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Hydrographic Conditions on Flemish Cap in July 2000 and Comparison with those Observed in 1999

by

Santiago Cerviño López

Instituto de Investigaciones Marinas. Eduardo Cabello, 6. 36208 Vigo, SPAIN
e-mail: santi@iim.csic.es

Abstract

Hydrographic conditions on Flemish Cap in July 2000 are described after a survey with 94 CTD stations. Current conditions over Flemish Cap are described and compared with those observed in 1999.

Since the middle-1990s temperatures have been increasing until 1999. In 2000 salinities and temperatures keep the above normal values of the last recent years with slightly lower values than those observed in 1999. This occurs in the water column up to 200 m depth. A well-developed layer with temperatures higher than 4ºC was observed all around the Cap below 200 m depth. This relative warming in water that spreads around the Cap at an unusual depth is probably due to a combination of two processes: firstly by a mixture with North Atlantic waters and secondly by a high permanence time in the anticyclonic gyre.

Introduction

The Flemish Cap is an underwater plateau located around 47ºN and 45ºW east of the Grand Bank of Newfoundland. It has a minimum water depth of 125 m in the centre and is separated from the Newfoundland shelf by the Flemish Pass, a region with minimum depth of about 1100 m.

The general circulation of water masses in the area is determined by the confluence of Labrador Current (LC), with temperatures between 3-4ºC and salinities between 34-35, and the North Atlantic Current (NAC) with temperatures higher than 4ºC and salinities with more than 34.8. In the Northwest of Flemish Cap, the offshore branch of LC, that flows southwards, is divided into two branches, one continues southwards through Flemish Pass and the other surrounds the bank by the East. The NAC flows northwards surrounding the 4000 m isobath in the South and East of Flemish Cap (Krauss *et al*., 1987). On the centre of the Cap, the general circulation is usually clockwise.

Water masses over the Cap have a typical anticyclonic gyre that characterise the oceanography in this area (Kudlo *et al*., 1984; Ross 1981). In general, typical geostrophic speeds range from 5 to 10 cm/s in the gyre over the Cap and may exceed 5 cm/s near bottom (referenced to 300 m, or less in shallower waters). The average residence time of the upper-layer is shorter than the average recirculation time of the clockwise gyre and the vertical diffusion time is much longer than the residence time as well as the recirculation time; this means that passive materials introduced in the Cap, usually leave the Cap in the same layer before one complete gyre. However, complete gyres may occur more often below the surface layers (Loder *et al.*, 1988).

Anticyclonic gyre circulation around the Cap is predominant, but there is a high degree of interannual variability. The stability of the gyre is strongly influenced by atmosferic forcing; winter storms frequently break the gyre that is more persistent in summer increasing the residence time of water on the Cap and hence of passive drifters like pelagic eggs and larvae (Colbourne and Foote, 2000).

The anticyclonic circulation was evident in summer 1996 (Cerviño *et al*., 1999; Colbourne, 1997), but measurements over the Cap in 1997 and 1998 show only some remnants of anticyclonic circulation (Colbourne 1998). However in summer 1998, Gil *et al*. (1999) found a well-developed anticyclone over Flemish Cap, as well as an intense mesoscale activity in form of cyclone rings surrounding the bank's periphery. Evidence of anticyclonic motion over the Cap was also observed in summer 1999 and 2000 (Colbourne, 2000)

Time series of temperature anomalies on Flemish Cap at standard depths (0, 20, 50, 100 m) shows three main cold periods: the 1970s, the late-1980s and early-1990s. Temperatures have been warming since 1995 in the top 100 m to above normal conditions. At 100 m depth temperature was about 1ºC under normal in the early-1990s; temperature increased until about 1ºC above normal from 1995 in 1999 (Drinkwater *el al*., 2000). In summer 2000, surface temperature decreased with respect to those of 1999 but remained above normal regarding to the 1961-1990 average and bottom temperatures also decreased to near normal (Colbourne, 2000).

In the upper 100 m layer, thermohaline properties on the centre of the Cap are mainly derived from Labrador Current waters modified by the gyre retention and the atmosferic influence (Akenhead, 1986). In deeper waters, where temperature generally ranges from 3’5 to 4ºC, there is a mixture between the cold and relatively low salinity of Labrador Current waters and the warmer high salinity of North Atlantic waters, specially along the South and Eastern slope (Cerviño *el al*., 1999; Colbourne and Foote, 2000). Other recent surveys with wider spatial coverture show that temperatures higher than 4ºC were frequent under 100 m depth in the summer of 1998 and 1999 (Garabana *et al.*, 2000) giving more weight to the influence of North Atlantic waters in the warming of the Flemish Cap deep waters in the last years.

This paper shows the hydrographic conditions on Flemish Cap in July 2000 compared with those observed in summer 1999 with special focus on warming of deep layers all around the Cap.

Materials and Methods

In July 2000 a stratified random bottom-trawl survey was carried out on Flemish Cap on board of R/V Cornide de Saavedra. The survey was performed from July 10th to July 28th following the same method that has been used since 1988 (Vázquez, 2000). A total of 120 valid bottom trawls were completed and 94 CTD station was established either at the beginning or at the end of some fishing hauls covering all the survey area (Figure 1).

The CTD sound used was a Sea-Bird, SBE 19, provided with pressure, temperature and conductivity sensors. It was dropped at a speed of 1m/s and it was configured to acquire two samples per second, down to a maximun depth of 410 m. Its calibration parameters had been checked before the cruise.

Data were processed out using the CTD Data Acquisition Software (Seasoft version 4.022). Data were first review and outliers were removed. Then a low pass filter was applied to conductivity before align it with pressure and temperature. Salinity and density were derived from this data. All variables were finally averaged meter by meter.

Two transects were designed to describe the vertical temperature and salinity distribution, one in N-S direction next to the 45º W meridian and the other in W-E direction next to the 47º N parallel (Figure 2). Temperature and salinity distribution charts at different depths (10, 50, 100 and 200 m) are showed in Figure 3 and 4. All contour maps were calculated by kriging with linear variogram using Surfer 7.

Hidrographic conditions in the year 2000 are compared with those of 1999 through their TS relationship. An average value was calculated with all stations every 10 m depth; both years are showed together in Figure 5 (top panel) and two graphs more that show individual data (taken every 10 m depth) of all the stations for the year 1999 (Figure 5, middle panel) and 2000 (Figure 5, bottom panel). The CTD sound used in 1999 was the same as that used in 2000.

Results

Vertical distribution of temperature and salinity in the N-S transect are shown in the left panels of figure 2. In surface temperature ranges from 10ºC in the North to 13ºC in the South. Temperature decreases towards deeper waters getting 4ºC at about 50m depth. Temperature stabilizes below 4 ºC under the termocline except in a broad layer between 200 and 300 m where temperatures are above 4 ºC. Salinity ranges from 33 to 32.5 psu at the surface, then decreases progressively to about 34.75 psu at the bottom.

Vertical distribution of temperature and salinity in the W-E transect are shown in the right panels of Figure 2. Temperature keeps about 12ºC at the surface and decreases until 4ºC in the first 50 m. Below this depth, temperature is very stable, slightly under 4ºC except in the depth range between 200 and 300 m where temperature reaches again values above 4ºC, specially in the western area. Salinity in surface ranges between 33.25 psu in the East to 32.25 in the West, it gets 34.25 psu at about 100 m depth and stabilizes at about 34.75 psu near the bottom in a similar way as that observed in the other transect.

Northwards and westwards transects show a similar pattern in temperature as well as in salinity: a mixed layer with temperatures that ranges from 12ºC in surface to 4ºC at 50 m depth. Then, temperature stabilizes under 4ºC except in the layer between 200 and 300 m depth where it is warmer than 4 ºC.

Horizontal temperature distribution on Flemish Cap at different depths is shown in Figure 3. Near the surface (10 m contour map) temperature reaches 14ºC in the South-central part of the bank and decreases northwards with values below 10ºC. At 50 m, temperature ranges between 1ºC and 6 ºC and there were a homogeneous warmer zone (>4ºC) in the central part and in the South edge whilst northern edges show colder values. At 100 m depth temperature ranges from 2 to 4.5ºC, with colder waters in the North. At 200 m depth, temperature ranges between 3.5ºC and 5ºC. In the 200 m upper layer, warmer values are found in the central and South-western region of the bank, and colder ones appear in the North and East boundaries.

Salinity distribution on Flemish Cap at several depths is shown in figure 4. At 10 m depth, salinity ranges between 32.5 and 33.5 psu. Maxima values occur mainly in the centre of the Cap and at the eastern edge, whilst minima values appear in the North and Southwest. At 50 m depth it ranges between 33.5 and 34.3 psu with lower values in the centre. At 100 m minima values (<34.2 psu) appear in the central part of the Cap. At 200 m salinity is around 34.5-34.8 psu. In general, it was observed that salinity increases with depth, from 33 psu at surface to 34.7 psu at 200 m. At surface, fresher water comes from the North and remains in the centre subsurface layers.

Temperature and salinities on the Flemish Cap in 1999 and 2000 are compared in Table 1. Temperature at the surface was slightly warmer in 2000 than in 1999. At deeper layers, from 25 m to 200 m, temperatures were higher in 1999 with more than 4ºC and from 300 to 400 m the warmest was the year 2000. Salinity differences along the years are lower than those in temperature but the general pattern is quite similar as that showed for temperature: fresher water in 2000 along the water column except between 300 and 400 m deep where year 2000 are saltier.

Figure 5 shows the average TS every 10 m for both 1999 and 2000 and also two TS plots with all stations every 10 m during the years 1999 and 2000. In the upper graph we can see that 1999 temperatures are higher through the plot until about 200 m where both lines cross themselves and year 2000 shows waters saltier and warmer than in 1999. In the 1999 TS plot we can see a general warming with frequent values higher than 4ºC. Both TS plots trend towards the typical Labrador Water with less than 4ºC and about to 34.8 psu but in waters deeper than 200 m, temperatures are frequently higher than 4ºC, especially in 2000, when we can find some TS values with similar features to those of North Atlantic waters.

Discussion

The general annual and interanual trend in thermohaline properties is quite similar in Labrador Current and in Flemish Cap waters. The early-1990s were a cold period with temperatures below normal in all the Labrador area. Since 1995 temperatures have been increasing until 1999 when values were above normal on the Cap. Colbourne (2000) describes temperature anomalies over the Cap during July 2000: at surface, anomalies range from 1 to 1.5ºC above normal, similar to those of 1999, below the surface temperature was between 0 and 0.5ºC below normal, colder than in 1999, and bottom temperatures were near normal. The results of the Flemish Cap survey are quite similar but with some differences: at surface, temperatures were quite similar between 2000 and 1999, below the surface until 200 m depth, temperatures in 2000 were colder than those of 1999, nevertheless, below 200 m, the Flemish Cap survey shows average temperature values higher than in 1999, especially between 200 and 300 m.

Labrador Current flowing from the North with fresh and cold water is the main responsible of the thermohalines properties of Flemish Cap but this water can be modified over the Cap in two different ways: first, by the atmospheric interaction during the retention caused by the anticyclonic gyre and second, by its mixture with the nearby North Atlantic water, warmer and saltier, that flows northwards surrounding Flemish Cap. This warm water could reach the Cap directly or by an intermediate mixture process as Slope water.

In summer 2000 the incoming LW in the surface is colder and fresher in the North than in the South. This water is retained and therefore heated by the sun in the Flemish Cap gyre; at 50 m depth the water is warmer and fresher in the centre than around the cap, this is the typical water modified by the summer anticyclonic gyre as described by Akenhead (1986). It is water that keeps the Labrador salinity properties but it is warmed by the atmospheric interaction during the summer gyre retention. Between 50 and 100 m depth temperature gets the lowest values coinciding with the CIL effect of the incoming Labrador Current. From 100 m to the bottom, the typical LW is colder than 4ºC, nevertheless, temperatures higher than 4ºC are frequent in the Flemish Cap in 2000, especially between 200 and 300 m depth; this waters are a mixture between Labrador and North Atlantic water. These mixed waters, frequently described in the South and East of the Cap, appear this year all around the Cap probably due to a longer residence time at deep layers, where the persistence of the clockwise gyre is longer than at sub-surface layers.

Acknowledgements

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Table 1. Water temperature (ºC) and salinity (psu) in Flemish Cap in 1999 and 2000.

	1999		**2000**	
Temp. (º C)	**mean**	**range**	**mean**	**range**
10	11.23	9.24 - 12.86	11.89	9.04 - 14.81
25	8.86	3.83 - 12.33	6.46	2.59 - 12.21
50	4.64	0.79 - 10.24	3.26	0.81 - 5.75
100	4.22	1.99 - 6.51	3.20	1.37 - 4.62
200	4.06	3.30 - 5.11	3.96	3.33 - 5.03
300	3.90	3.63 - 4.32	4.03	3.50 - 4.92
400	3.76	3.48 - 4.11	3.85	3.55 - 4.03

Sal. (psu)	**mean**	**range**	**mean**	**range**
10	33.41	33.03 - 33.82	33.03	32.60 - 33.40
25	33.61	33.06 - 34.53	33.50	32.91 - 34.08
50	34.04	33.14 - 34.38	33.86	33.50 - 34.27
100	34.39	34.04 - 34.64	34.27	33.93 - 34.58
200	34.70	34.59 - 34.87	34.69	34.52 - 34.80
300	34.80	34.69 - 34.87	34.83	34.76 - 34.91
400	34.82	34.78 - 34.86	34.84	34.82 - 34.86

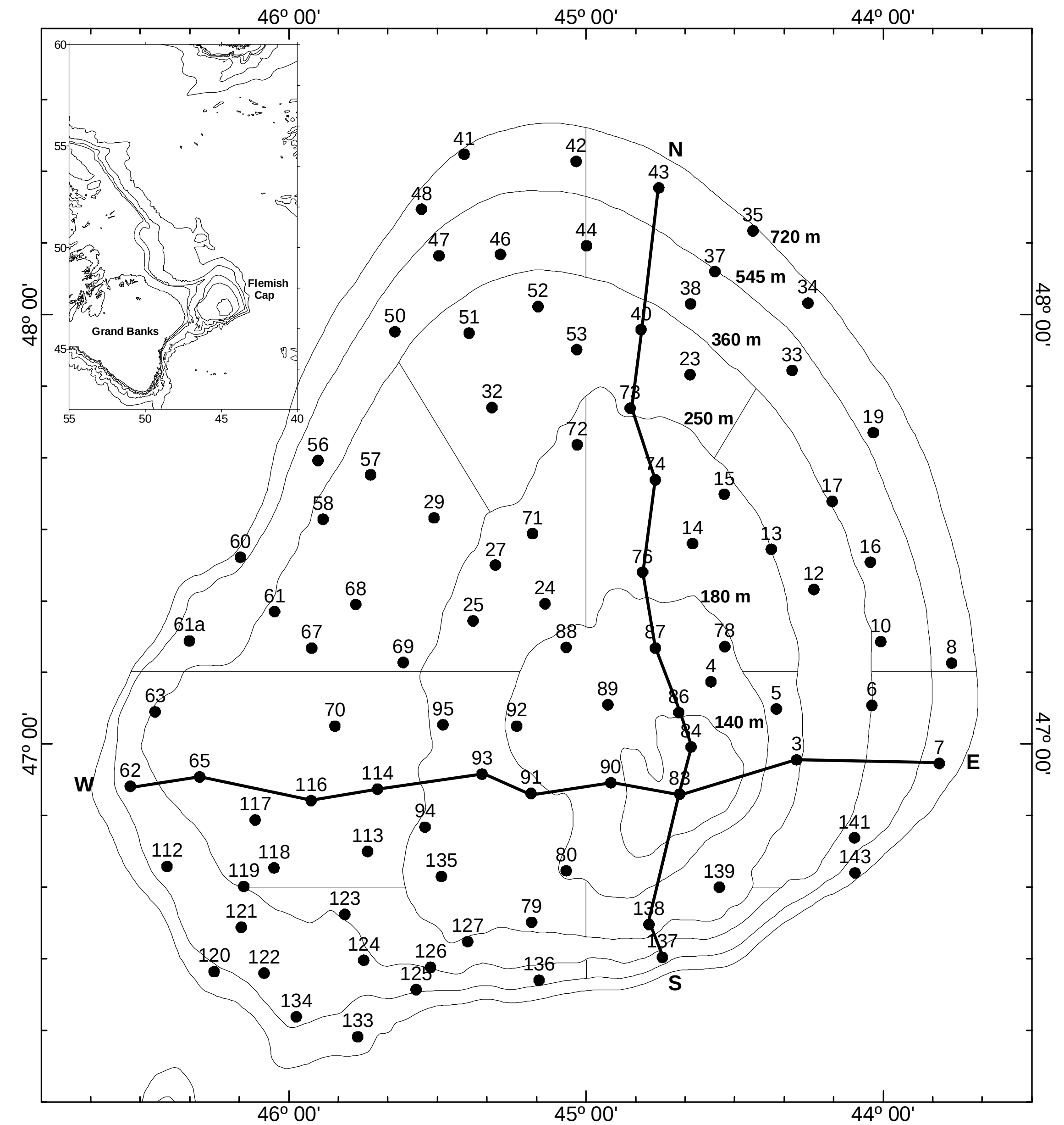

Fig. 1. Location of CTD stations, and N-S and E-W section established in Flemish Cap survey in July 2000

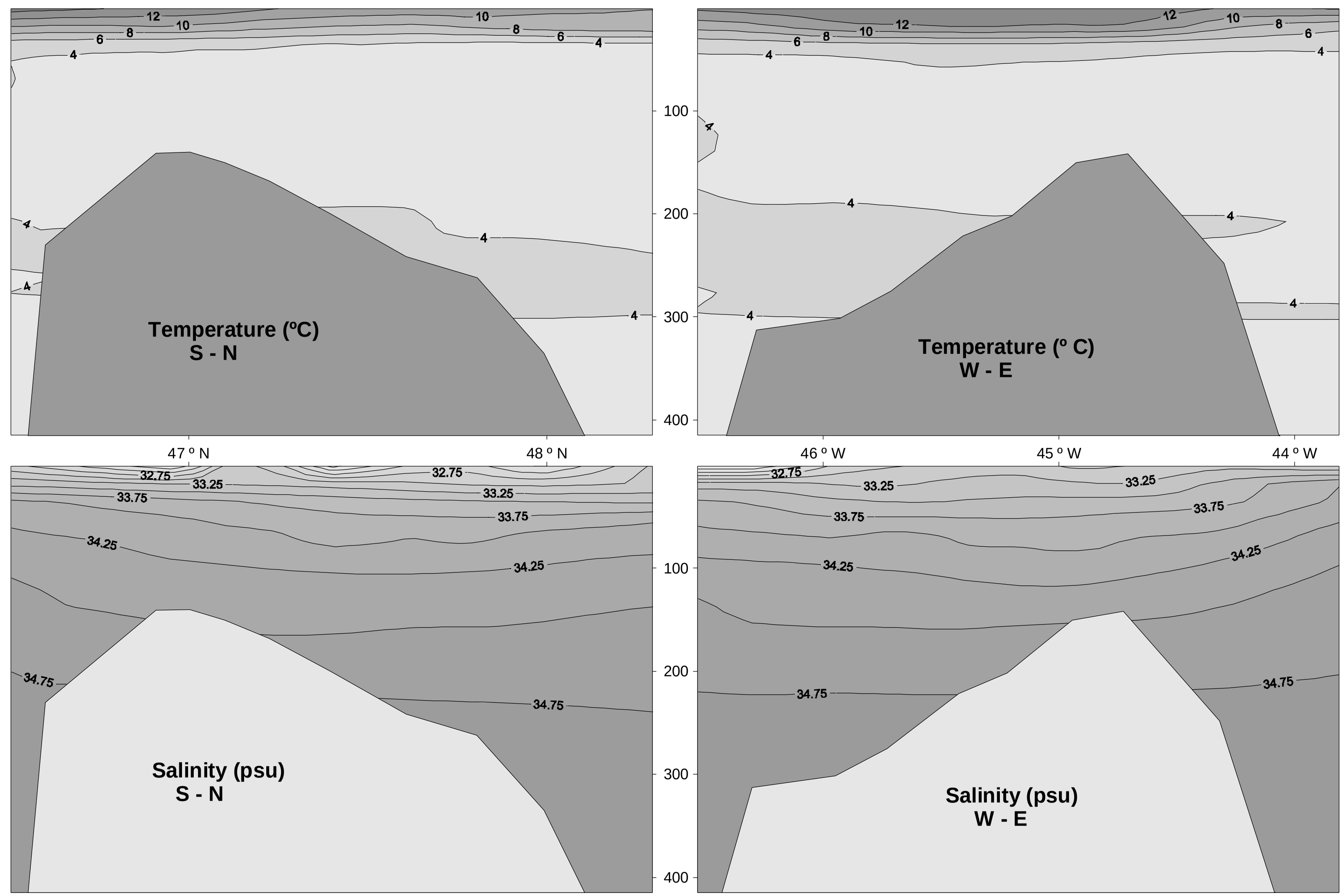

Fig. 2. Isohaline and isotherm contours versus depth in the N-S and W-E section.

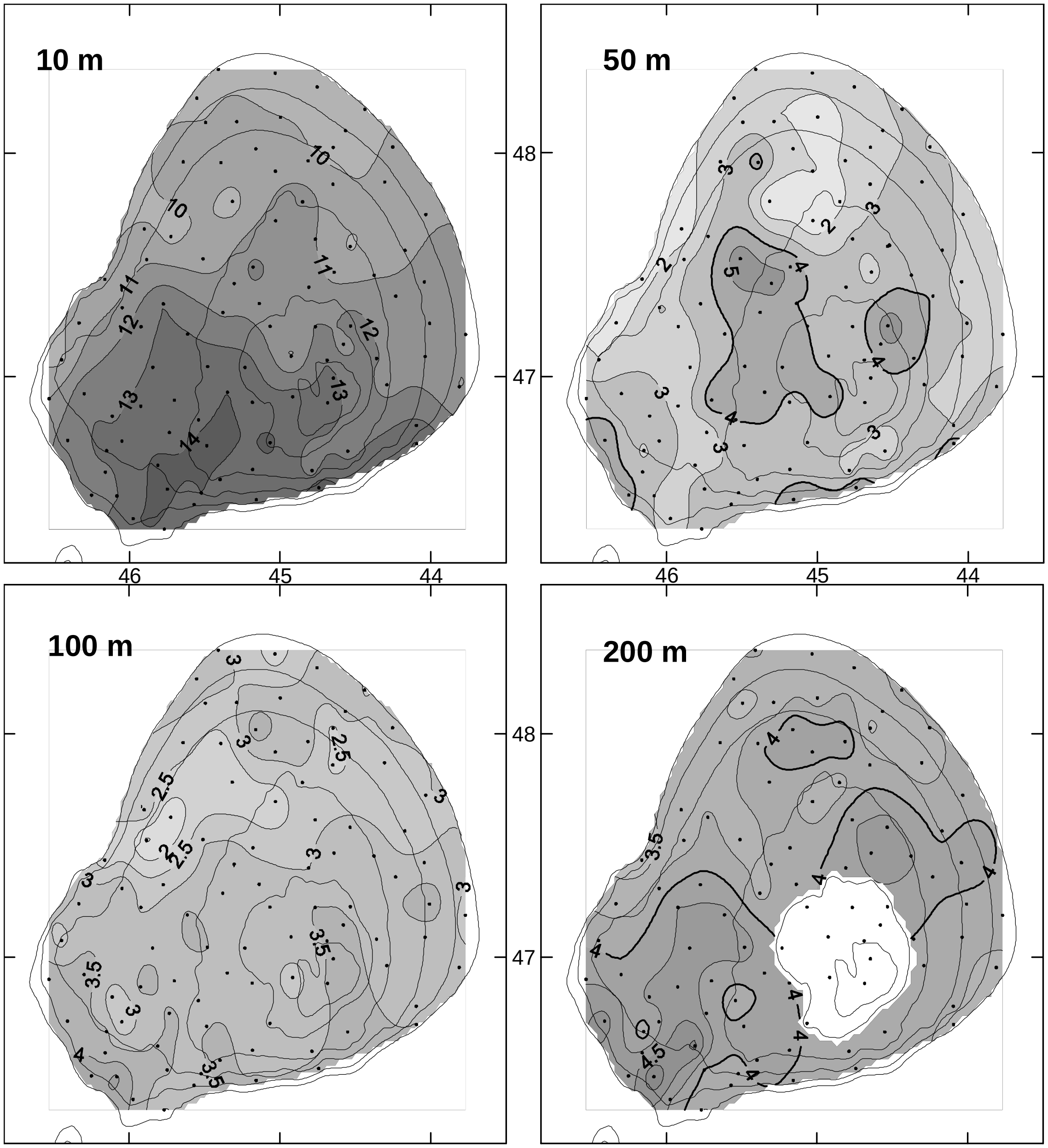

Fig. 3. Isotermal contour maps at 10, 50, 100 and 200 depths on Flemish Cap.

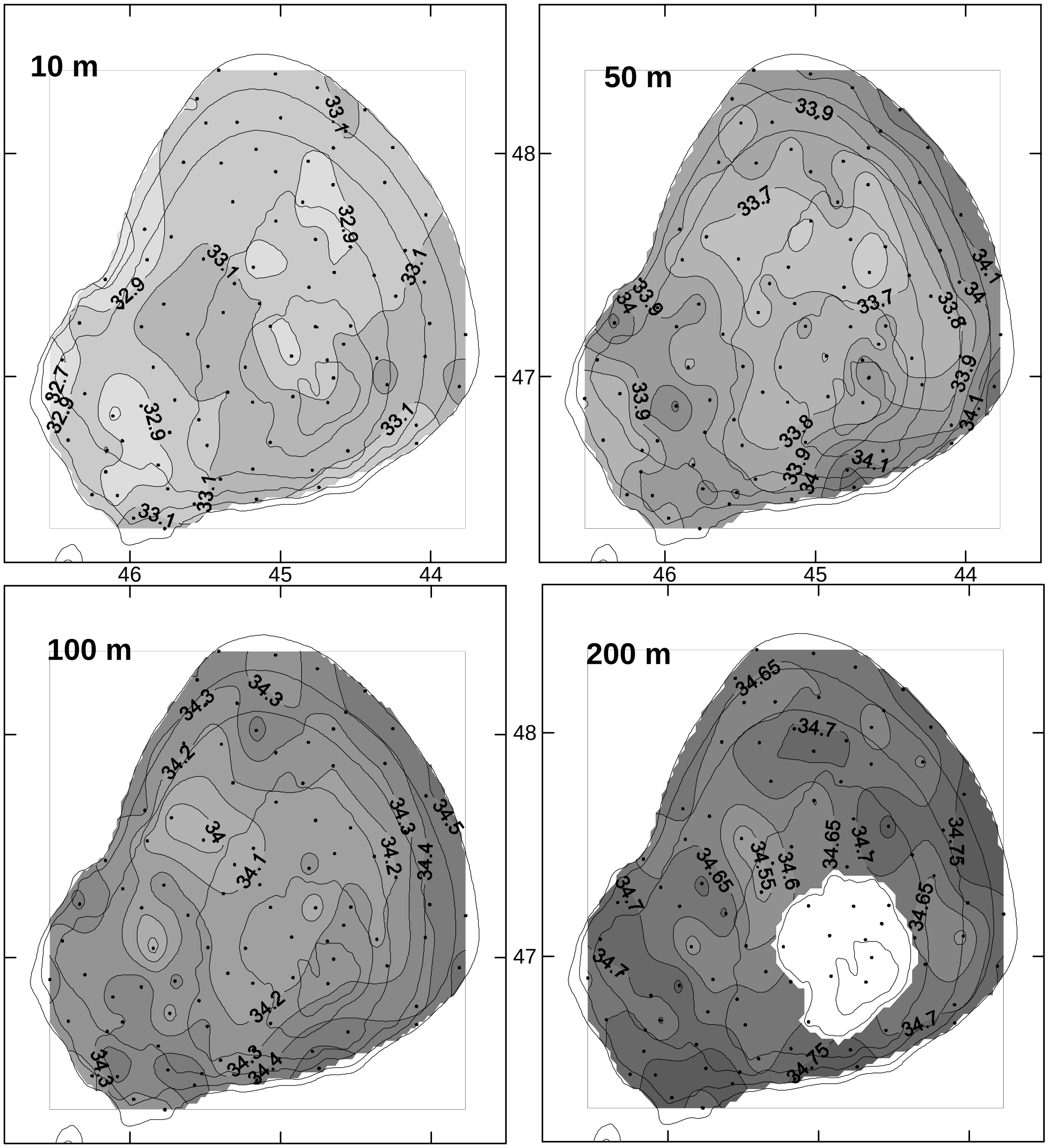

Fig. 4. Isohaline contours maps at 10, 50, 100, and 200 m depth on Flemish Cap.

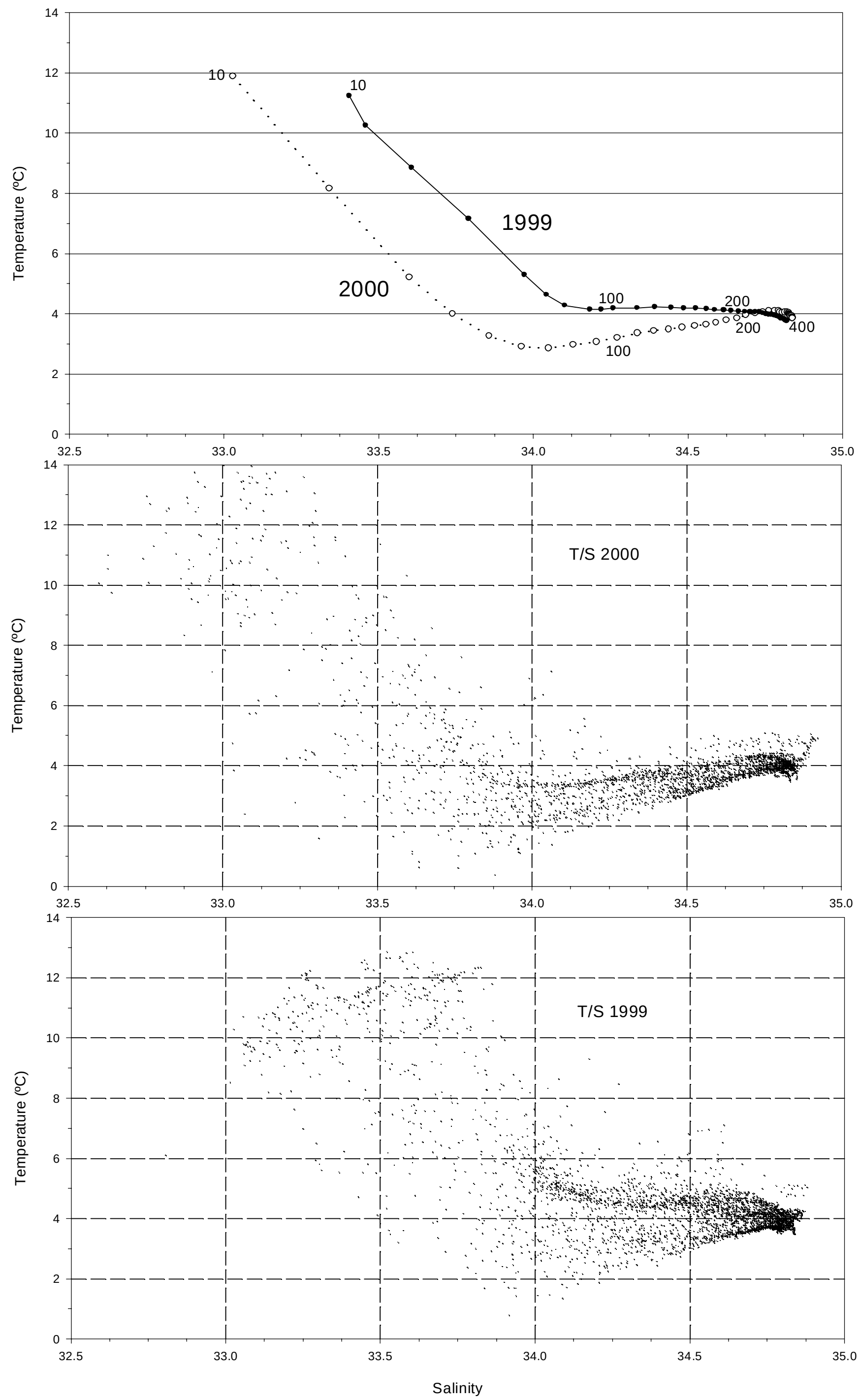

Fig. 5. Top panel: TS plot with average value each 10 m for 1999 and 2000.
Intermediate panel: TS plot for all stations in year 2000
Bottom panel: TS plot fro all stations in year 1999