap (Fig. 5) are characterized 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 but returned again by 1988 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 100-m.

4. 1998 and 1999 Salinity

The vertical distribution of salinities for July of 1999 (Fig. 6, bottom panel) show values ranging from less than 33 psu near the surface in the Flemish Pass, where the influence of the Newfoundland Shelf Water is evident. Across the Cap in the upper 50-m of the water column salinities were between 33.25 to 33.75 psu, somewhat lower than the 1998 values (Fig. 6, upper panel). In the depth range of 50-m to the bottom salinities generally ranged from 34.5 to 34.75 psu.

The corresponding salinities anomalies in both 1998 and 1999 were similar, with slightly saltier than normal values (by 0.2 to 0.4) over most of the Cap in the surface layer (Fig. 7). In the Flemish Pass during 1998 and on the eastern side of the Cap during 1999 salinities were slightly below normal indicating the possible influence of the offshore branch of the Labrador Current, this is also evident in the temperature anomaly plot of Figure 4. In the deeper water (below 300-m) of the Flemish Pass and on the continental slope to the east of the Cap, values were near normal.

Long-Term Trends

The time series of salinity anomalies (Fig. 8) shows fresher than normal conditions from 1971 to 1976 and from 1983 to 1986 in the upper 100-m of the water column with peak amplitudes reaching 0.9 psu below normal. The trend in salinity values during the early 1990s range from slightly above normal at the surface to below normal at 20 to 100-m depth. During the summer of 1999 salinities were very near the long-term average on the Flemish Cap. In general, the temperature and salinity anomalies are very similar to those at Station 27 and elsewhere on the continental shelf over similar depth ranges (Colbourne 1998b).

5. 1998 and 1999 Chlorophyll and Dissolved Oxygen

The vertical distributions of chlorophyll and dissolved oxygen saturation for July of 1998 and 1999 along the standard NAFO transect across the Grand Bank and the Flemish Cap are shown in Figs. 9 and 10. These data were collected in conjunction with the temperature and salinity data using a YSI type polarographic element dissolved oxygen sensor and a fluorometer 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. No field calibrations were applied to the chlorophyll measurements presented here.

The chlorophyll concentrations show relatively high values over the Flemish Cap compared to over the adjacent Grand Bank during both 1998 and 1999. These values are also similar to the 1995 and 1996 observations (Colbourne 1996). Maximum values were confined to a sub-surface layer of about 50-m thick (Fig. 9). The higher chlorophyll values over the Flemish Cap during mid summer appear to be a common occurrence and may indicate a delayed or extended offshore plankton bloom relative to the Newfoundland Shelf areas.

Over the Flemish Cap dissolved oxygen saturation levels during both 1998 and 1999 ranged from 95 to 105% from the surface to about 50-m depth (Fig. 10). Below 50-m depth values ranged from 85 to 95%, except near bottom where values ranged from 75 to 80% in 1999. Overall, oxygen saturation values were very similar during both 1998 and 1999. 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 1995 and 1996 and are typical for this region.

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. 1a). 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.

From 1993 to 1999 (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 11 shows a vertical cross-section of the north-south currents over the Flemish Cap during July of 1998 and 1999 along 47^{o} N latitude. The 1998 measurements show a northward component ranging from 5 to 20 cm/s over the shoreward 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 30 cm/s. The 1999 measurements show similar features, such as the northward flow in the Flemish Pass area and over the western side of the Cap and the southward flowing surface water on the eastern side of the Cap, however current speeds were somewhat lower than those observed in 1998.

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 estimated from the density data collected during 1998 and 1999 are shown in Fig. 12. These calculations 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 shoreward of the Cap and the northward flowing water of the North Atlantic Current east of the Cap are evident. The estimates over the Cap itself show some remnants of anticyclonic circulation particularly during 1999, however the values exhibit a high degree of variability. This is in contrast to the 1996 results in which the anticyclonic circulation was strongly evident (Colbourne 1997). Also the results differ significantly from the direct current measurements made with the ADCPs, 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.

ACKNOWLEDGEMENTS

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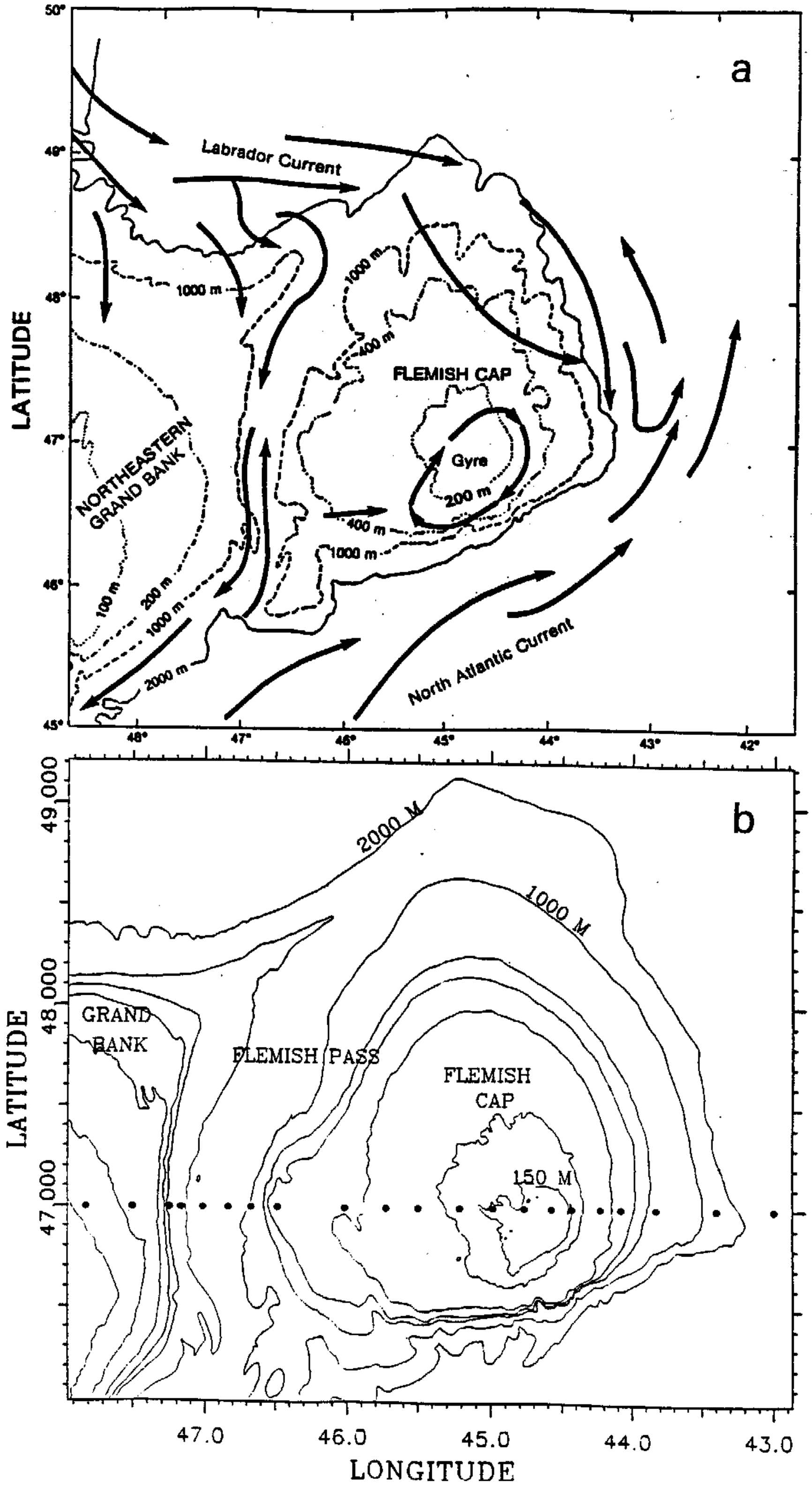

Fig. 1. (a) The major circulation features around the Flemish Cap area (Adapted from Anderson, 1984) and (b) the location of stations occupied during the summer of 1998 and 1999. Bathymetry lines are 2000, 1000, 500, 400, 300,200 and 150 m.

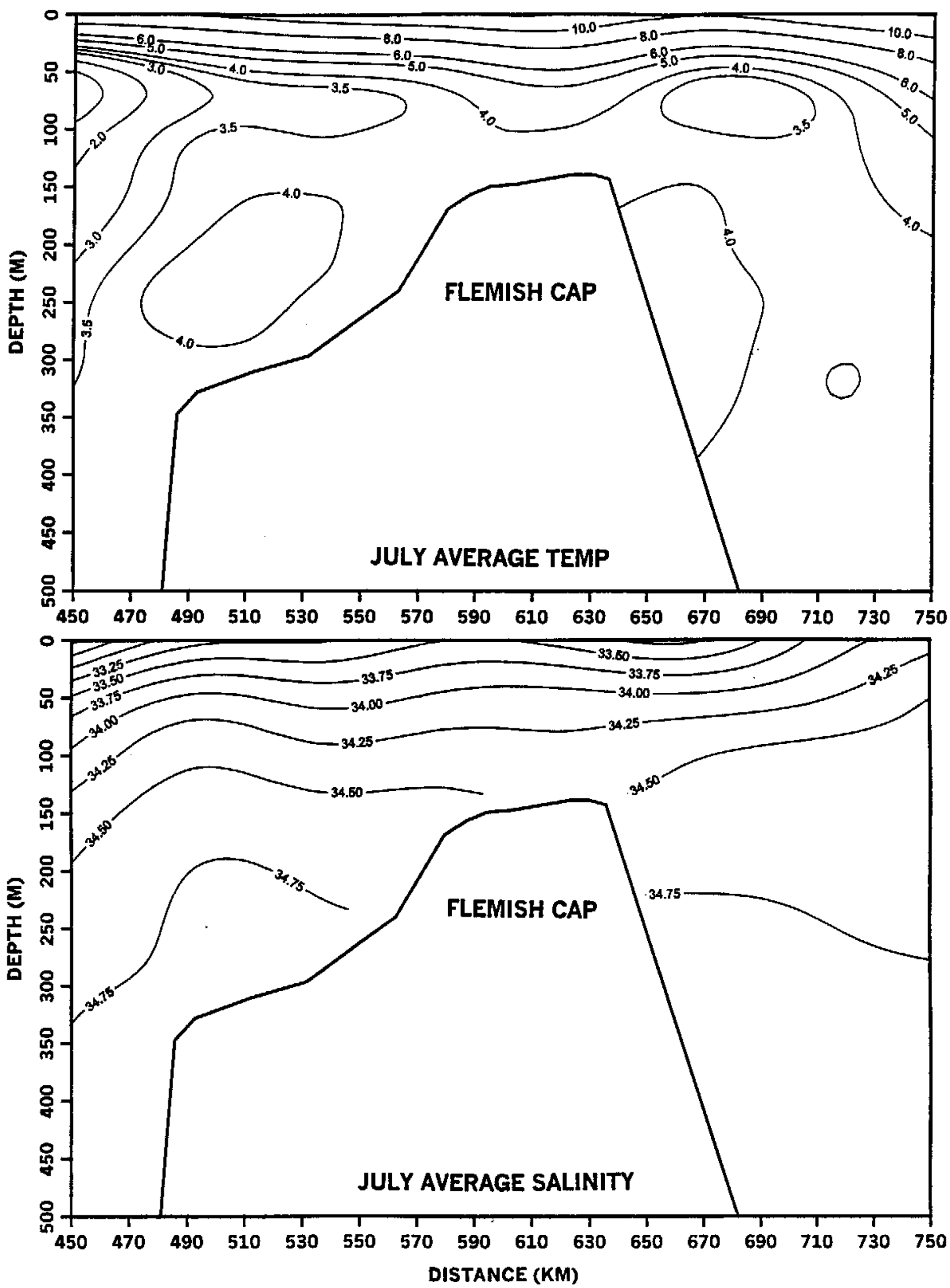

Fig. 2. The vertical distribution of the average temperature and salinity over the Flemish Cap based on all available historical data from 1961-1990 for the time period of July 3 to August 2.

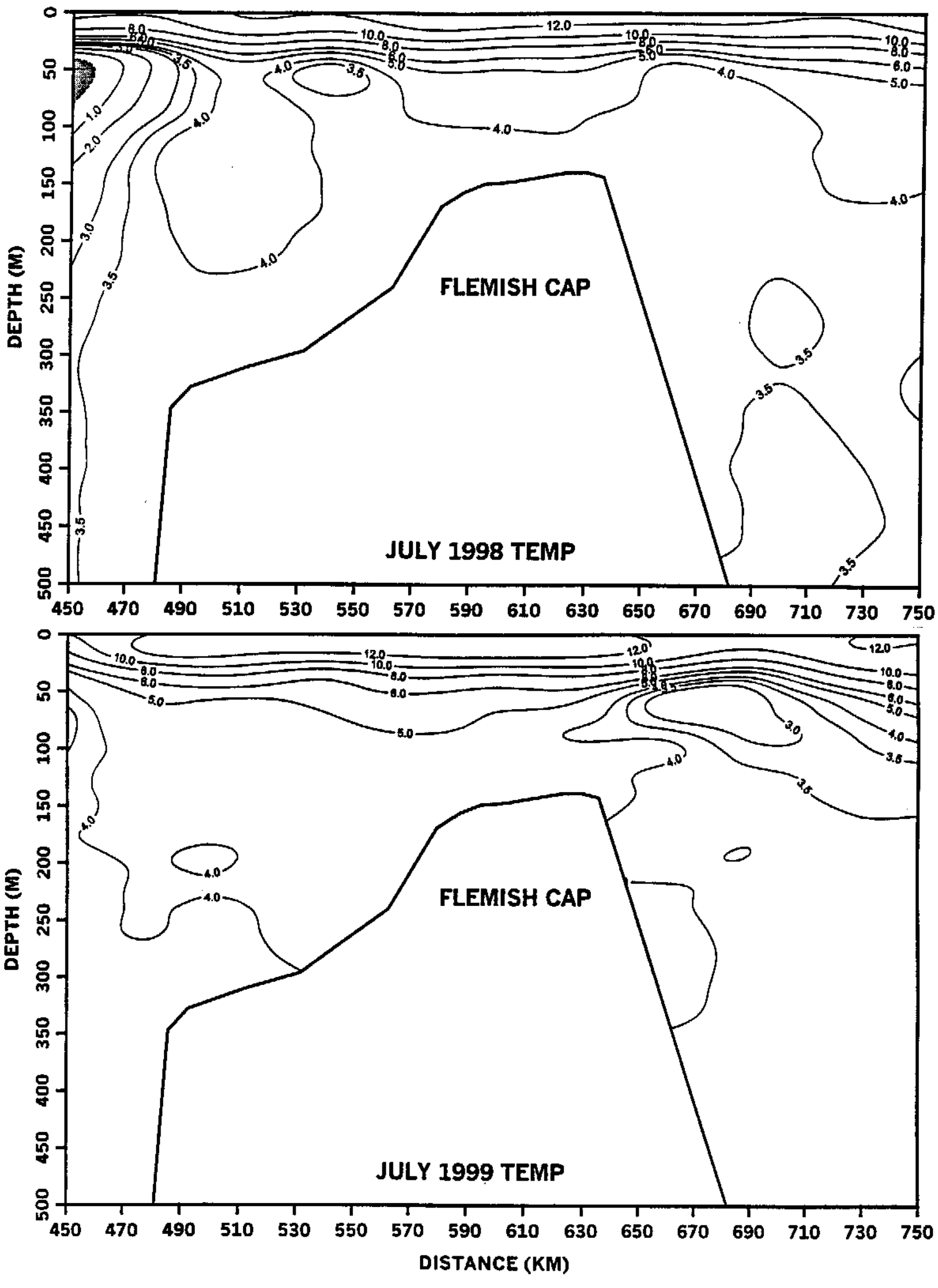

Fig. 3. The vertical distribution of temperature over the Flemish Cap (along 47°N) for July of 1998 and 1999.

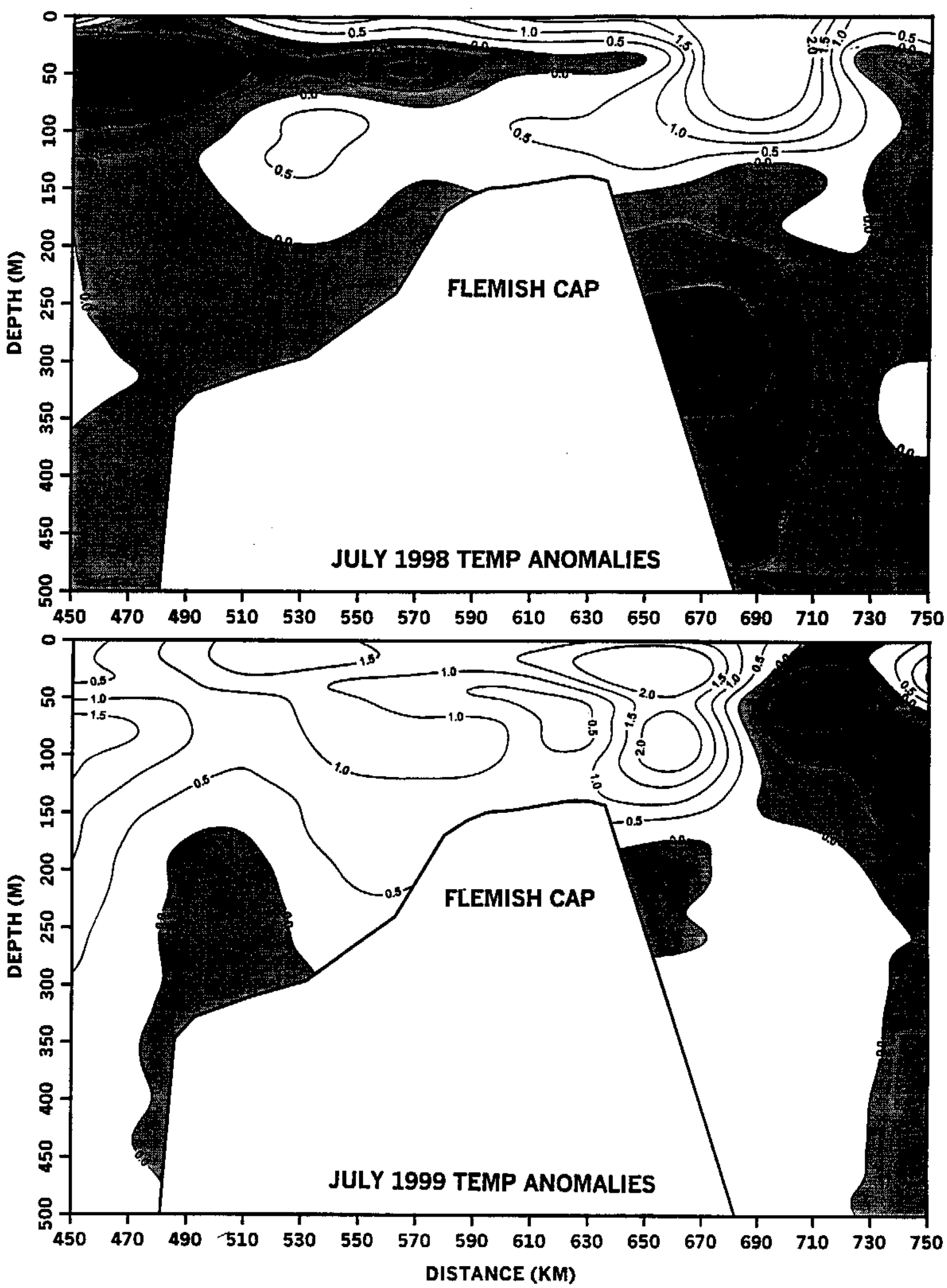

Fig. 4. The vertical distribution of temperature anomalies over the Flemish Cap (along 47° N) for July of 1998 and 1999. Negative anomalies are shaded.

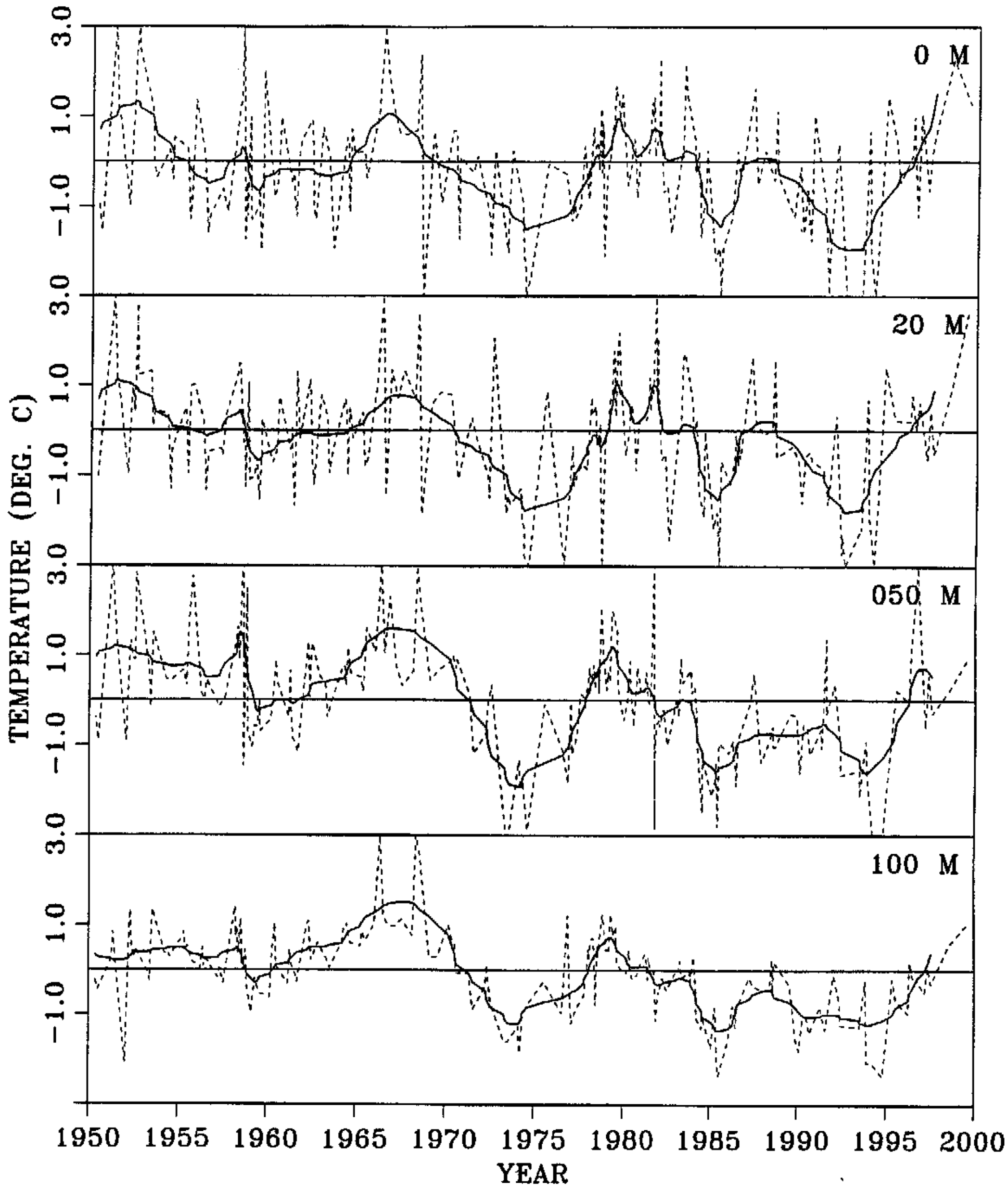

Fig. 5. Time series of monthly temperature anomalies at standard depths of 0, 20, 50 and 100 m on the Flemish Cap in NAFO Division 3M. The solid line represents the smoothed temperature anomalies.

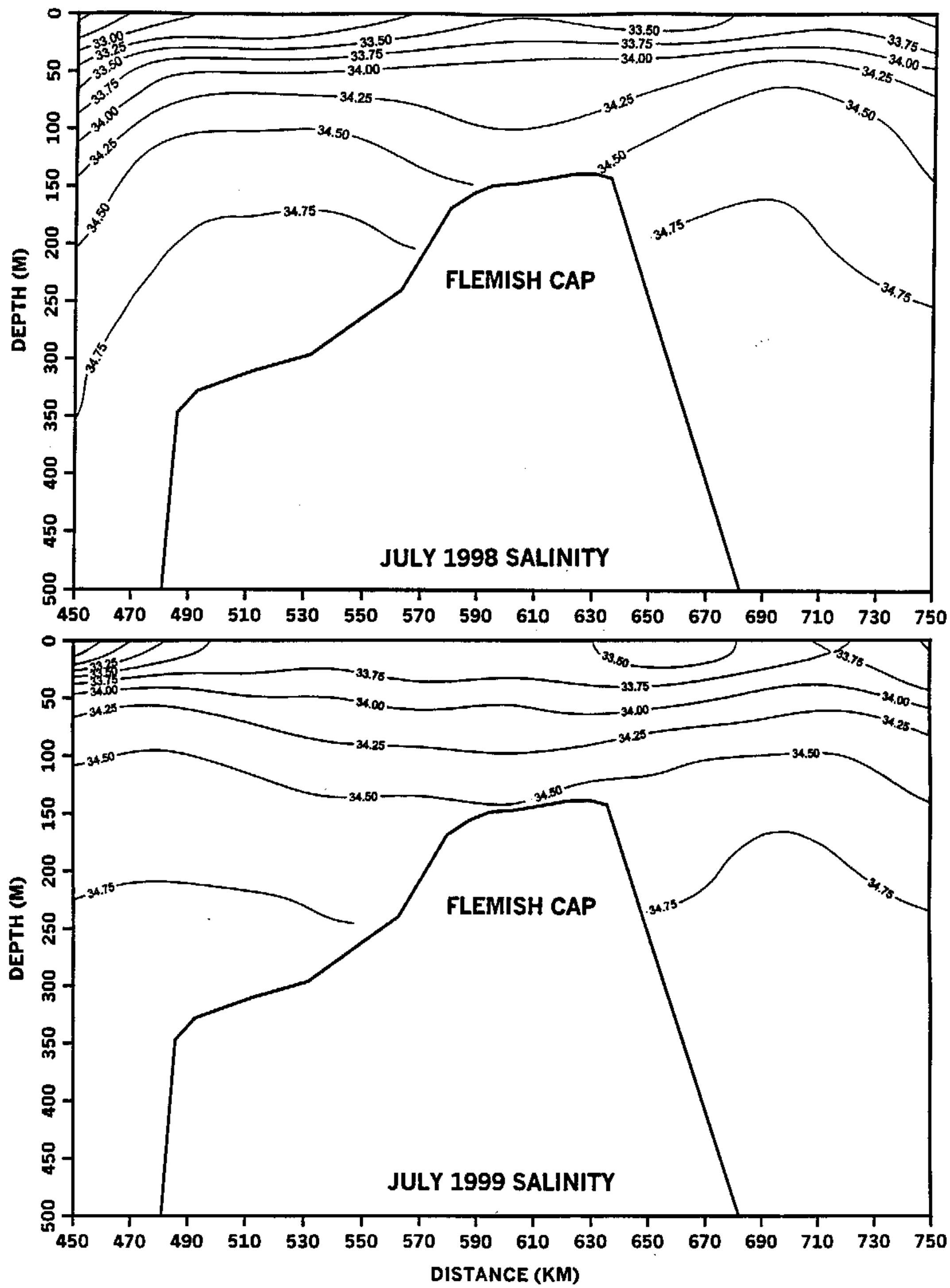

Fig. 6. The vertical distribution of salinity over the Flemish Cap (along 47°N) for July of 1998 and 1999.

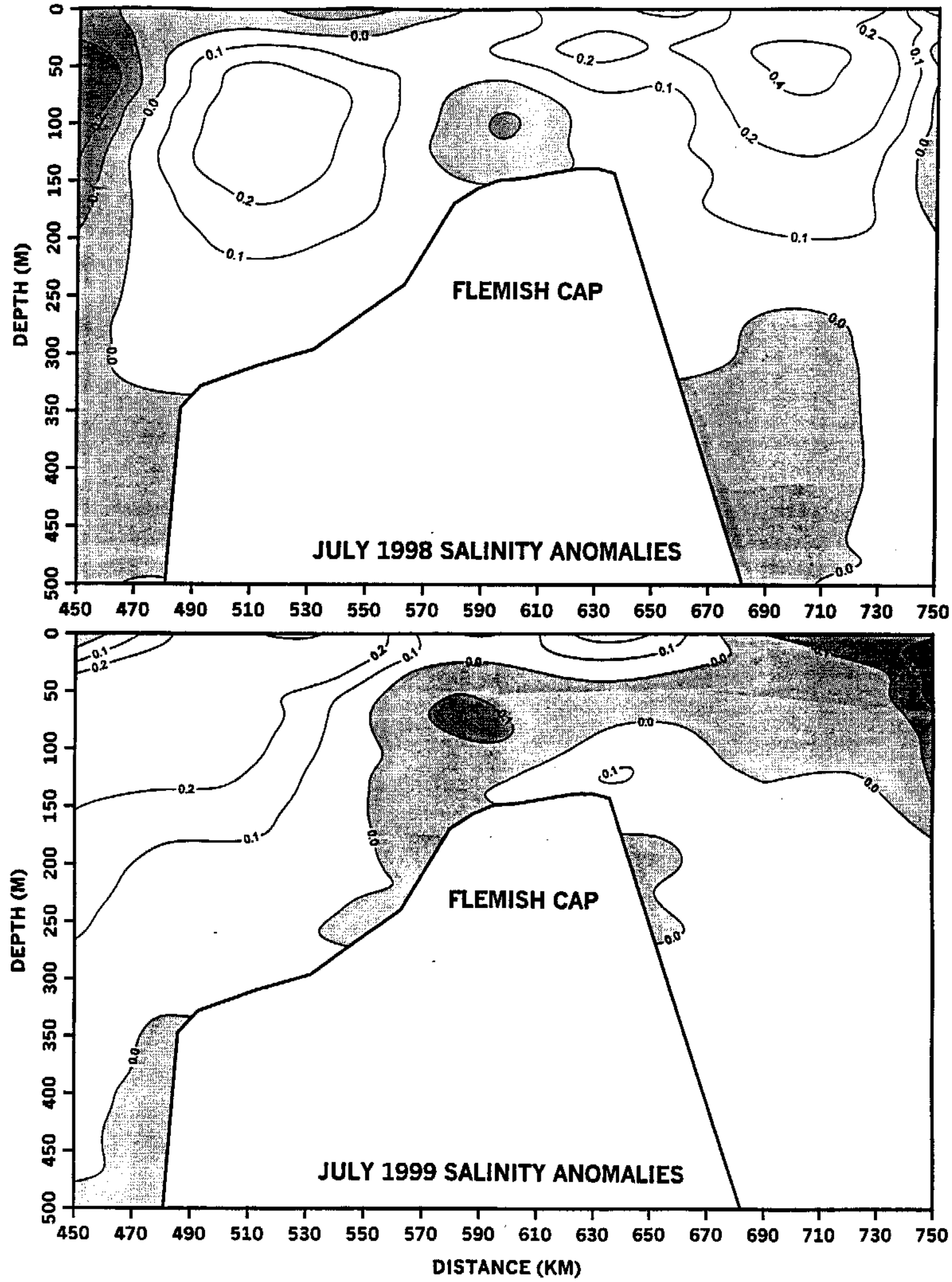

Fig. 7. The vertical distribution of salinity anomalies over the Flemish Cap (along 47° N) for July of 1998 and 1999. Negative anomalies are shaded.

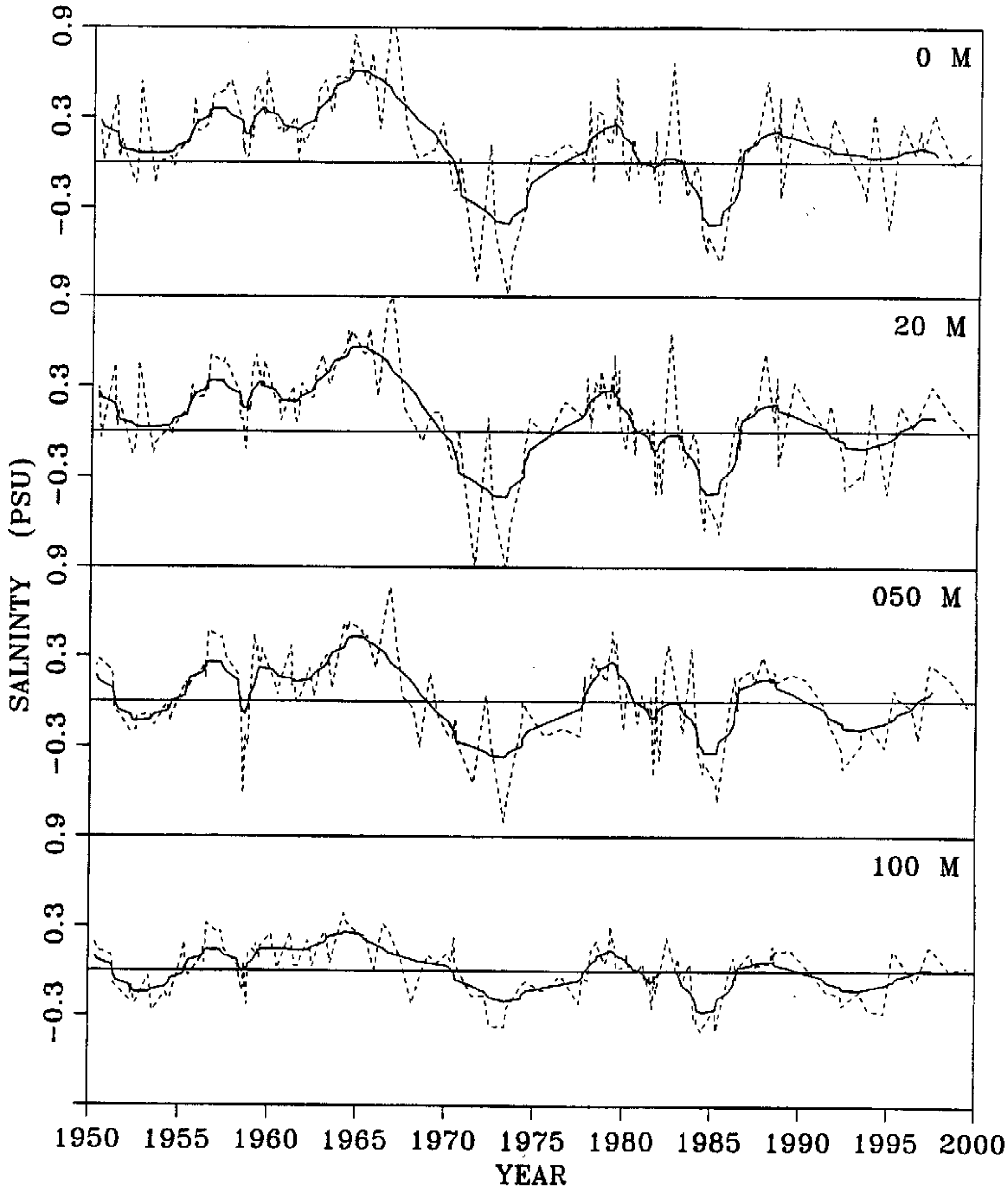

Fig. 8. Time series of monthly salinity anomalies at standard depths of 0, 20, 50 and 100 m on the Flemish Cap in NAFO Division 3M. The solid line represents the smoothed salinity anomalies.

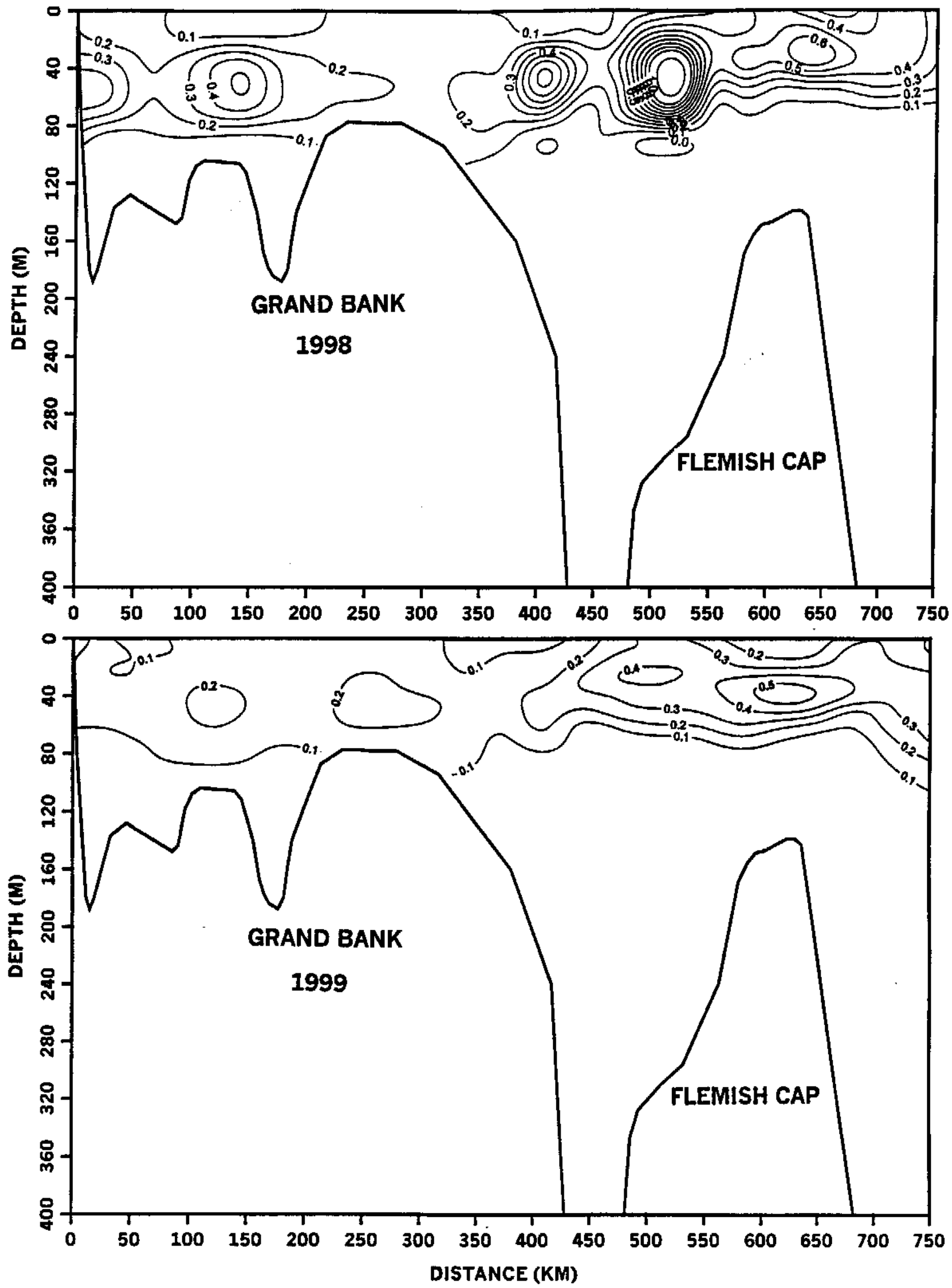

Fig. 9. The vertical distribution of chlorophyll concentrations (mg/l) along the 47°N transect for July of 1998 and 1999.

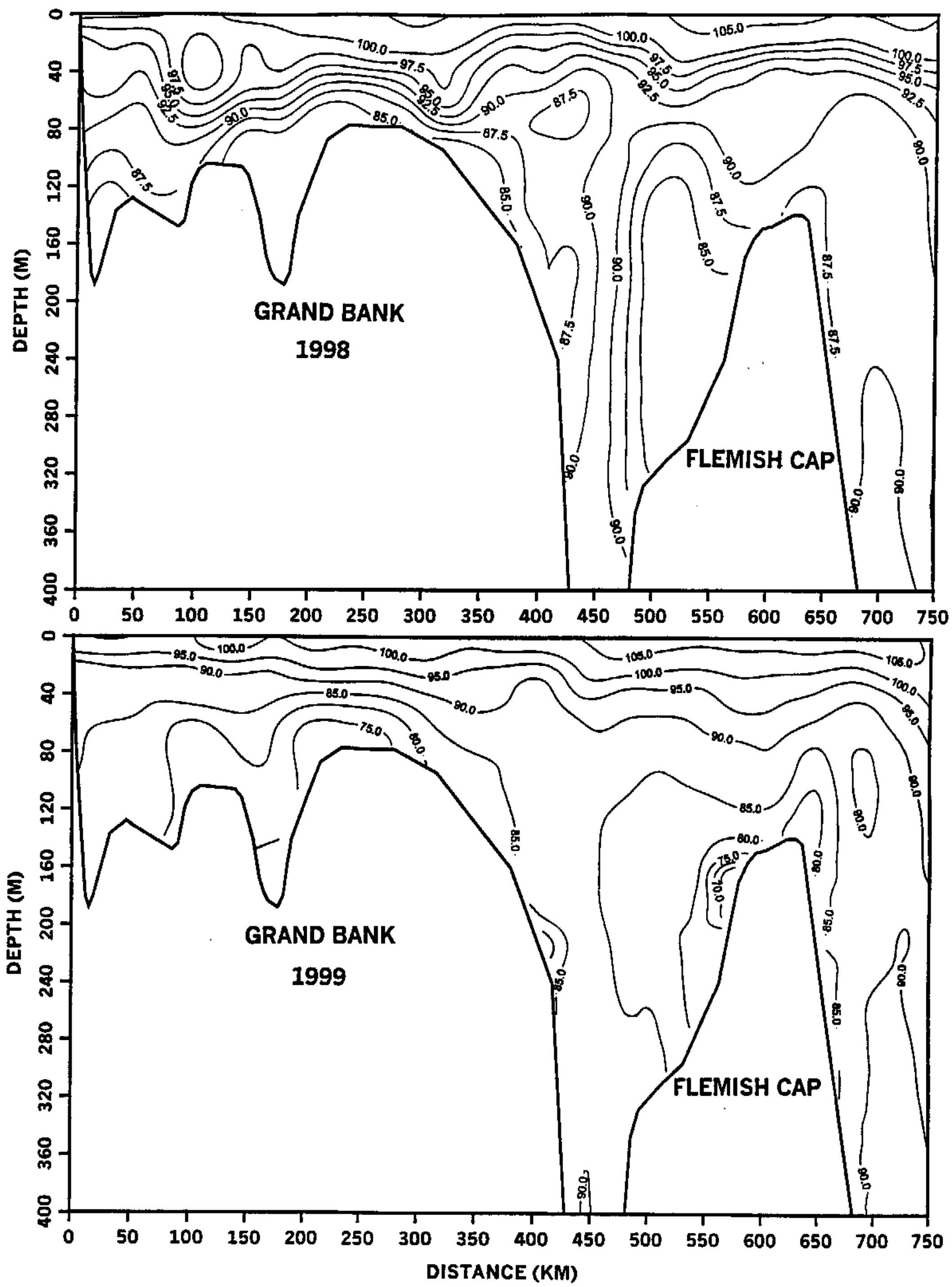

Fig. 10. The vertical distribution of dissolved oxygen percent saturation along 47° N for July of 1998 and 1999.

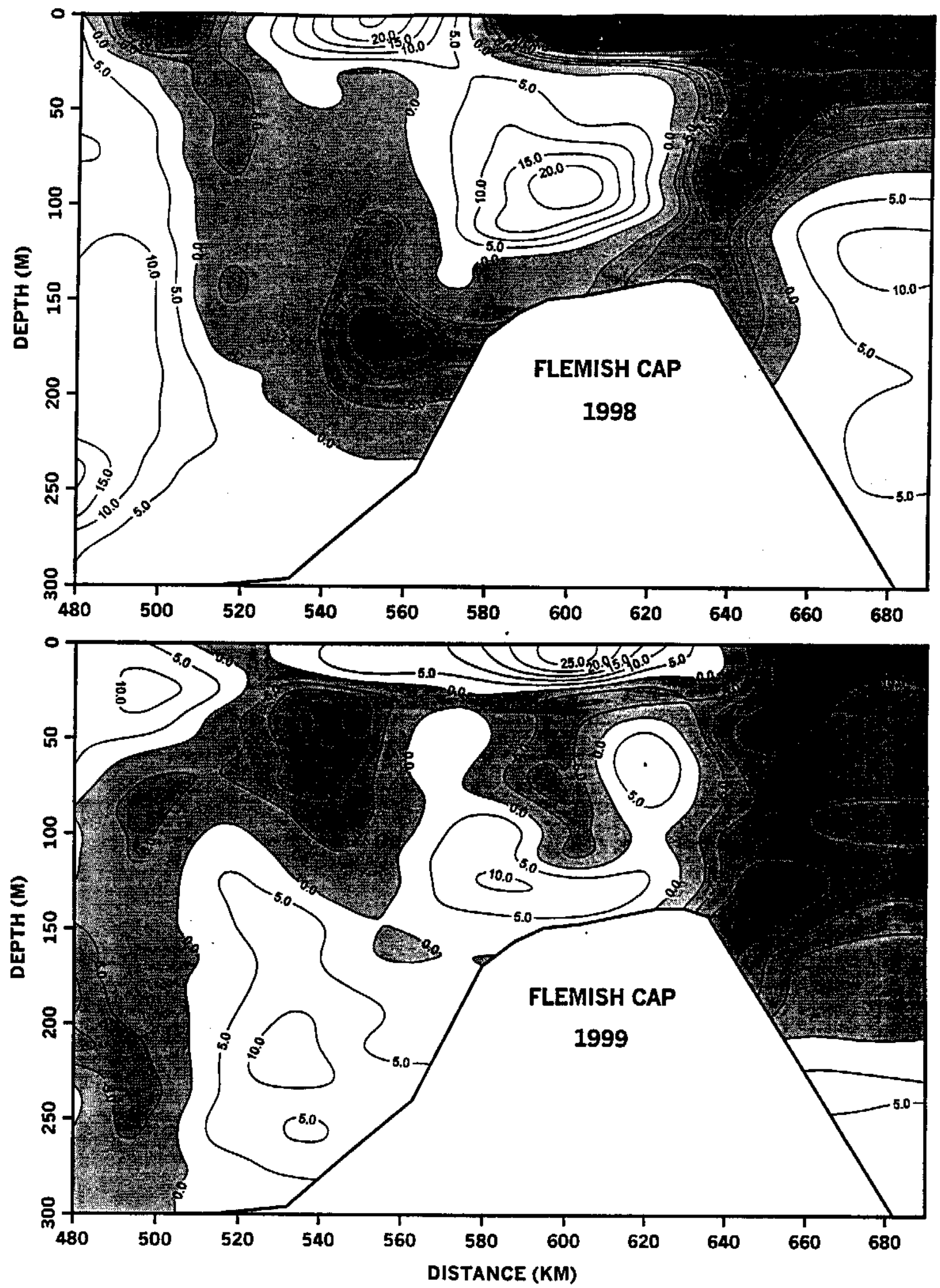

Fig. 11. A vertical cross-section of the N-S current field in cm/s over the Flemish Cap (along 47° N) during July of 1998 and 1999 measured with a 150 kHz ADCP. Negative (shaded) currents are southward and positive are northward.

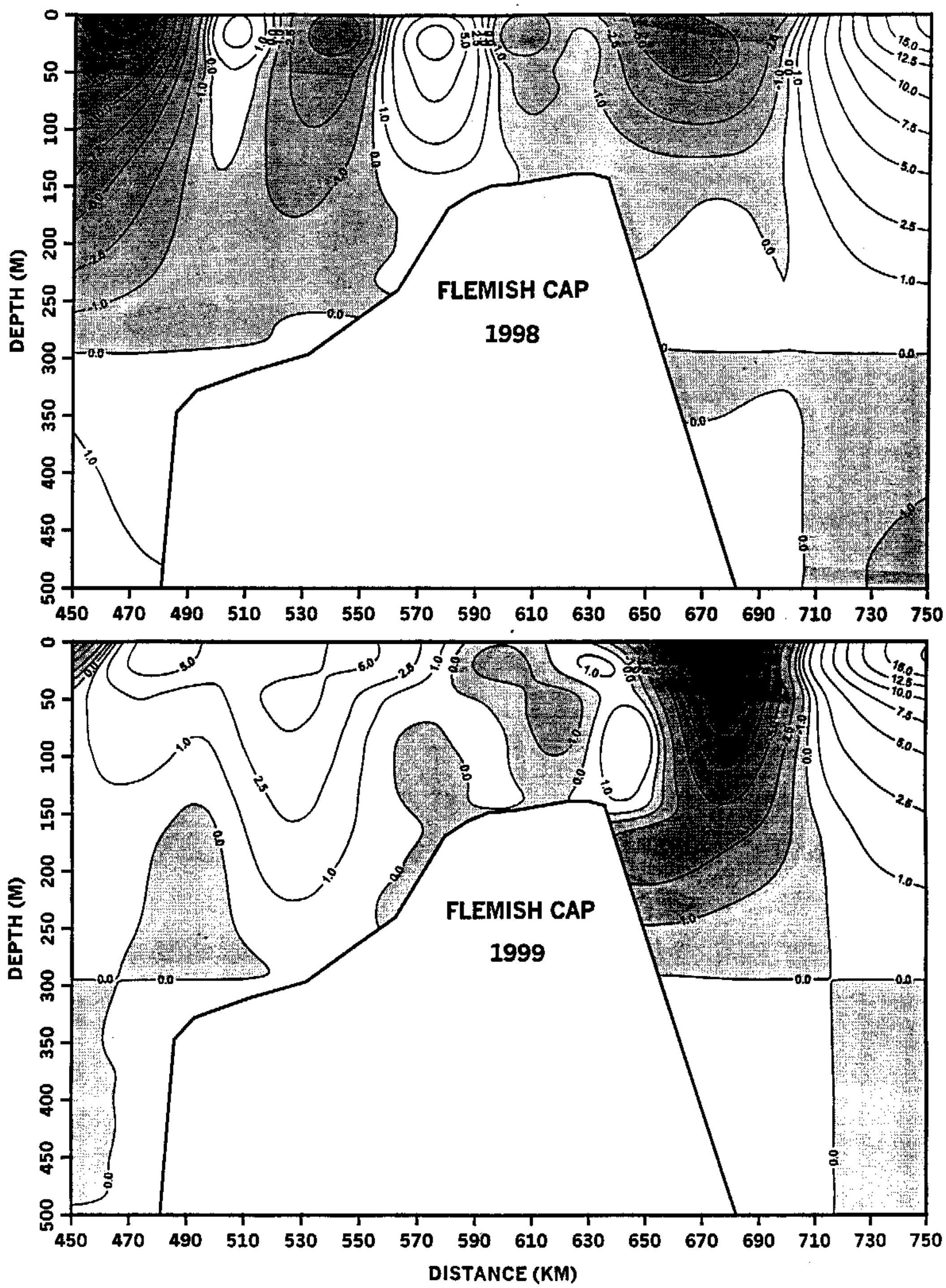

Fig. 12. The vertical distribution of the N-S geostrophic current field in cm/s over the Flemish Cap during July of 1998 and 1999 calculated from the density data. Negative (shaded) currents are southward and positive are northward.