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Oceanographic conditions in NAFO Subdivisions 3Pn and 3Ps during 1999 with comparisons to the long-term (1961-1990) average

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ABSTRACT

Oceanographic data from NAFO subdivisions 3Pn and 3Ps during 1999 are examined and compared to the long-term (1961-1990) average. The temperature and salinity data are presented in several ways, as vertical transects across the major banks and channels, horizontal bottom maps, time series of areal extent of bottom water in selected temperature and salinity ranges and as time-series of temperature anomalies at standard depths. Temperature anomalies in the 3Ps St. Pierre Bank area show anomalous cold periods in the mid-1970s and since the mid-1980s, similar to conditions on the continental shelf along the East Coast of Newfoundland. The most recent cold period, which started around 1984, continued to the early 1990s with temperatures up to 1oC below average over all depths and up to 2oC below the warmer temperatures of the late 1970s and early 1980s in the surface layers. Temperatures in deeper water off the banks show no significant trends. Since 1991, temperatures have moderated in some areas from the lows experienced from the mid-1980s and early 1990s but negative temperature anomalies continued over large areas of the banks into the spring of 1995. During 1996 temperatures started to moderate, decreased again during the spring of 1997 and returned to more normal values during 1998. Temperatures during 1999 continued to warm and were above normal over most of the water column and near bottom. An analysis of the areal extent of subzero oC bottom water covering the banks shows a dramatic increase since the mid-1980s, very low values in 1998 and a complete disappearance in 1999. The areal extent of bottom water with temperatures above 1oC on the banks was about 50% of the total area during 1998 the first significant amount since 1984 and it increased further to about 70% during 1999. The salinity data clearly shows a change in water mass characteristics during the last 2 years, compared to conditions that prevailed during the first half of the 1990s. The areal extent of the relatively saltier water (>32.5) on the banks increased by approximately 40% during this time, indicative of a shift from the cold-fresh conditions of the late 1980s and first half of the 1990s on the Newfoundland Continental Shelf to warmer-saltier conditions.

RÉSUMÉ

Les données océanographiques obtenues pour les sous-divisions 3Pn et 3Ps de l'OPANO en 1999 font l'objet d'un examen et d'une comparaison avec les moyennes à long terme (1961-1990). Les données de température et de salinité sont présentées de diverses façons : transects verticaux traversant les bancs et les chenaux importants, cartes horizontales des fonds, séries chronologiques de superficies des eaux des fonds présentant certaines gammes de température et de salinité et séries chronologiques d'anomalies de température à des profondeurs normalisées. Les anomalies de température au banc St. Pierre en 3Ps font état de périodes anormalement froides au milieu des années 1970 et depuis le milieu des années 1980, ces conditions étant semblables à celles notées sur le plateau continental le long de la côte est de Terre-Neuve. La période de froid la plus récente, qui a débuté vers 1984, s'est poursuivie jusqu'au début des années 1990, les températures pouvant être jusqu'à 1ºC inférieures à la moyenne à toutes les profondeurs et jusqu'à 2ºC inférieures aux températures plus chaudes notées à la fin des années 1970 et au début des années 1980 dans les couches de surface. Les températures de l'eau plus en profondeur au large des bancs ne présentaient pas de tendances notables. Depuis 1991, les températures se sont rétablies, dans certaines zones, des faibles valeurs du milieu des années 1980 et du début des années 1990, mais des anomalies négatives ont continué d'être notées dans de larges zones des bancs jusqu'au printemps de 1995. En 1996, elles ont commencé à devenir modérées, ont diminué ensuite au printemps de 1997 et sont redevenues plus normales en 1998. Elles ont continué de s'accroître en 1999 et étaient supérieures à la normale dans la plus grande partie de la colonne d'eau et à proximité du fond. Une analyse de la superficie des eaux du fond des bancs à moins de 0ºC a montré une augmentation extrêmement importante depuis le milieu des années 1980, de très faibles valeurs en 1998 et à leur disparition complète en 1999. La superficie des eaux du fond des bancs à température supérieure à 1ºC représentait 50 % environ de la superficie totale en 1998, soit la première augmentation appréciable depuis 1984, et elle a continué de s'accroître pour atteindre 70 % environ en 1999. Les données de salinité montrent clairement une variation des caractéristiques de la masse d'eau au cours des deux dernières années, comparativement aux conditions existant au cours de la première demie des années 1990. La superficie d'eau relativement plus salée (>32.5) présente sur les bancs a augmenté de 40 % environ au cours de cette période, ce qui indique un changement des conditions d'eau froide et peu salée de la fin des années 1980 et de la première moitié des années 1990 sur le plateau continental de Terre-Neuve, à des conditions d'eau plus chaude et plus salée.

INTRODUCTION

The general circulation in the 3Ps region consists of modified Labrador Current water, the inshore branch of which flows through the Avalon Channel, and around Cape Race. This branch then divides into two parts, one flowing to the west around the north of St. Pierre Bank, and the other flows to the south between Green Bank and Whale Bank. Additionally, part of the offshore branch of the Labrador Current flows around the tail of the Grand Bank, westward along the continental slope (where it may interact with the Gulf Stream and slope waters), to the Laurentian Channel and into the Gulf of St. Lawrence.

Since the early 1970s the oceanographic, meteorological, and ice conditions of the Northwest Atlantic have been dominated by three anomalous periods: the early 1970s, mid-1980s and the early 1990s. During these time periods, colder-than-normal winter air temperatures prevailed over the Northwest Atlantic, which were correlated with strong positive winter North Atlantic Oscillation (NAO) index anomalies. This resulted in increased winter and spring ice cover and colder and fresher than normal water mass characteristics over most of the continental shelf in Atlantic Canada (Colbourne et al. 1994; Drinkwater 1996). The extent to which these oceanographic anomalies may have influenced the 3Ps region are documented by several studies (Hutchings and Myers 1994; Moguedet and Mahe 1991; Battaglia and Poulard 1987; Forest and Poulard 1981; Colbourne 1994,1996,1999).

This report summarizes oceanographic conditions in NAFO subdivisions 3Pn and 3Ps (Fig. 1) up to 1999 with a comparison to the long-term mean. Similar reports were published for data from 1990-1994 (Colbourne 1994), 1995 and 1996 (Colbourne 1996) and 1997 and 1998 (Colbourne 1999). The base time period used to compute the averages in these analyses has been defined as the 30-year period from 1961-1990 in accordance with the convention of the World Meteorological Organization and recommendations from the North Atlantic Fisheries Organization's (NAFO) Scientific Council. Unfortunately, there were insufficient salinity data available in this base period to produce meaningful averages, therefore the base period for salinity encompassed all available data from the late 1920s to 1999.

DATA AND METHODS

Oceanographic data for NAFO Subdivisions 3Ps and 3Pn are available from archives at the Marine Environmental Data Service (MEDS) in Ottawa and a working database at the Northwest Atlantic Fisheries Center (NAFC) in St. John's Newfoundland. The bulk of these data are temperatures collected during the Canadian groundfish assessment surveys of February, March and

April since 1973. The station positions where oceanographic measurements were available for the 1999 survey are shown in Fig. 2. Since the winter of 1990, water temperatures on these surveys have been measured, for the most part, using a trawl-mounted Seabird 19 CTD. Prior to that, XBTs were the primary instrument. Data from the net-mounted SBE-19 CTDs are not field calibrated, but are checked periodically and factory calibrated annually maintaining an accuracy of 0.005^{o}C in temperature and 0.005 psu in salinity. The XBTs are accurate to within 0.1^{o}C. In addition to these data, all available historical data were used to establish the long-term means.

Vertical cross-sections of the temperature and salinity fields across the region were constructed by projecting the positions of all observations in corridor A (Fig. 1) along a straight line with their offshore distances calculated from the shoreline. The transects were constructed for April of the years 1961-1990 and for 1999. It starts near Rose Blanche on the south coast of Newfoundland, then follows a southeasterly direction crossing Burgeo Bank, Hermitage Channel, and St. Pierre Bank and terminates near the edge of the continental shelf on the southwestern Grand Bank.

Bottom temperature and salinity maps were produced from all available data from 1961 to 1990 (T only) and for the spring survey of 1999. These maps were constructed by contouring all bottom-of-the-cast temperature and salinity values and rejecting ones for which the cast depths were not within 10% of the total water depth. Some temporal and spatial biasing may be present in the analysis given the large area and wide time interval (up to one month) over which the maps were produced.

An analysis of bottom T/S data from the surveys was made by calculating the total area of the grids used in the bottom T/S maps within selected ranges. The mean bottom temperature and salinity of all grid values was also computed. A time-series of the percent of the total area covered by bottom water in selected temperature and salinity ranges as well as average bottom values were constructed from 1970 to 1999 for temperature and from 1990 to 1999 for salinity. Salinity data covering the complete 3Ps geographical area within any one year are only available since the net-mounted CTDs came into service in 1990.

Finally, time-series of monthly temperature anomalies were constructed at standard depths from St. Pierre Bank corresponding to area B of Fig. 1. The 1961-1990 data set from this area were sorted by day of the year to determine the annual cycle. Following the general methods of Petrie et al. (1992) and Myers et al. (1990), the seasonal cycle at the selected depths was determined by fitting a least squares regression of the form $\mathbf{\cos(\omega t-\phi)}$ to the data. Where ω is the annual frequency, $\mathbf{t}$ is the time in days and ϕ is the phase. The fitted values were the mean, the annual frequency ω and two of its harmonics. The seasonal cycle was then removed to determine anomalies. Unlike the time series of anomalies from fixed points, e.g. Station 27, these anomalies are based on data collected over larger geographical areas and therefore may exhibit variability due to spatial differences in the monthly estimates.

VERTICAL TEMPERATURE FIELD

The vertical cross-section of the average temperature field for April based on the historical data is shown in Fig. 3. No attempts were made to adjust this average for possible temporal or spatial biasing arising from variations either in the number of observations within the time interval or within the area. An examination of the data indicates that the observations are well distributed geographically across the complete transect; however, temporally most of the data have been collected since the early 1970s.

The average upper layer temperature for April from near shore at Rose Blanche on the south coast of Newfoundland over Burgeo Bank and Hermitage Channel is about 1°C. Over St. Pierre Bank the temperature ranges from 1°C near the bottom to 2°C near the surface and 1°-2°C beyond the shelf edge in the upper 100-m of the water column. In the deeper water of Burgeo and Hermitage Channels and on the continental slope temperatures range from 2°C at approximately 125 to 150 m to 5° to 6°C near the bottom. At the edge of the continental shelf on the southwestern Grand Bank the temperature field is marked by a strong gradient separating the warmer slope water from the Labrador Current water over St. Pierre Bank. In this region temperatures increase from 1°C at about 100-m depth to between 5° to 6°C at about 175-m depth, an average vertical temperature gradient of 1°C per 15-m depth change (Fig. 3).

During April of 1999 (Fig. 3, bottom panel) upper layer (0-75 m) temperatures ranged from 1.5° to 2°C near the coast and over Burgeo Channel and Bank and from 2° to 3°C over St. Pierre Bank and up to 4°C over the edge of the shelf. These values were above normal by 0.5°C over St. Pierre and Burgeo Banks and up to 3°C above normal in the upper water column at the shelf edge. The cold water associated with the Labrador Current normally present near the edge of the shelf, particularly during the 1990s (Colbourne 1999) was not present during 1999. In the deeper waters of Burgeo and Hermitage Channels temperatures ranged from 2° to 5°C in the 125 to 200-m depth range, which is about normal. Near-bottom temperatures in these channels were also about normal, between 4° to 7°C. On the continental slope near-bottom temperatures were above normal (up to 2°C), in the depth range from 100 to 200-m depth. Below 200-m depth temperatures were about normal. In general temperatures over most of the water column during the spring of 1999 were above normal continuing the trend established in 1998.

BOTTOM TEMPERATURES

Horizontal Maps

The average bottom temperature for April ranges from 5°C in the Laurentian, Burgeo and Hermitage Channels to about 3° to 4°C on Rose Blanche and Burgeo Banks (Fig. 4). On St. Pierre Bank temperatures range from 0°C on the eastern side to 2° to 3°C on the western side. In general, the bottom isotherms follow the bathymetry around the Laurentian Channel and the southwestern Grand Bank decreasing from 2°C at 200-m depth to 5°C below about 300-m.

During April 1999 bottom temperatures were above average over Burgeo Bank and Channel. Hermitage Channel bottom temperatures appear near normal while values over most of St. Pierre Bank were above normal with temperatures ranging from 1° to 3°C over most of the Bank (Fig. 4). In general, bottom temperatures over most areas during the spring of 1999 were above normal. During the last 2 years conditions in the 3Ps region have moderated significantly from the cold period of the mid-1980s to early 1990s and the 1997 values.

Areal Index

Oceanographic data from groundfish assessment surveys have been collected in the 3Ps region since the early 1970s between January and June. These data together with other oceanographic data were gridded for the winter-spring time period of each year at a spatial resolution of 97 km^2 or approximately 0.1° latitude by 0.1° longitude. A total of 580 grid points or 56,260 km^2

were used within the boundaries of the 3Ps and 3Pn regions. Except for 1980 (which is not included), the percentage of the total area gridded ranged from about 85% to 100%. The mean bottom temperature for each grid was then calculated and combined with the grid area to produce a time series of bottom area covered by water in selected temperature ranges. The areas are expressed as a percentage of the total surveyed area.

Shown in Fig 5 are time series of the areal extent of the bottom covered with water in the temperature ranges of <0°C, 0°C to 1°C and >1°C. Note the large increase in the percentage area of the bottom covered by subzero °C water in 1985 that persisted well into the mid-1990s. The percentage area covered by subzero °C water during the spring of 1998 decreased to pre-1985 levels and to less than 10% during 1999. The bottom area covered with water between 0°C to 1°C, except for 1979 and 1988, has remained below 20%. The bottom area with temperatures above 1°C before 1985 was approximately 70% to 80% and from 1984 to 1995 had been nearly constant between 50% to 70%. Since 1995, except 1997 this area has been increasing and approached pre-1985 values during 1999.

Shown in Fig. 6 are the areal indices for the same temperature ranges but restricted to water depths less than or equal to 100-m, which includes Burgeo, St. Pierre and Green Banks. During 1985 the areal extent of subzero °C bottom water increased from an average of approximately 20% to 100%. Except for 1988 it remained near 80% until 1994, at which time it started to decrease and was less than 10% in 1998. During the spring of 1999 subzero °C water had completely disappeared from the Banks. The area in the temperature range of 0°C to 1°C exhibit large fluctuations with relatively high values during the 1970s, 1988 and during 1996. The area of the banks covered with bottom water with temperatures greater than 1°C was significant prior to 1985, virtually non-existent until 1996 and increased to about 50% in 1998 and to near 70% in 1999.

The average bottom temperature of the surveyed area in Subdivision 3Ps ranged between 3° to 4°C from 1970 to 1984 and decreased to between 2° to 2.5 °C from 1985 to 1997. During 1999 the average temperature increased to over 3°C (Fig. 7, upper panel). On the banks, in water depths generally less than 100-m, the average temperature from 1970 to 1985 ranged between approximately 0.5° to 1°C, decreased significantly during 1985 and has slowly recovered to about 1°C by 1998 and to 1.6°C during 1999 (Fig. 7, bottom panel).

TEMPERATURE TRENDS

As described above, monthly temperature anomalies from 1950 to 1999 on St. Pierre Bank bounded by the 100-m isobath (region B in Fig. 1) were computed at standard depths of 0, 20, 50 and 75 m (Fig. 8). The time series is characterized by large variations in the monthly averages with amplitudes ranging from ±3°C from normal. The long-term trend shows amplitudes generally less than ±1°C with periods between 5 to 10 years. The cold periods of the mid-1970s and the mid-1980s in the upper water column are coincident with severe meteorological and ice conditions in the Northwest Atlantic and colder and fresher oceanographic anomalies over most of the Canadian Continental Shelf. During the cold period beginning around 1984 temperatures decreased by up to 2°C in the upper water column and by 1°C in the lower water column. This below normal trend continued until 1994 in the upper water column. Since 1994 the temperatures have moderated over the top 50 m of the water column but have remained colder-than-average below 50 m depth. During 1997 to 1999 anomalies fluctuated, but were mostly above normal. Examination of deeper (200–400 m) bottom temperatures revealed considerable variability, but no significant trend from 1950 to 1996 (Colbourne 1996).

VERTICAL SALINITY FIELD

The vertical cross-section (depth versus horizontal distance from the shore along the transect) of the average salinity field for April based on the historical data is shown in Fig. 9. In order to obtain enough data to construct this map the complete data set dating back to the late 1920s was used. No attempts were made to adjust the average for possible temporal or spatial biasing arising from variations either in the number of observations within the time interval or within the area. An examination of the data indicates that the observations are well distributed geographically across the complete transect, however temporally most of the data have been collected since the early 1990s.

The average upper layer salinity for April from near shore at Rose Blanche on the south coast of Newfoundland over Burgeo Bank and Hermitage Channel ranges from about 32 to 32.2. Over St. Pierre Bank it ranges from 32.5 near bottom to 32.1 near the surface. Along the shelf edge in the upper 100-m of the water column there is a strong density front separating the warmer slope water from the Labrador Current water over St. Pierre Bank where salinities increase from 32.3 to over 34. In the deeper water of Burgeo and Hermitage Channels and on the continental slope region salinities increase from 33 at 130-m to 34.5 near bottom (Fig. 9).

During April of 1999 (Fig. 9, bottom panel) upper layer (0-75 m) salinities ranged from 32 to 32.4 near the coast and over Burgeo Channel and Bank and from 32.3 to 32.6 over St. Pierre Bank. At the edge of the shelf salinities were about 32.7. These values were slightly above normal over the center of St. Pierre Bank, otherwise about normal. In the deeper waters (below 200-m) of Burgeo and Hermitage Channels and on the continental slope salinities ranged from 33.5 to 34.5 which were also slightly above normal. In general, salinities over most of the water column during the spring of 1999 were about normal except on St. Pierre Bank and in the deep channels where they were slightly above normal.

BOTTOM SALINITIES

Horizontal Maps

The average bottom salinities for the winter-spring time period ranges from 34 to 34.5 in the Laurentian, Burgeo and Hermitage Channels, from about 33 to 33.5 on Burgeo Bank and from about 32.25 to 33 on most of St. Pierre Bank. On the slopes of St. Pierre Bank in the depth range of 100-300 m salinities range from 33 to 34.5. During April of 1999 bottom salinities were above average over Burgeo Bank and Hermitage Channel by up to 0.5 psu. Also on St. Pierre Bank salinities were above normal as indicated by the area of the bank with salinities below 32.5 (Fig. 10). In general, bottom salinities over most areas during the spring of 1999 were above normal continuing the trend established in 1998.

Areal Index

As mention above oceanographic data from groundfish assessment surveys in 3Ps have included salinity only since 1990. Areal indices based on different salinity ranges were computed using the same method as was used for temperature. Shown in Fig 11 are time series of the areal extent of the bottom covered by water with salinities of $\leq$ 32.5 and > 32.5 psu. These two limits were selected simply because they show the largest change in the areal index and also theses ranges are indicators of advection of fresh Newfoundland Shelf water into the area. The areal index was only presented for the banks with water depths $\leq$ 100-m, below that there do not appear to be any significant trend in the salinity data.

The areal extent of bottom water with salinities ≤32.5 ranged from about 80 to 90% from 1990 to 1997. During 1998 it decreased to about 35% and to about 55% during 1999. The areal extent of bottom water on the banks with salinities >32.5 ranged from less than 10% to 25% from 1990 to 1997 but increased to about 65% in 1997 which decreased to near 45% during 1999.

The average bottom salinity of the surveyed area in Subdivision 3Ps ranged between 33.3 to 33.45 from 1990 to 1996. From 1997 to 1999 the average salinity increased to 33.56, the highest in the 10-year record (Fig. 12). On the banks in water depths less than 100-m the average bottom salinity was near constant at about 32.35 from 1990 to 1997 but had increased to 32.6 in 1998 and to 32.48 in 1999 (Fig 12, bottom panel). In general, the limited time series of bottom salinity data clearly shows a change in water mass characteristics during the last 2 years compared to the conditions that prevailed during the first half of the 1990s, particularly on the banks in the 3Ps region. The change is indicative of a shift from the cold-fresh conditions of the late 1980s and first half of the 1990s on the Newfoundland Continental Shelf to warmer-saltier conditions.

SUMMARY

Time series of temperature anomalies in the 3Ps (St. Pierre Bank) area show anomalous cold periods in the mid 1970s and since the mid-1980s, similar to conditions on the continental shelf along the east coast of Newfoundland. The most recent cold period, which started around 1984, continued to the early 1990s with temperatures up to 1°C below average over all depths and up to 2°C below the warmer temperatures of the late 1970s and early 1980s in the surface layers. Temperatures in deeper water off the banks show no significant trends. Since 1991, temperatures have moderated in some areas from the lows experienced from the mid to late-1980s and early 1990s. Negative temperature anomalies continued over large areas of the banks into the spring of 1995. During 1996 temperatures started to moderate, decreased again during the spring of 1997 and returned to more normal values during 1998. Temperatures during 1999 continued to warm and were above normal over most of the water column and near bottom in the region. An analysis of the areal extent of subzero °C bottom water covering the banks shows a dramatic increase since the mid-1980s, very low values in 1998 and a complete disappearance in 1999. The areal extent of bottom water with temperatures above 1°C on the banks was about 50% of the total area during 1998 the first significant amount since 1984 and increased to about 70% during 1999. An examination of the limited salinity data clearly shows a change in water mass characteristics during the last 2 years compared to the conditions that prevailed during the first half of the 1990s. The areal extent of the relatively saltier water (>32.5) on the banks increased by approximately 40% during this time, indicative of a shift from the cold-fresh conditions of the late 1980s and first half of the 1990s on the Newfoundland Continental Shelf to warmer-saltier conditions.

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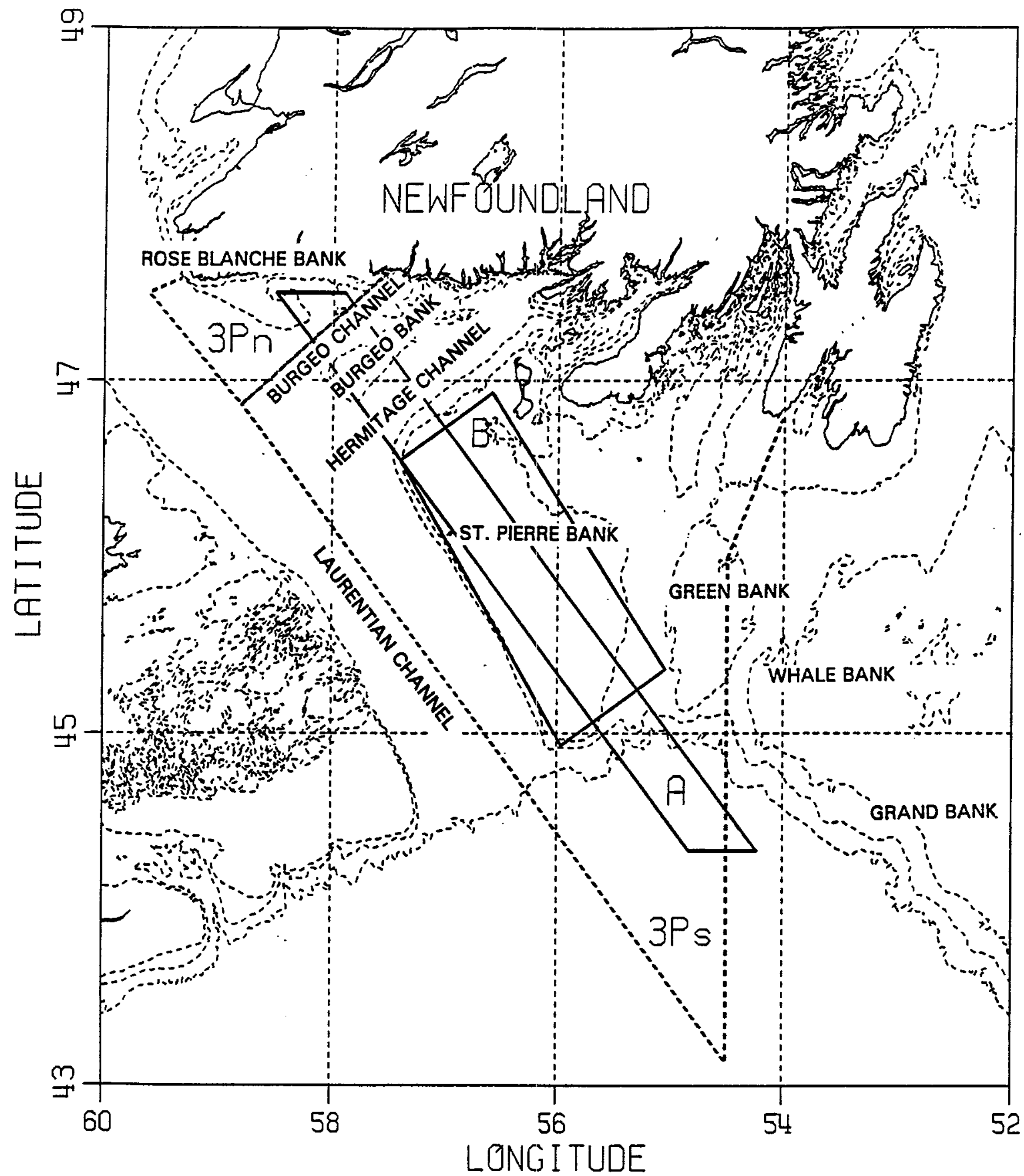

Fig. 1. Location map showing NAFO Subdivisions 3Pn and 3Ps and the areas A and B from which data were examined. The bathymetry lines are 100, 200 and 1000 m.

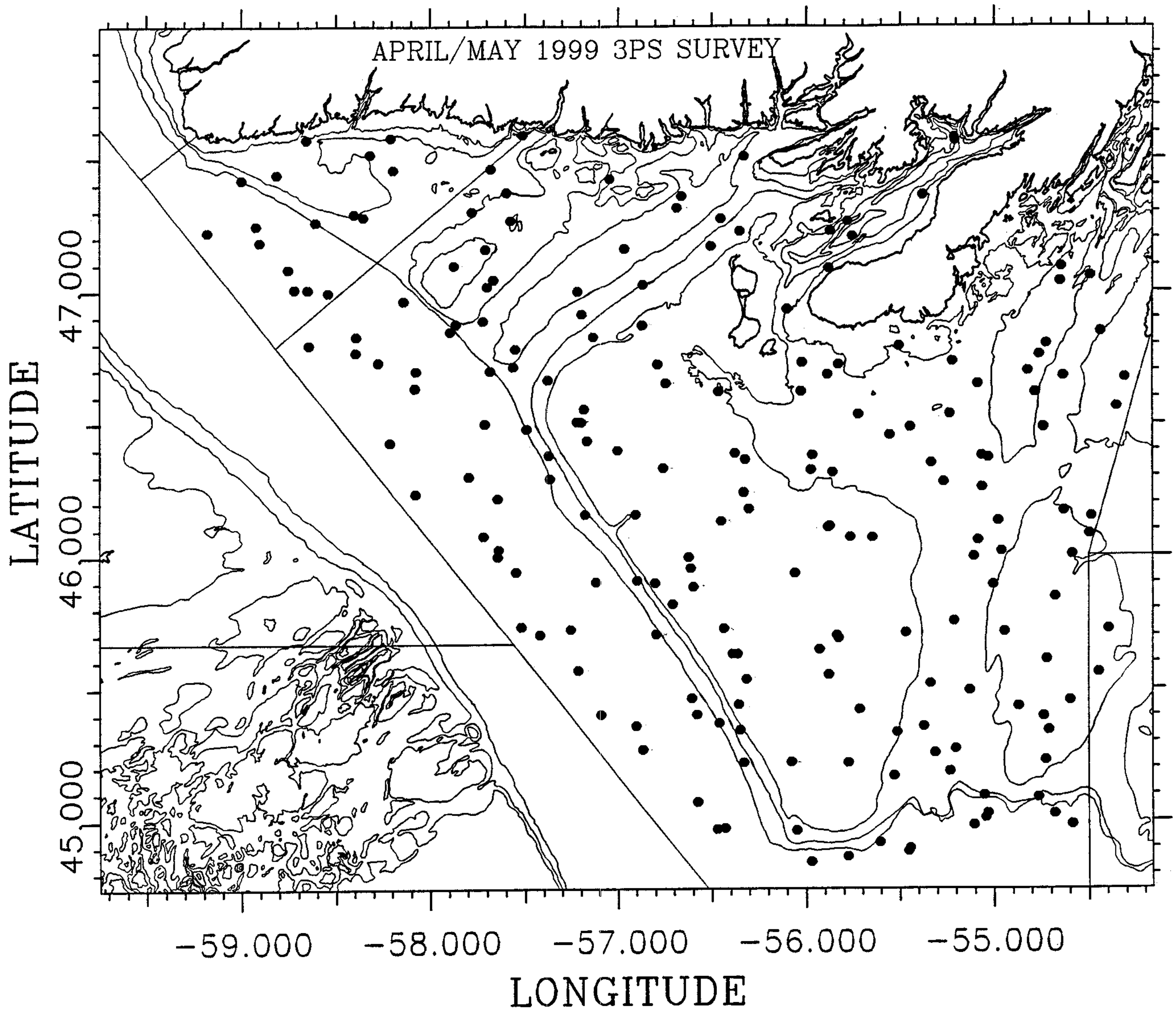

Fig. 2. Location map showing the positions where oceanographic measurements were available in NAFO Subdivisions 3Pn and 3Ps during the 1999 spring groundfish survey. The bathymetry lines are 100, 200 and 300 m.

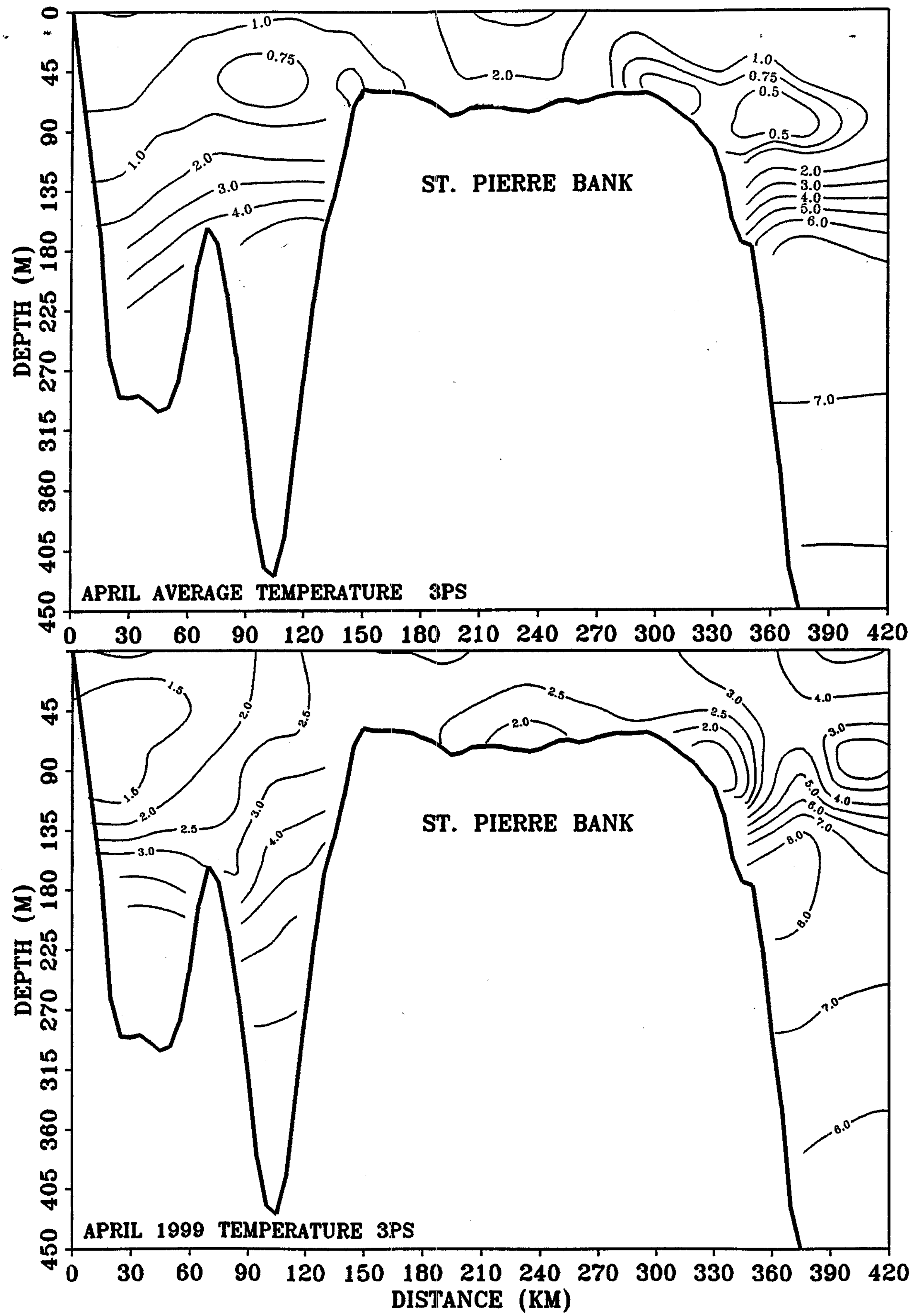

Fig. 3. The April average and the April 1999 temperature (in °C) along the transect constructed from the data in Box A of Fig. 1 for NAFO Subdivisions 3Pn and 3Ps. The average is based on the historical data from 1961 to 1990.

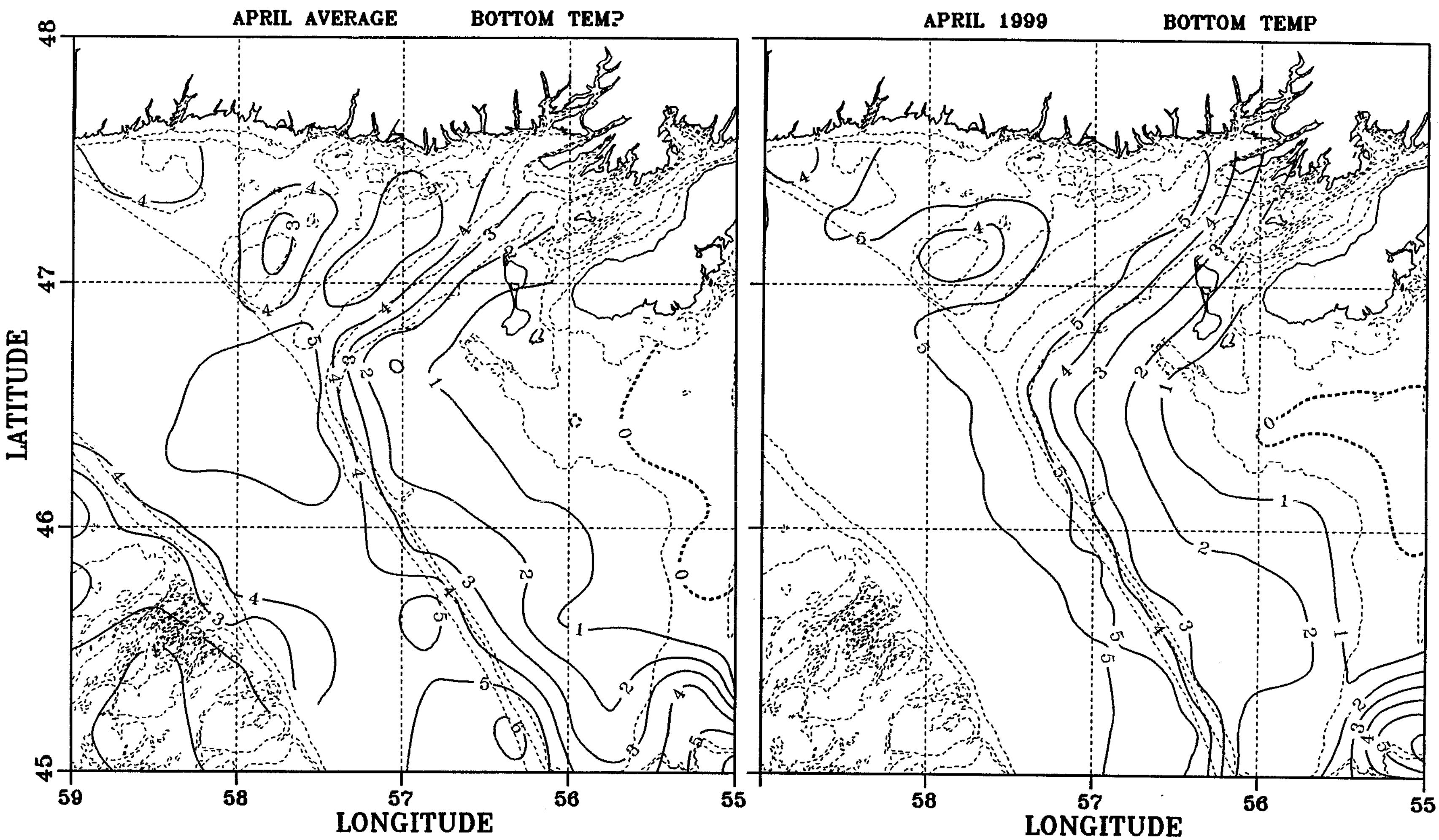

Fig. 4. The April average and the April 1999 bottom temperature (in °C) in NAFO Subdivisions 3Pn and 3Ps. The average is based on the 1961-1990 historical data set.

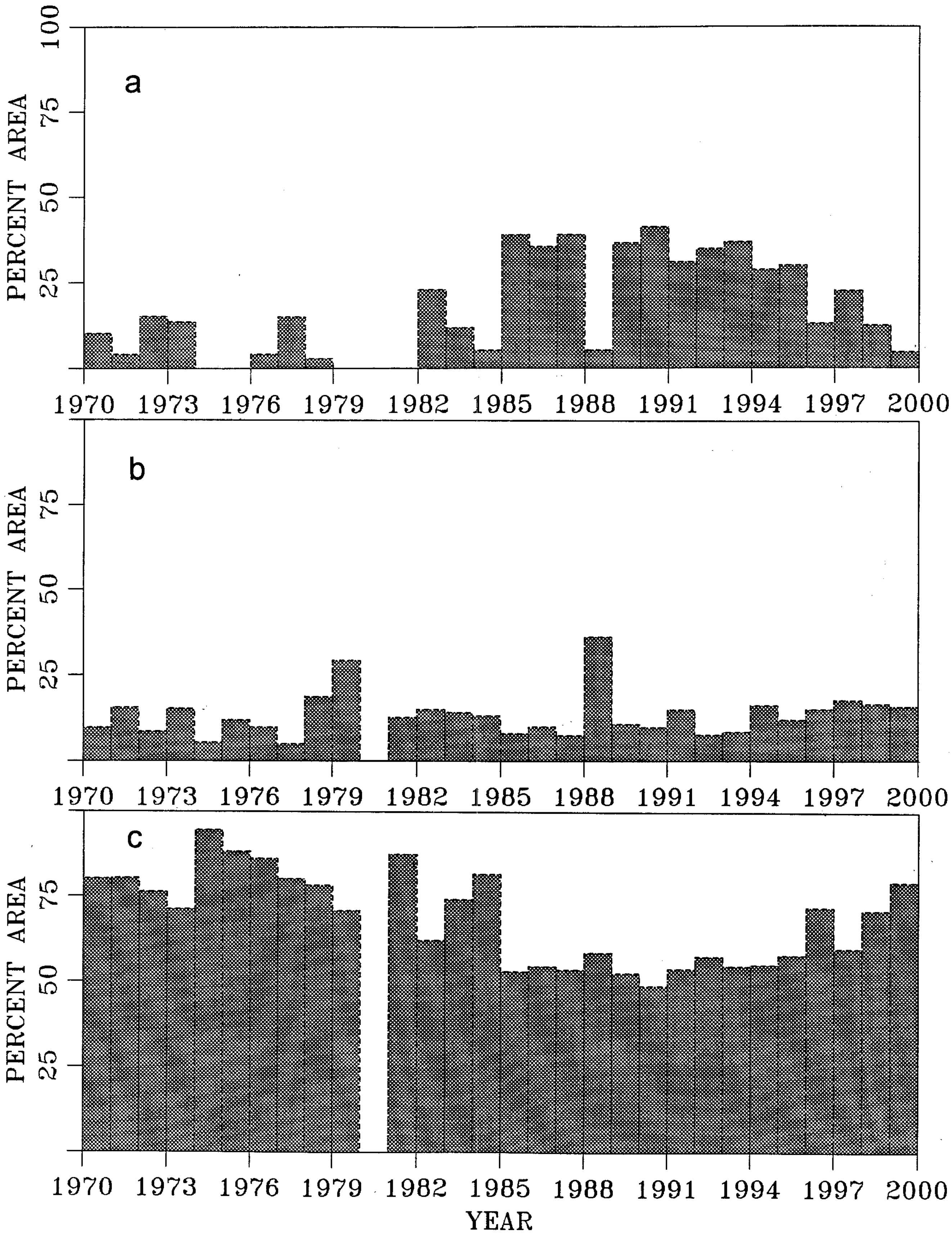

Fig. 5. Time series of the percentage area of the 3Pn and 3Ps NAFO Subdivisions covered by water with bottom temperatures in the range of (a) less than 0°C, (b) 0 to 1°C and (c) greater than 1°C.

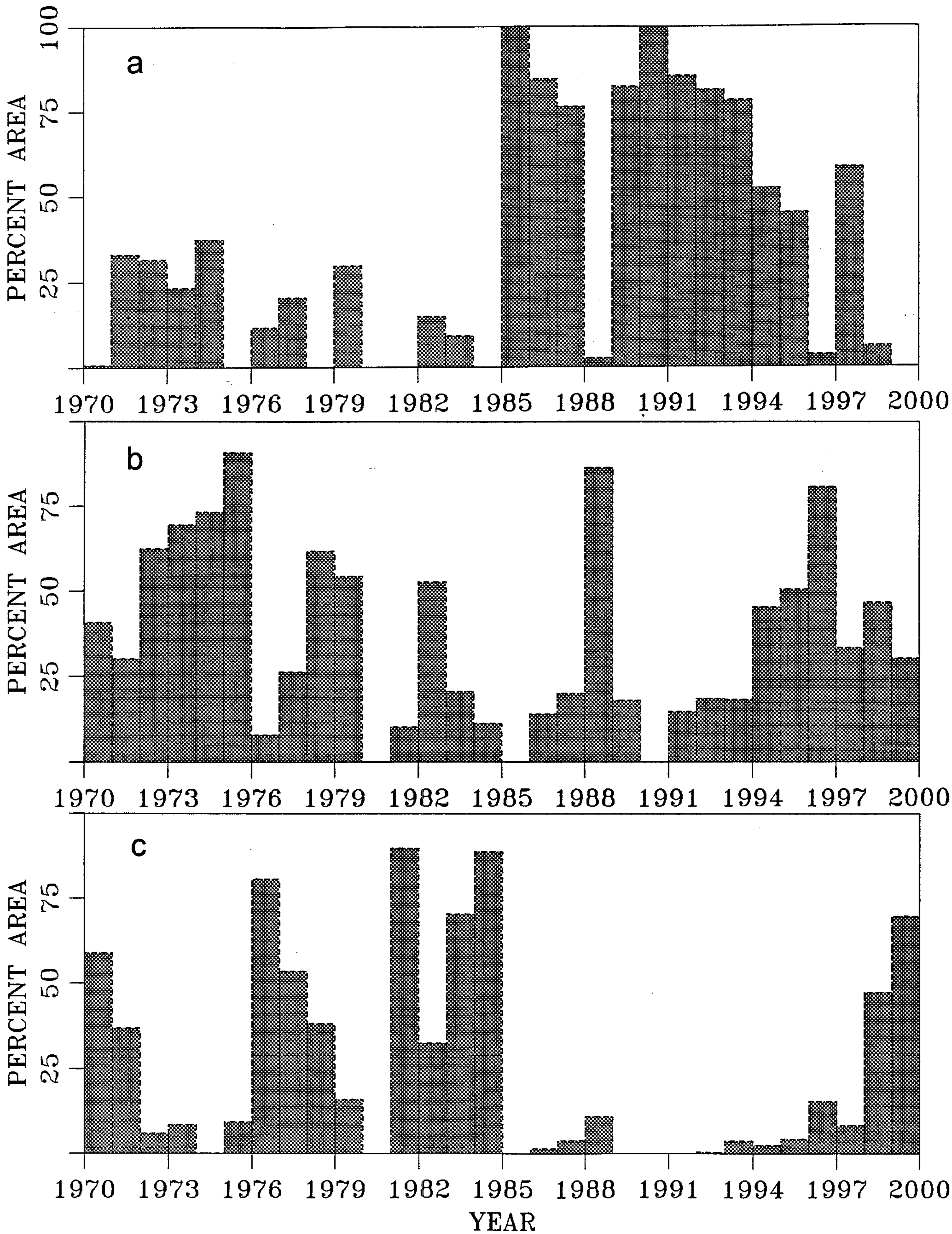

Fig. 6. Time series of the percentage area of Burgeo, St. Pierre and Green Banks, located in NAFO Subdivisions 3Pn and 3Ps, covered by water with bottom temperatures in the range of (a) less than 0°C, (b) 0 to 1°C and (c) greater than 1°C.

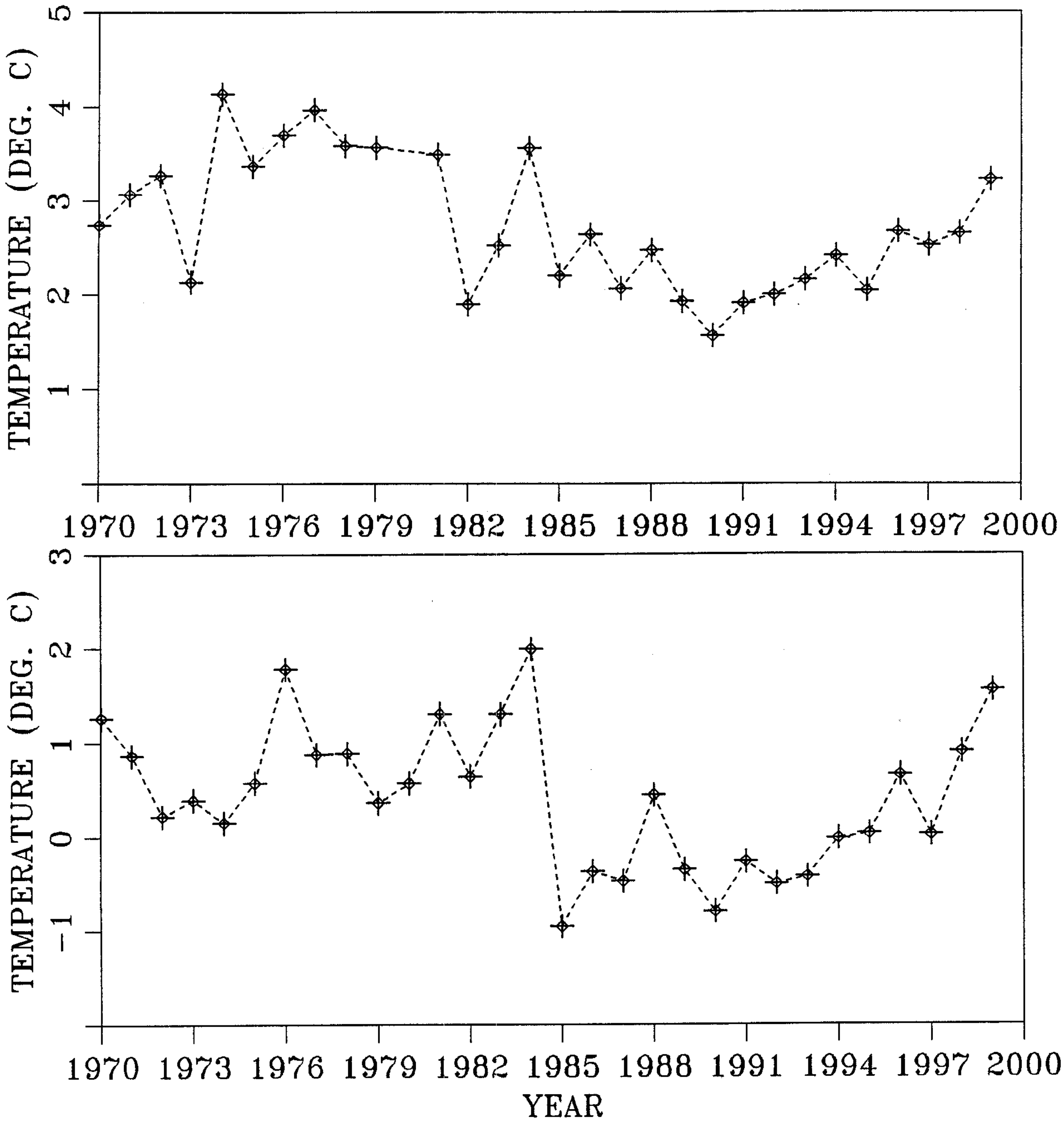

Fig. 7. Time series of the mean bottom temperature (in °C) in NAFO Subdivisions 3Pn and 3Ps (top panel) and the mean bottom temperature of Burgeo, St. Pierre and Green Banks (bottom panel).

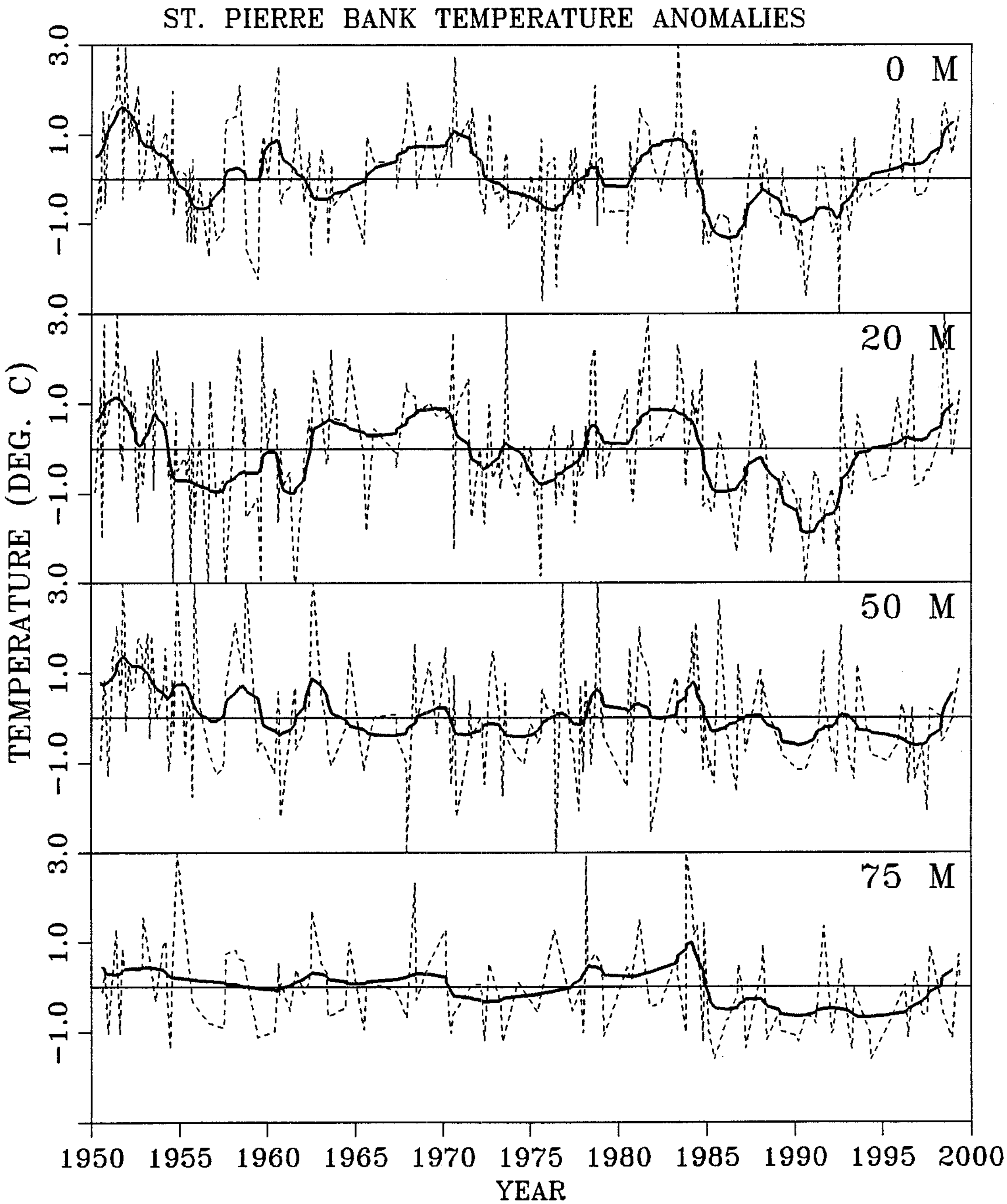

Fig. 8 . Monthly temperature anomaly time series (in °C) at standard depths of 0, 20, 50 and 75 m for Box B in Fig. 1. The heavy solid line represents the low passed filtered temperature anomalies.

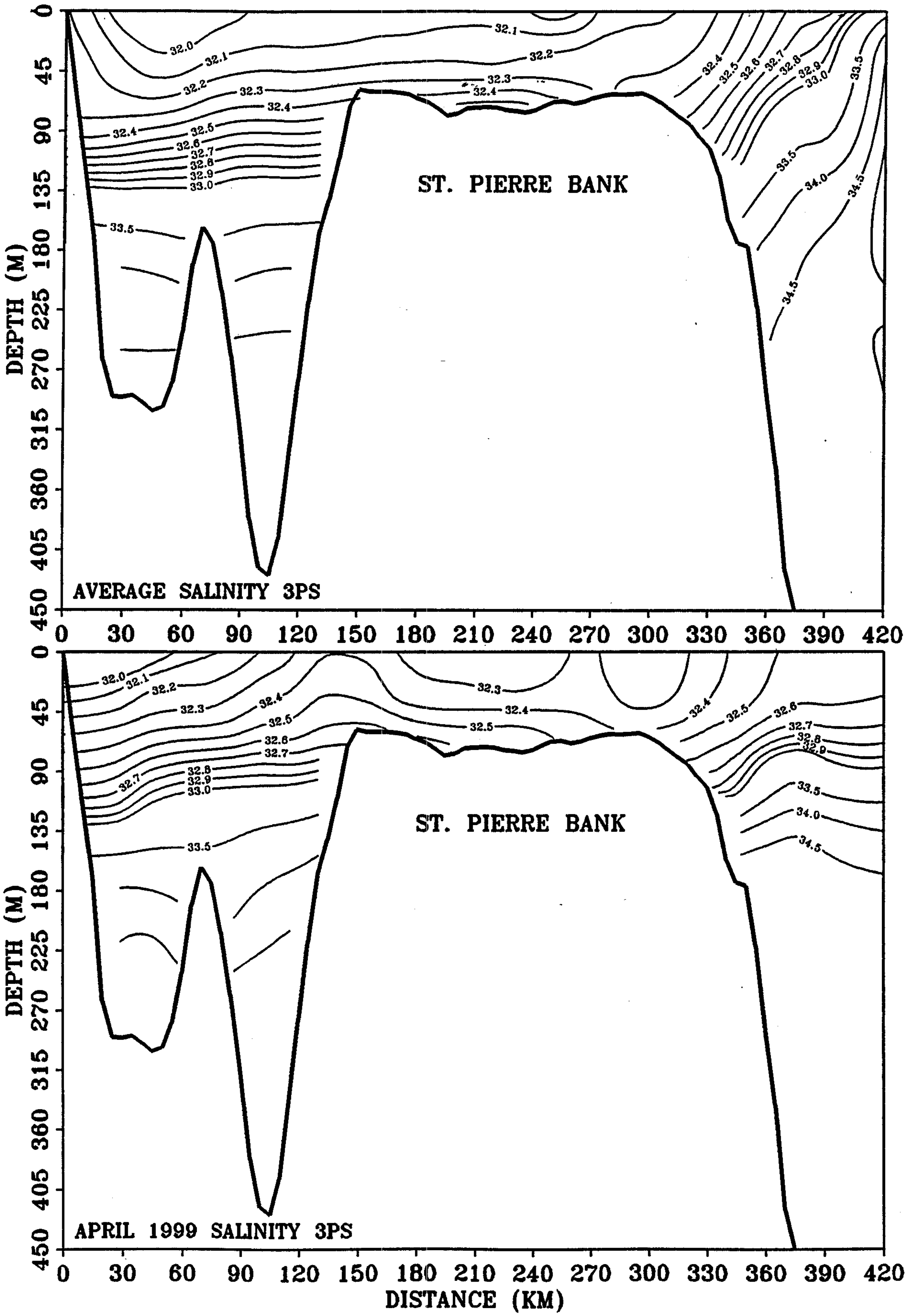

Fig. 9. The winter-spring average and the April 1999 salinity along the transect constructed from the data in Box A of Fig. 1 for NAFO Subdivisions 3Pn and 3Ps. The average is based on the historical data from 1925 to 1999.

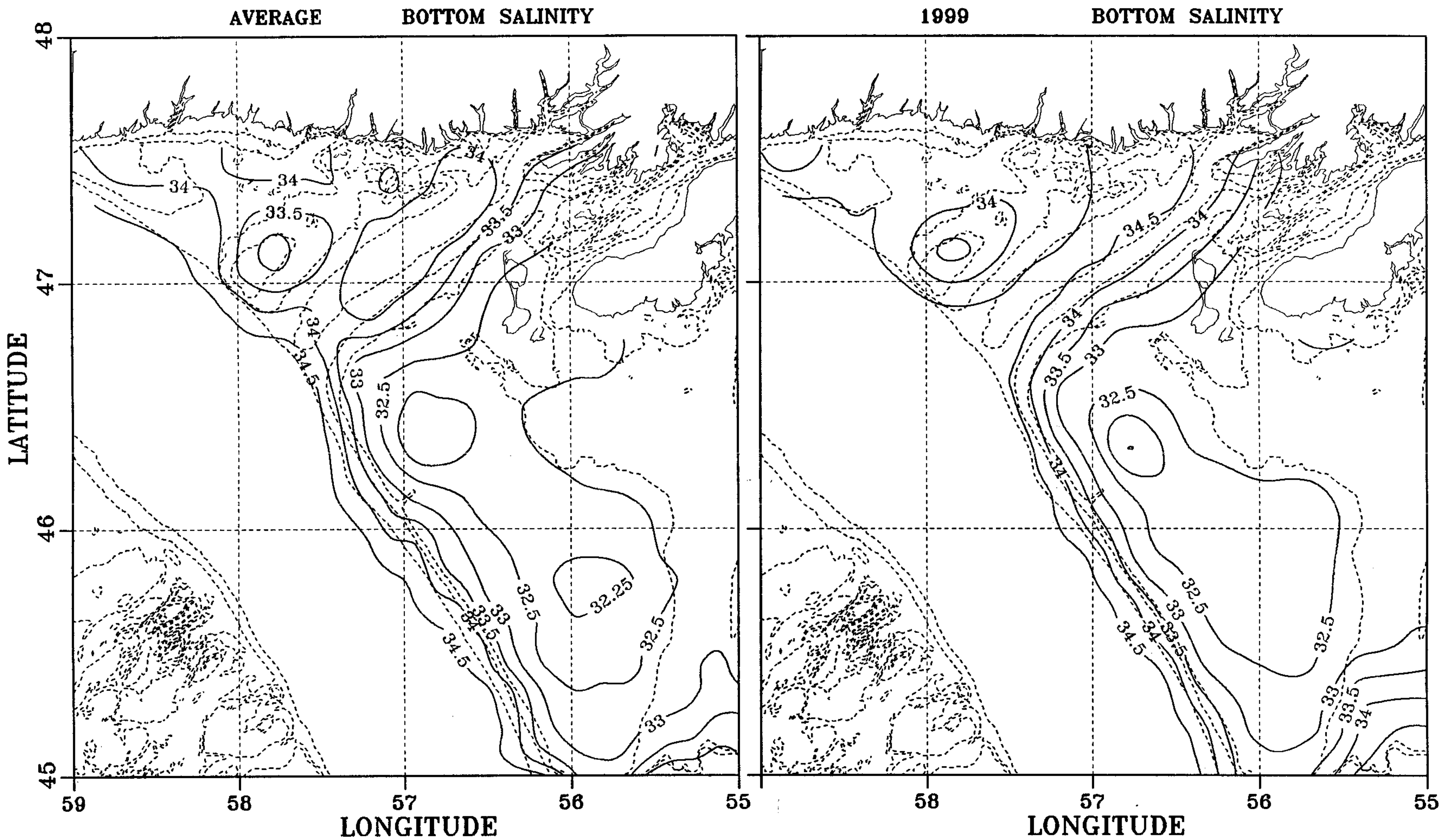

Fig. 10 The winter-spring average and the April 1999 bottom salinity in NAFO Subdivisions 3Pn and 3Ps. The average is based on the 1925-1999 historical data set.

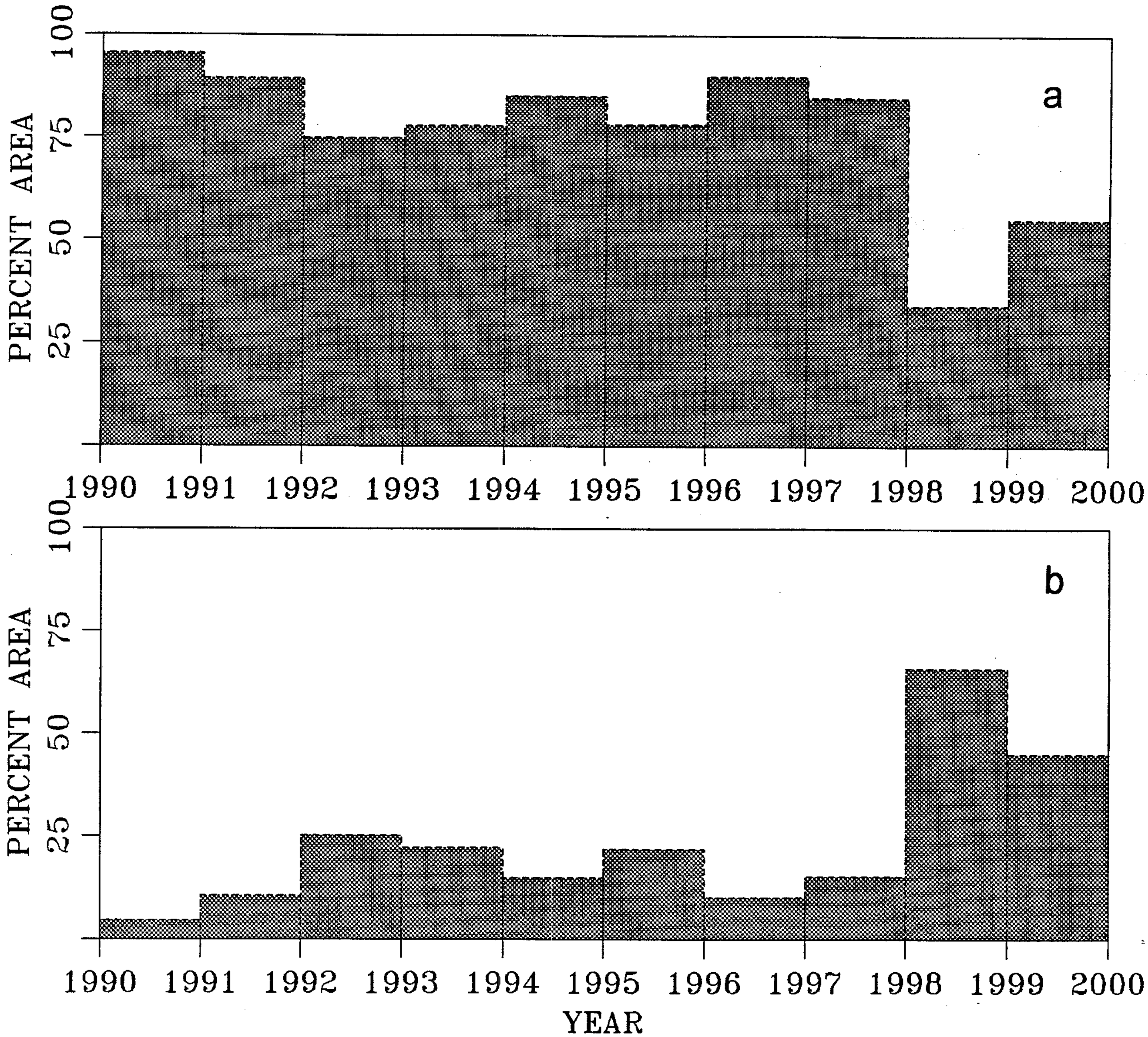

Fig. 11 Time series of the percentage area of Burgeo, St. Pierre and Green Banks, located in NAFO Subdivisions 3Pn and 3Ps, covered by water with bottom salinities in the range of (a) less than or equal to 32.5 and (b) greater than 32.5.

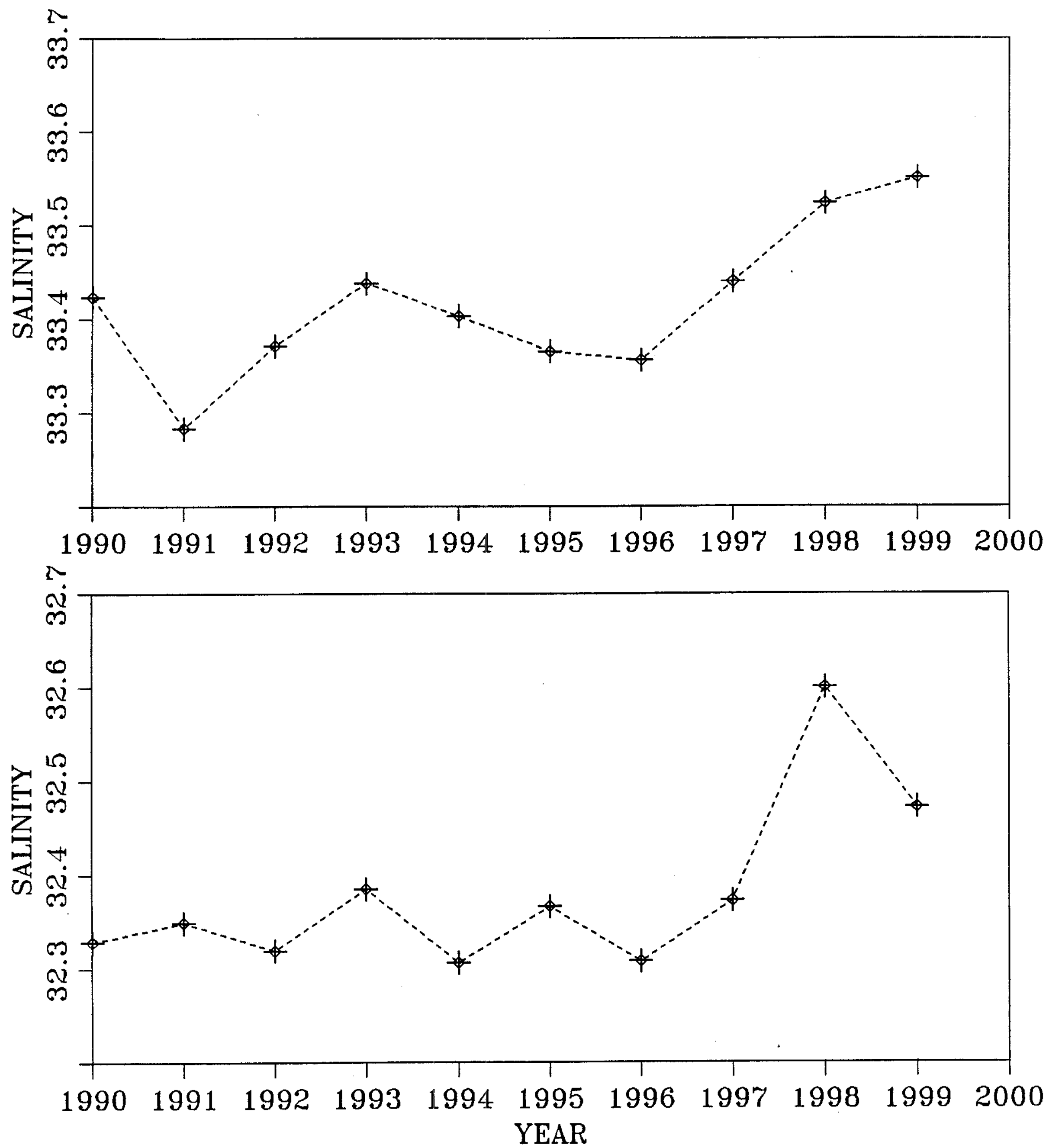

Fig. 12 Time series of the mean bottom salinity in NAFO Subdivisions 3Pn and 3Ps (top panel) and the mean bottom salinity of Burgeo, St. Pierre and Green Banks (bottom panel).