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Hydrographic Conditions on Flemish Cap in July 1999 and Comparison with Those Observed in Previous Years

by

D. Garabana [1], J. Gil [2] and R. Sanchez [2]

[1] Instituto de Investigaciones Marinas, Eduardo Cabello 6, 36208 Vigo, Spain
e-mail: lola@iim.csic.es

[2] Instituto Español de Oceanografía, P.O. 240, 39080 Santander, Spain
e-mail: julio.gil@st.ieo.es

Abstract

Hydrographic conditions on Flemish Cap in July 1999 are described after a CTD survey with 116 stations. Water masses present over Flemish Cap are compared with those observed in the three previous years.

The hydrographic pattern on Flemish Cap in the summer is the consequence of earlier processes and the summer effect. The incoming fluxes over the bank and its relative strength determine the initial water masses field. Later modifications within the topography of the bank give the resulting water masses field. Anomalous warm summer weather with intense solar heating results in AGW (Anticyclonic Gyre Water) with high superficial temperatures. A well-developed anticyclonic gyre may be the consequence of an intense LC (Labrador Current) over the bank and an ulterior Taylor's column formation.

Keywords : Flemish Cap, Hydrography

Introduction

The Flemish Cap is a underwater plateau centred at about 47º N and 45º W with minimum water depths of 125m. The Cap is separated from the Grand Bank of Newfoundland to the West by the Flemish Pass, a region with minimum depth of about 1100m.

The general circulation of water masses in the zone is determined by the confluence of Labrador Current (LC) and the North Atlantic Current (NAC). To the Northwest of Flemish Cap, the LC is divided into two branches that surround the bank. The NAC flows SW-NE along the 4000m isobath in the Southeast of Flemish (Krauss *et al*. 1987). Several authors referred Flemish Cap waters as the result of the mixture between the cold and relatively low salinity LC waters and the warmer high salinity NAC waters (Hayes *et al*. 1977, Cerviño and Prego 1997, Colbourne 1998), but in Akenhead's (1986) opinion, only the LC contributes to the Flemish Cap waters. Cerviño and Prego (1999) found a third water mass on Flemish Cap besides LC and NAC waters, that were described as intrusions of Slope Water.

Water masses over the Cap have a typical anticyclonic gyre movement (Kudlo *et al*. 1984, Ross 1981) that characterise oceanography in the area. The anticyclone circulation was strongly evident in 1996 (Colbourne 1997), but measurements over the Cap during 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, united to intense mesoscale activity in form of cyclone rings surrounding the periphery of the bank. This dynamical configuration seems to be relevant on considering the distribution of photic layer fertilisation-related parameters. Anticyclonic gyre circulation around the Cap is predominant, but there is a high degree of interanual variability (Colbourne *et al*.1998).

This paper shows the hydrographic conditions on Flemish Cap in July 1999 and compares the different water masses present in Flemish Cap in summer 1996, 1997, 1998 and 1999.

Materials and Methods

A random bottom-trawl survey on Flemish Cap was carried out in July 1999 on board of R/V Cornide de Saavedra. The survey was conducted from July 2nd to July 21st following the same method used since 1988 (Vázquez 2000). A total of 117 valid bottom trawls were completed in Flemish Cap. A CTD station was established at the beginning or the end of each fishing haul except in one of them due to its proximity to the preceding one. So, a total of 116 stations had been carried out at the end of the survey and its distribution was paired to the hauls (Figure 1).

The CTD sound used was a Sea-Bird, SBE 19 provided with depth, 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 limit depth of 410 meters. Its calibration parameters had been checked before the cruise against seawater samples in which salinity had been measured in an Autosal salinometer.

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 used on density and salinity data. All variables were finally interpolated to each precise meter depth to get a proper database, which would later allow a correct processing of the results.

Temperature and salinity distribution charts at several depths (10, 50, 100 and 200 meters) were calculated. Two transects were design, one in N-S direction next to the 45º W meridian and the other in W-E direction next to the 47º N parallel, to analyse the vertical temperature and salinity distribution. Each transect contains eleven stations nearly located to the reference line (Figure 1). All contour maps have been made with Surfer 6.03 from a grid traced with a linear variogram, according to Krigin's method.

This paper provides TS diagrams for 1996, 1997, 1998 and 1999. CTD data for all these years have been acquired during the EU surveys that are annually carried out on Flemish Cap in summer. As noted above, these surveys follow the same method since 1988. So, CTD stations plan was the same for the four years (1996 to 1999). The model of CTD sound used for 1996 and 1999 was the above-mentioned (SBE-19) and for 1997 and 1998 was the SBE -25.

Results

Vertical distribution of temperature and salinity in the N-S transect are shown in Figure 2. Temperature decreases downward from 11-12ºC near the surface to 4ºC at 75m depth. The layer above the termocline is wider in the northern stations than in the southern ones. Water is warmer (4-5ºC) on the shallowest central part of the Cap than in the border at the same depth. It can be explained by the Taylor's column effect: the bank topography induces anticyclonic gyre over the central region of the cap (Kudlo *et al*. 1984, Ross 1981) and retains masses of water that were heated up by sun radiation. Deeper than 150m, temperature keeps stable at about 3.5ºC. Salinity decreases progressively from 33.5psu near the surface to 34.75psu at the bottom.

Vertical distribution of temperature and salinity in the W-E transect are shown in Figure 3. Temperature decreases from 12ºC to 5ºC downward in the first 50m. Temperature is very stable (4-5ºC) in the West in the 50-300m depth range zone but a slightly colder (3-4ºC) mass of water appear in the East. Salinity increases from 33.5psu in the surface to 34.75psu in the bottom.

Temperature distribution on Flemish Cap at different depths is shown in Figure 4. Near the surface (10m map) temperature reach 13ºC in the central upper part of the bank. From the centre of the Bank towards the southern and western edge, temperature is roughly constant whilst towards northern edge it decreases progressively to 10ºC. At 50m, temperature ranges between 3ºC and 6ºC; there are a homogeneous warmer zone (5-6ºC) from the central upper part to the south-western edge whilst northern and eastern edges show colder values. The maximum and the minimum temperature (10ºC and 1ºC) were observed in two closed stations in the central-east of the bank. Temperature distribution shows the same pattern in both, 50m and 100m depth. The temperature gradient is abrupt at the northern and eastern edges in contrast to the central and the west parts of the bank where temperature is quite homogeneous. At 200m, temperature range between 3.5ºC and 4.5ºC. Warmer values are found in the central and western region of the bank, and colder values appear in the northern and eastern boundaries, like at the other depths.

As in previous surveys in July, a pronounced thermocline in less than 50m depth and temperature minima in around 100m depth were observed in the whole bank.

Salinity distribution on Flemish Cap at several depths is shown in Figure 5. At 10m depth, salinity ranges between 33.0 and 33.8psu. Maxima values occur mainly in the Southwest and centre of the Cap and at the eastern edge, whilst minima values appear in the North and Southeast. At 50m depth it mainly ranges between 33.8psu and 34.3psu. At 100m minima values (34.2psu) appear in the northern and central-eastern parts of the Cap and maxima values (34.6psu) are located on the central part of the bank. At 200m salinity are around 34.6-34.7psu. Only in the Southeast appears a zone with 34.8psu, a value slightly higher. In general it was observed that salinity increase with depth.

Temperature on the Flemish Cap from 1996 to 1999 is compared in Table 1. Data belong to summer period and were taken at different depths. Temperature at the surface was warmer this year than in previously years. The surface layer is very influenced by weather conditions and it highest temperature might be the consequence of a longer period of sunny days and without wind, actions that break the cyclonic gyre.

Discussion

Flows from the Labrador Current (LC) and from the North Atlantic Current (NAC) converge over Flemish Cap. This convergence origins the starting mass field in Flemish. Later modifications of these waters due to the dynamic induced by the topography of the bank will constitute the resulting mass field. Alternatively, Akenhead (1986) states that the water mass characteristics on Flemish Cap can be explained by heating up the Labrador Current Water, without making use of a mixing process with the North Atlantic Current.

Temperature-Salinity diagrams (T/S) from 1996, 1997, 1998 and 1999 show the different types of water that constituted the water masses over Flemish. They are presented in Figure 6 overprinted on the Hayes *et al.* (1977) criteria to define water masses near the Grand Bank. The equivalence between the Hayes' criteria and present nomenclature is presented in Table 2.

Four distinct types of water can be found in the different hydrographic states in this four years: Labrador Water (LW), Modified Labrador Water (MLW), Anticyclone Gyre Water (AGW) and North Atlantic Current component Water (NACW). All water types have the closed TS characteristics at depths below 100m, as it is quite noticeable in the Hayes' diagram. A weakly gradient is observed between 50 and 100m depth.

<u>Labrador Water (LW).</u> In the present paper Labradorian waters are referred to as Labrador Water instead of Labrador Current Water. The typical T-S diagram shows that subsurface temperature minima (around 0ºC) is always found above 50m depth, so superficial temperature in this water type are the coldest of all the water types. Salinity also shows the lowest values, at least for the first 50m depth.

Over Flemish Cap both, the environmental conditions and, particularly, the gyro dynamic, affect Labrador Waters whose TS characteristics are modified by heating up. Subsequently they are referred as typical Flemish Cap Water by other authors to obviate its origin. So, the typical Flemish Cap Water has its origin in the Labrador Water, and it will become AGW or MLW as the results of later modifications. These two water types are designate as Mixed Water by Hayes, which seems indicate a different origin. Mixed water would be the results of the mixing of Labrador Current water and the North Atlantic Current water (Hayes 1977). In our view, following Akenhead

(1986), the typical Flemish Cap water (both, AGW & MLW) proceeds from the Labrador Current water, by heating (AGW) or by modifying by several external unspecific factors (MLW).

Anticyclone Gyre Water (AGW). It is the heating LW after has been retained by the dynamic of the gyro. This water presents the warmest temperature in the homogeneous superficial layer, due to the summer dynamical pattern. Likewise, an evaporative process changes original low salinity of LW into relatively higher salinity.

Modified Labrador Water (MLW). It is the LW after has been modified by external agents and perhaps the dynamic of the gyro. It is neither isolate in a dynamic structure, nor presenting dynamic boundaries with the LW, and that is why their profile looks like AGW but colder in the superficial layers. It differs from the youngest LW in the higher salinity values and in the no-presence of subsurface temperature minima. It is possible that it were gyre waters that periodically have became modified, allowing characteristic T-S profiles.

NAC Component Water (NACW). NACW subsurface TS properties typify this water as NAC showing a clear difference from the LC waters. However, superficial layers have not definite characteristics. Temperature and salinity maxima clearly appear at subsurface layers. In 1996, (Cerviño *et al*. 1999) described a water mass with temperatures higher than 4.5ºC and salinity higher than 34.90psu, known as Slope Water (Loder 1991, Drinkwater 1993) (the characteristics of this water are the same now attributed to the NACW). This water has its origin in the north-eastward moving component of a denser water mass created by the mixing of Labrador Current and North Atlantic Current near the Grand Bank (Hayes *et al*. 1977).

As is shown by Figure 6, in 1996 three different types of water masses may be observed: LW, AGW and NACW. The points belonged to these three water mass types are those in each zone of the Hayes' diagram noted as Labrador Current (LW), Mixed (AGW) and Atypical (NACW). Cerviño and Prego (1997) found typical Labrador Current water on the periphery of the bank, according to its TS characteristics. They concluded that the water mass on the central part of the bank (AGW) proceeded from the same Labrador Current water by solar heating. They found a third water mass type, with highest salinity, which was identified as Slope Water (named NACW in this paper).

In 1997, slightly modified Labrador Water (LW), that is, water masses characterised by T<3.0ºC and S<33.6psu types are predominant.

In 1998 the four types of water masses previously described are present and with clearly different characteristics. The NACW (North Atlantic Current in Hayes' diagram in Figure 6) is well observed with subsurface temperature and salinity maxima, showing extreme values nearly 7ºC and 35psu at 150m depth. The LW is observed, bringing the coldest and low-salinity types. Most of the stations show the characteristic AGW profile, with very high temperature in superficial layers and a quite homogeneous profile around the 4ºC under the thermocline. The MLW constitutes the remaining waters, with colder temperature in the homogenous superficial layer than the AGW. Both, AGW and MLW, appear in the zone named mixed in the Hayes' diagram in Figure 6.

In 1999 MLW appears predominant, and NACW is not found. This abundance of Modified Labrador Waters generates quite homogeneous T-S diagrams at all levels over the Plateau.

The hydrographic pattern on Flemish Cap in the summer is the consequence of earlier processes and the summer effect. The incoming fluxes over the bank and its relative strength determine the initial water masses field. Later modifications within the topography of the bank give the resulting water masses field. Therefore, the summer TS pattern provides information about the aforementioned features. For instance, anomalous warm summer weather with intense solar heating results in AGW with high superficial temperatures. A well-developed anticyclonic gyre may be the consequence of an intense LC over the bank and an ulterior Taylor's column formation.

Acknowledgements

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Table 1 .- Water temperature (ºC) in Flemish Cap in the period 1996-1999 (Summer).

YEAR	SURFACE		SUBSURFACE			
	Depth	Tª	Depth	Tª	Depth	Tª
1996	10 m	7.0-11.0	100 m	2.5-4.0	200 m	3.5-4.0
1997	15 m	7.0-11.5	140 m	3.1-3.9	190 m	3.4-4.0
1998	25 m	6.0-12.0	135 m	2.0-5.0	-	-
1999	10 m	10.0-12.0	100 m	2.5-5.0	200 m	3.5-4.5

1996 data: Cerviño and Prego, (1997).
1997 data: Gil *et al*. (1997).
1998 data: Gil *et al*. (1998).

Table 2 .- Equivalence between the Hayes' criteria and present paper nomenclature.

HAYES'S CRITERIA	**PRESENT PAPER**
LABRADOR CURRENT	Labrador Water (LW)
MIXED	Anticyclone Gyre Water (AGW) Modified Labrador Water (MLW)
ATYPICAL NORTH ATLANTIC CURRENT	NAC component Water (NACW) Slope water

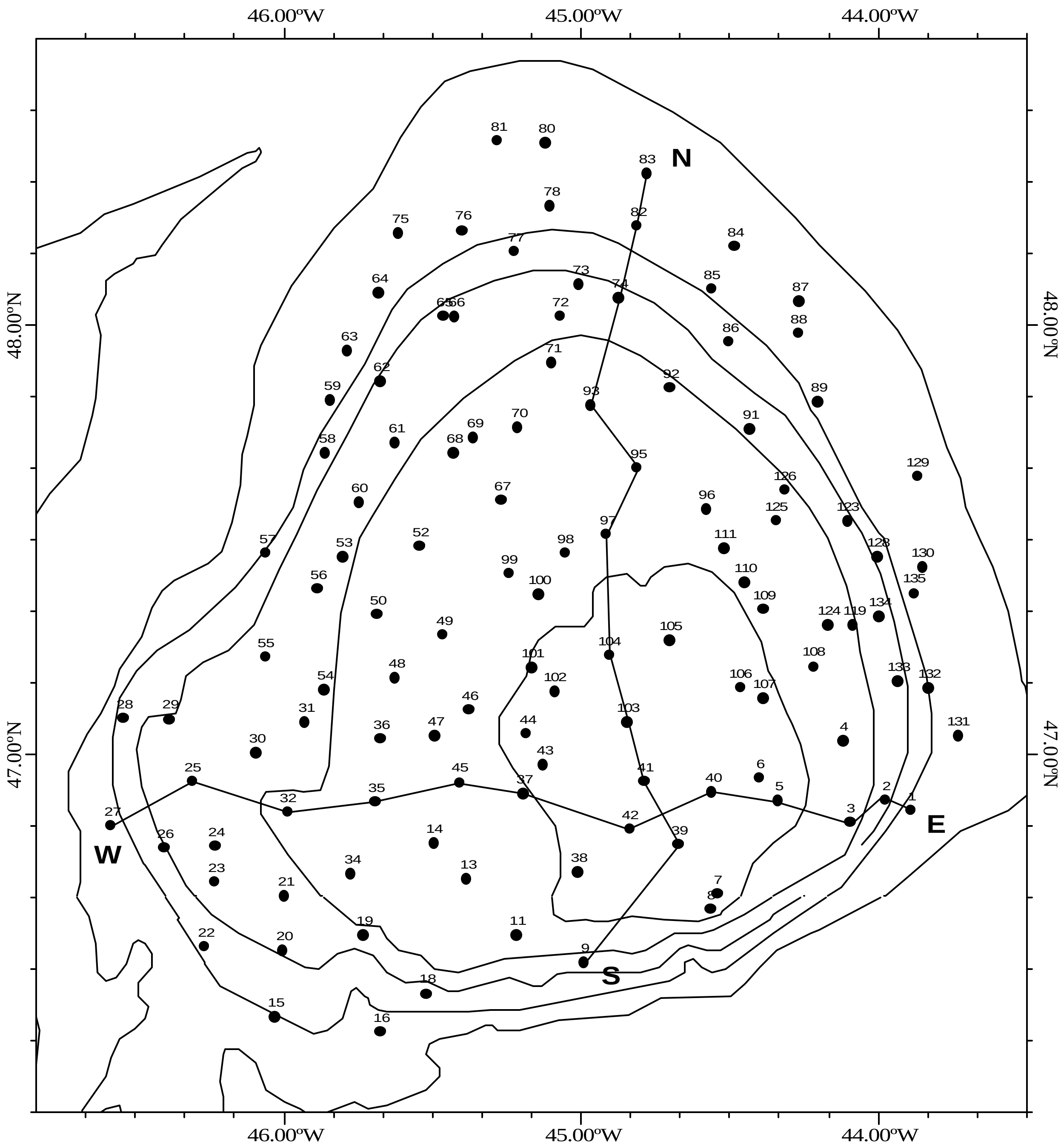


Figure 1. Location of CTD stations and N-S and W-E transects stablished on Flemish Cap (July 1999).

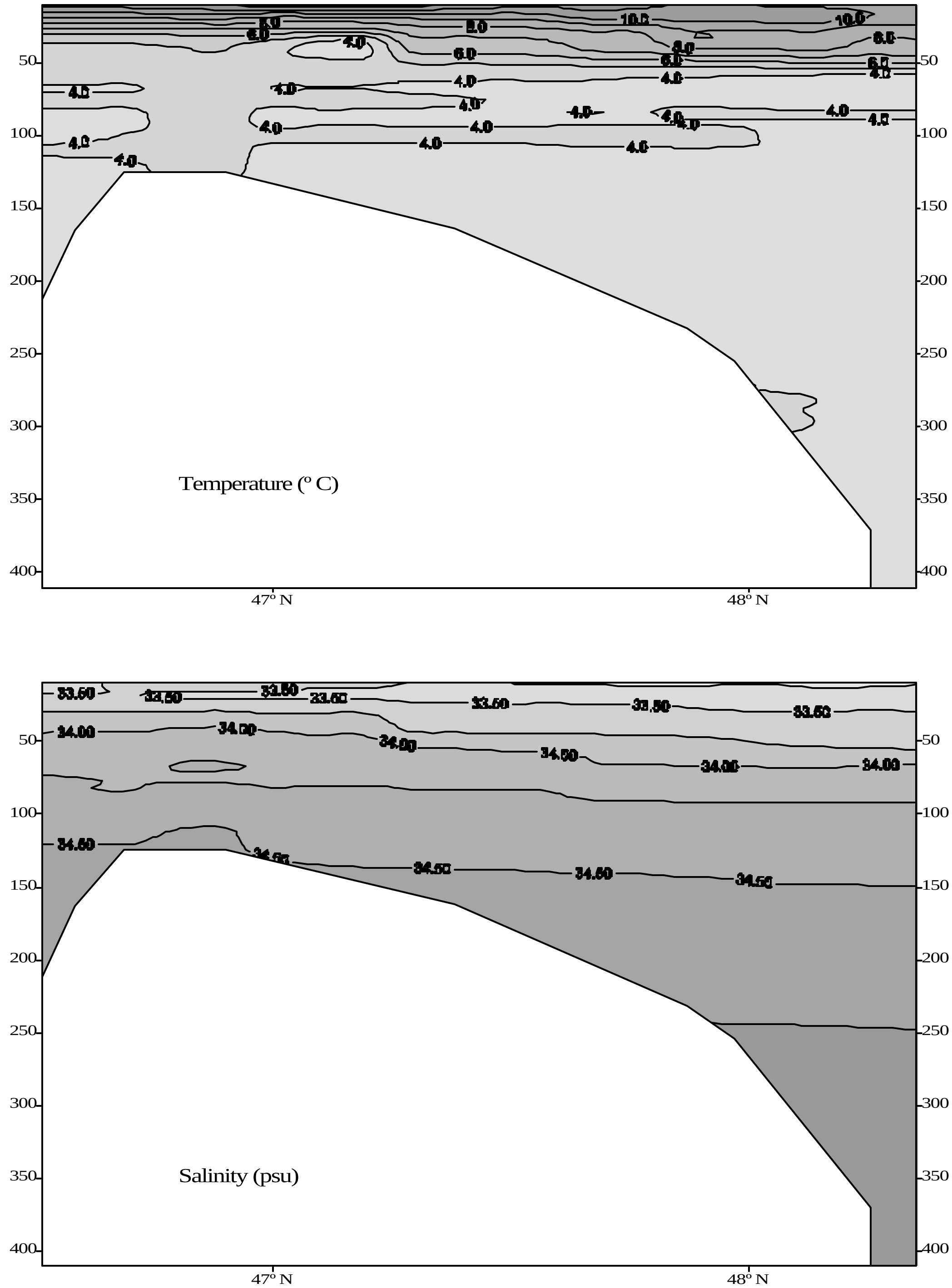


Figure 2. Temperature and salinity in the N-S transect

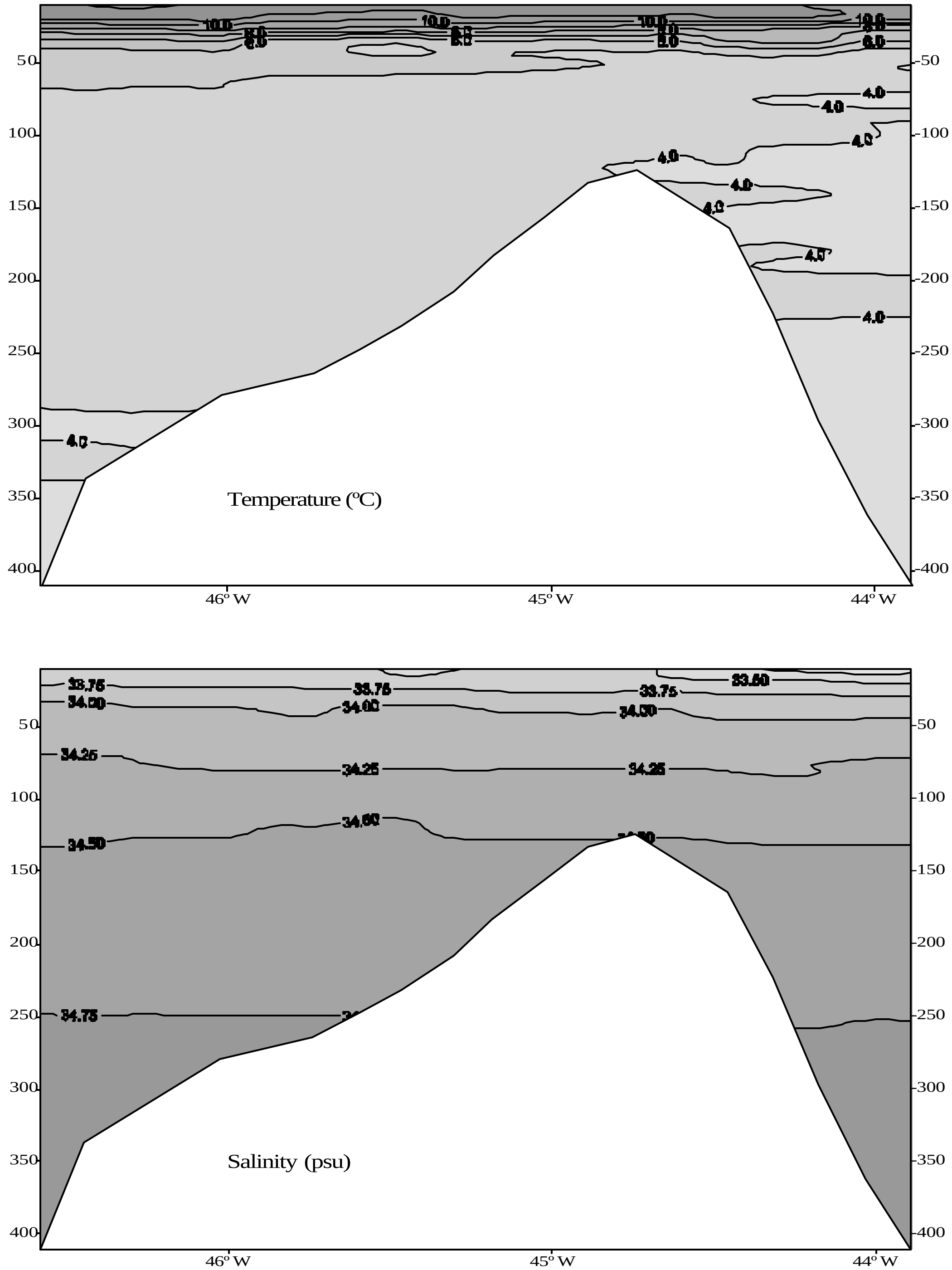


Figure 3. Temperature and salinity in the W-E transect.

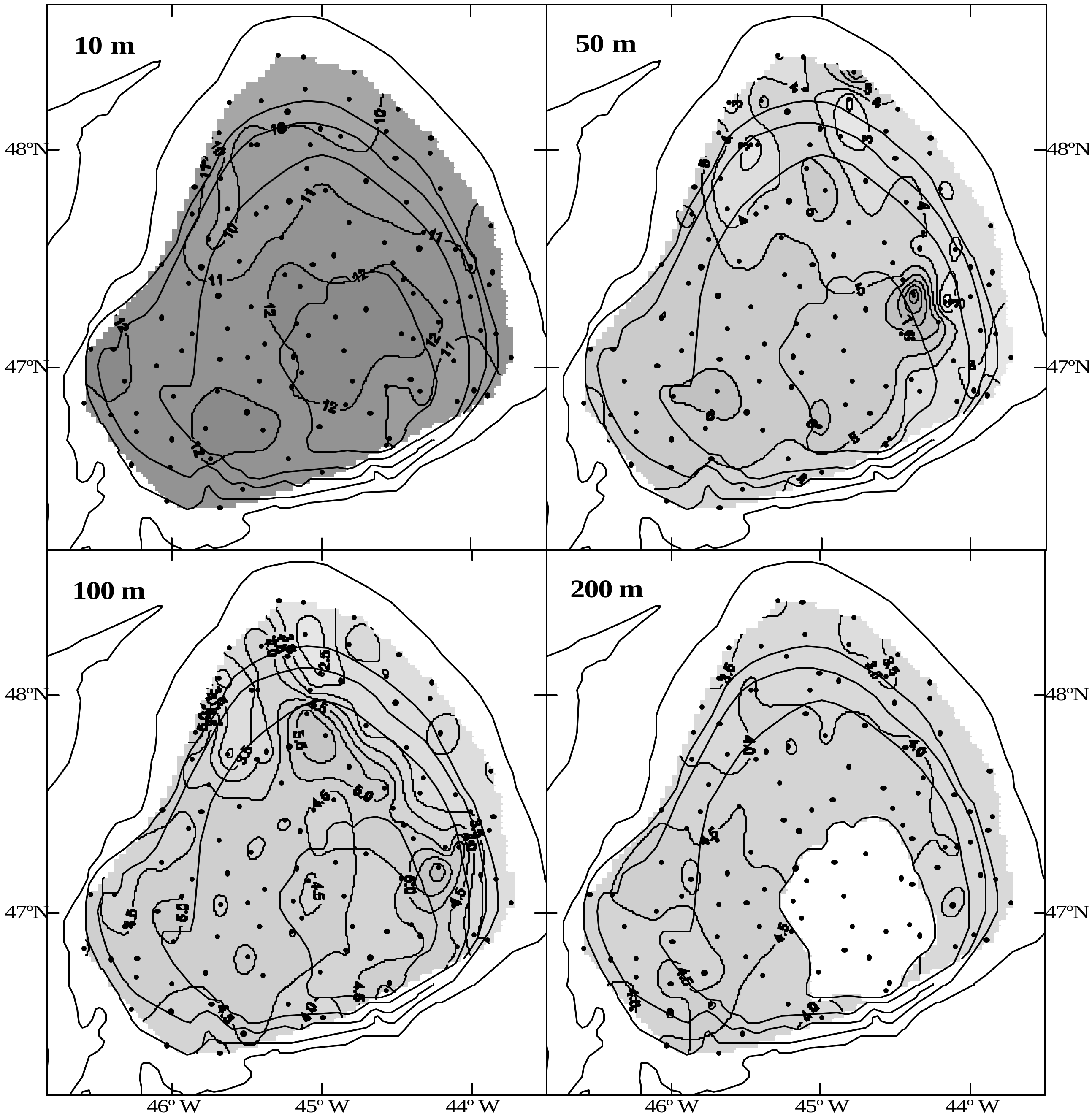


Figure 4. Distribution of temperature at several depths in Flemish Cap (July 1999).

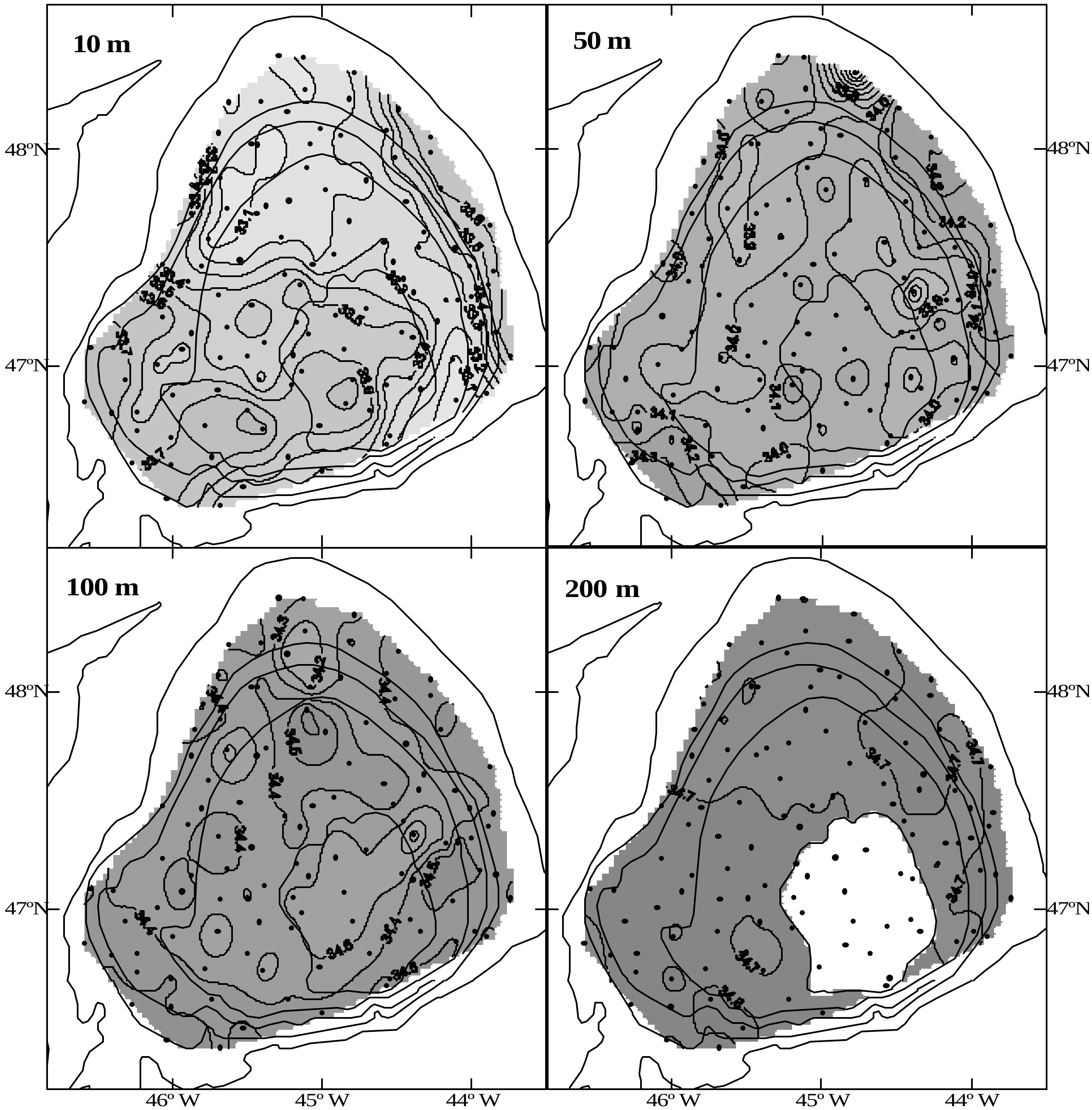
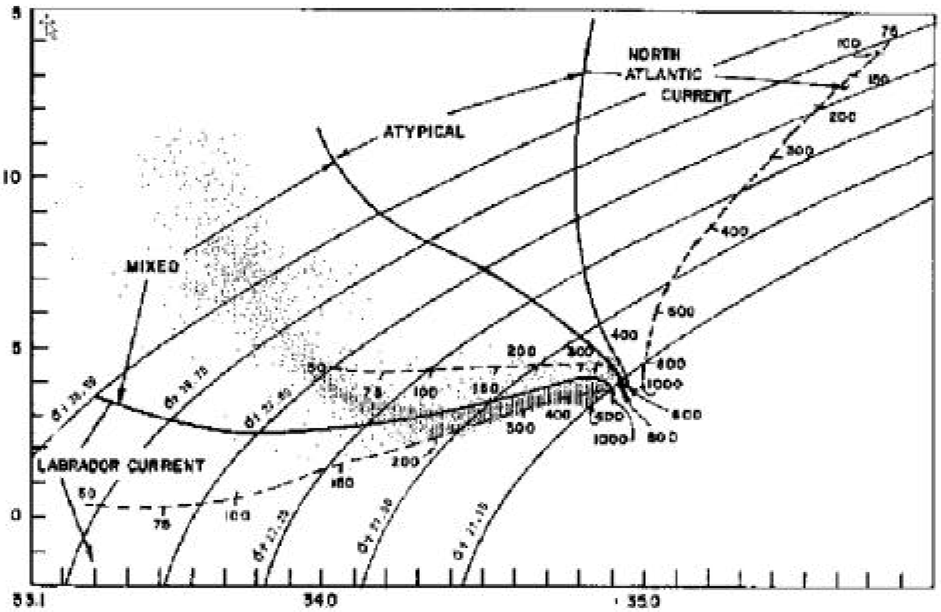
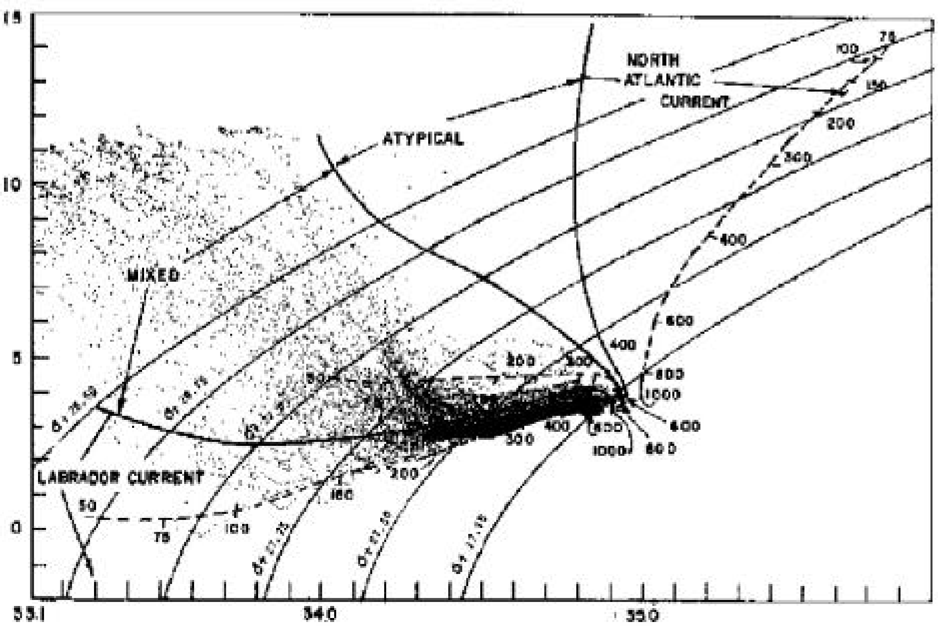


Figure 5. Distribution of salinity at several depths in the Flemish Cap (Summer 1999)

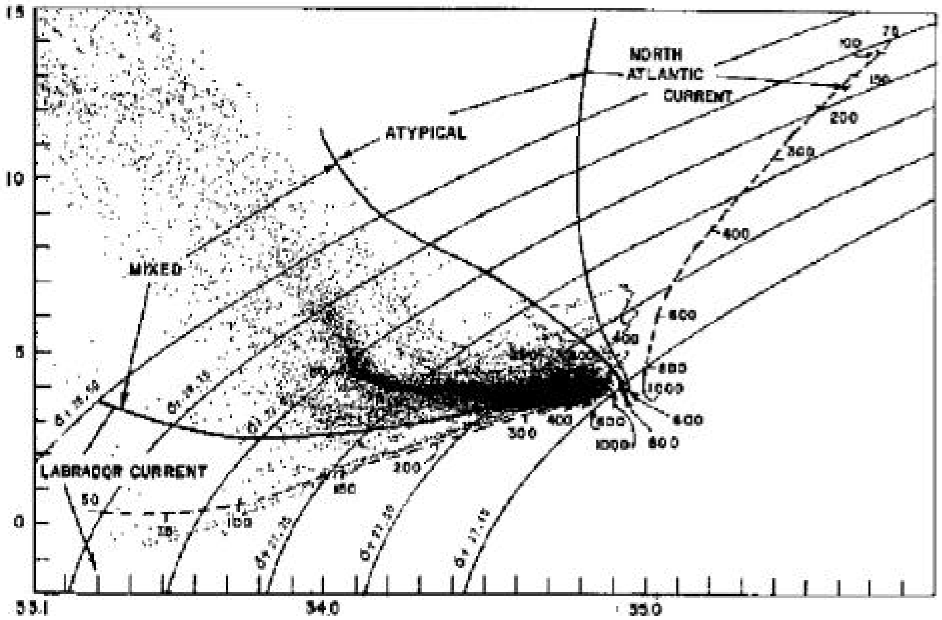


July 1996

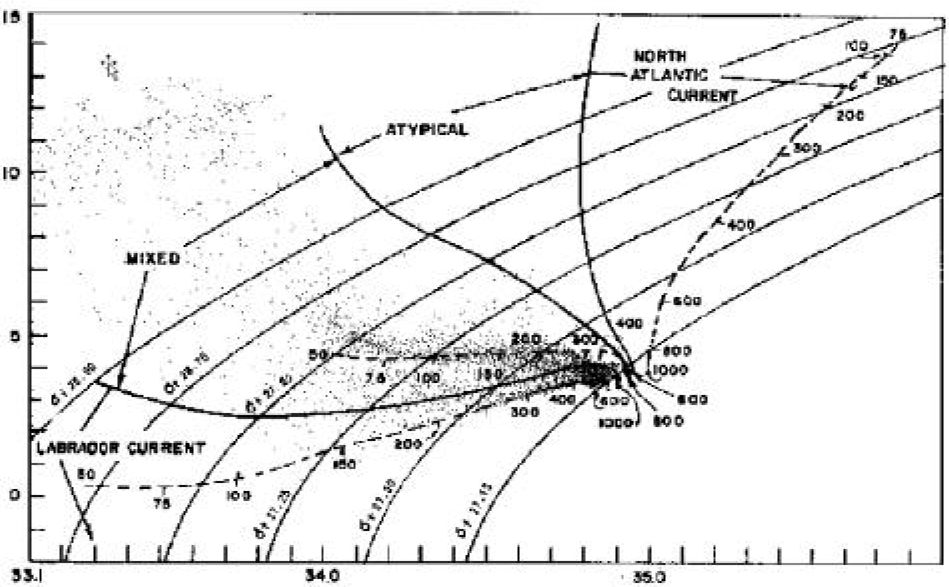


July 1997

Figure 6. T/S diagram for all stations in the 1996, 1997, 1998 and 1999 surveys, represented over the criteria diagram to determine water masses found near the Grand Bank. Points represented in the 1996 and 1999 graphics are T/S records every 10 meters in the water column. They are only 1 meter apart in 1997 and 1998.



July 1998



July 1999

Figure 6. Continued