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Oceanographic conditions in NAFO Subdivisions 3Pn and 3Ps during 2001 with comparisons to the previous year and the long-term (1971-2000) average

Conditions océanographiques dans les sous-divisions 3Pn et 3Ps de l'OPANO en 2001 par rapport à l'année précédente et à la moyenne à long terme (1971-2000)

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Abstract

Oceanographic data from NAFO subdivisions 3Pn and 3Ps during the spring of 2000 and 2001 are examined and compared to the long-term (1971-2000) average. Temperature anomalies on St. Pierre Bank show anomalous cold periods in the mid-1970s and from the mid-1980s to mid 1990s. Beginning around 1996 however, temperatures started to moderate, decreased again during the spring of 1997 and returned to more normal values during 1998. During 1999 and 2000 temperatures continued to warm to above normal values over most of the water column. During the spring of 2001 however, temperatures cooled significantly over the previous two years to values observed during the mid-1990s. The areal extent of <0°C bottom water increase significantly from the mid-1980s to mid-1990s, but decreased to very low values in 1998-2000. During 2001 it increased again, returning to values observed during the mid-1990s. Since 1995 the areal extent of bottom water with temperatures >1°C has been increasing, reaching pre-1985 values by 1999-2000. During 2001 the area of warmer water decreased significantly compared to the pervious 2-years. On St. Pierre Bank <0°C water completely disappeared during 1999-2000 but increased to near 30% during 2001. The area of near-bottom water on the banks with temperatures >1°C was about 50% of the total area during 1998 the first significant amount since 1984. This increased to about 70% during 1999 and to 85% during 2000 but decreased to a very low value during 2001. In general, there were significant variations in water mass characteristics particularly on St. Pierre Bank during the past several years, with cold conditions from 1990 to 1997 and above normal temperatures during 1998 to 2000, which decreased to below normal values during the spring of 2001.

Résumé

Les données océanographiques recueillies dans les sous-divisions 3Pn et 3Ps de l'OPANO aux printemps 2000 et 2001 sont examinées et comparées à leur moyenne à long terme (1971-2000). Les anomalies de température sur le banc Saint-Pierre indiquent l'existence de périodes d'eaux anormalement froides au milieu des années 1970 et entre le milieu des années 1980 et le milieu des années 1990. Cependant, la température a commencé à remonter en 1996 environ, puis a diminué à nouveau au printemps 1997 pour ensuite revenir à des valeurs normales en 1998. Elle a continué à augmenter en 1999 et 2000, se situant au-dessus de la normale dans presque toute la colonne d'eau. Puis, au printemps 2001, la température a baissé de manière significative par rapport aux deux années précédentes pour atteindre des valeurs semblables à celles observées au milieu des années 1990. La superficie du fond couverte d’eau de moins de 0 oC a significativement augmenté entre le milieu des années 1980 et le milieu des années 1990, mais elle a considérablement baissé entre 1998 et 2000. Elle a augmenté à nouveau en 2001 pour atteindre les valeurs observées au milieu des années 1990. Depuis 1995, la superficie du fond couverte par des températures supérieures à 1 oC augmente, atteignant en 1999-2000 des valeurs semblables à celles d’avant 1985. En 2001, la zone d’eau plus chaude a significativement rapetissé par rapport aux deux années précédentes. Sur le banc St-Pierre, les eaux de moins de 0 oC ont entièrement disparu en 1999-2000, puis sont réapparues pour couvrir presque 30 % de la superficie en 2001. La superficie couverte par des eaux de plus de 1 oC près du fond sur les bancs comptait pour environ 50 % de la superficie totale en 1998; la première proportion importante depuis 1984. Cette superficie a augmenté à 70 % en 1999 et à 85 % en 2000, mais elle a chuté à une très faible valeur en 2001. En général, les caractéristiques des masses d’eau ont varié significativement, notamment sur le banc St-Pierre depuis quelques années, où la température était froide entre 1990 et 1997, supérieure à la normale entre 1998 et 2000 et inférieure à la normale au printemps 2001.

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 ocean environment in the Northwest Atlantic have been dominated by four anomalous periods: the cold early 1970s, mid-1980s and early 1990s and the warm late 1990s. During the cold 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 a colder and fresher than normal water mass overlying 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, 2000 and 2001).

This report summarises oceanographic conditions in NAFO subdivisions 3Pn and 3Ps (Fig. 1) up to the spring of 2001 and represents the seventh such review of winter/spring oceanographic conditions in support of the annual cod assessments for this region (Colbourne 1994, 1996, 1997, 1998, 1999, 2000 and 2001). The base time period used to compute the averages and reference anomalies up to 2000 was defined as the 30-year time 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 the current base period for the 2001 analysis has been advanced to 1971-2000. There are however insufficient salinity data available in this time period to produce meaningful averages, therefore the base period for salinity encompassed all available data from the late 1920s to 2000.

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 2001 survey are shown in Fig. 1. 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 CTDs are not field calibrated, but are checked periodically and factory calibrated when necessary maintaining an accuracy of 0.005^{o}C in temperature and 0.005 in salinity. The XBTs are accurate to within 0.1^{o}C. In addition to these data, all available historical data in the period 1971-2000 were used to establish the long-term means.

Vertical cross-sections of the temperature and salinity fields and their anomalies for April 2000 and 2001 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 in subdivision 3Pn. The cross-sections 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.

Oceanographic data from the multi-species 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 approximately 100 km^2 or approximately 0.1^o latitude by 0.1^o longitude. The mean bottom temperature for each grid element was calculated and combined with the grid area to produce a time series of the spatially averaged bottom temperature and the total bottom area covered by water in selected temperature ranges. Bottom temperature and salinity maps and their anomalies for the spring of 2000 and 2001 were constructed by contouring near bottom 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 data were collected. A time-series were constructed from 1970 to 2001 for temperature and from 1990 to 2001 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, a time-series of annual surface and bottom temperature anomalies were constructed corresponding to area B of Fig. 1, mainly St. Pierre Bank. The 1971-2000 data set from this area were sorted by month to determine monthly means. The seasonal cycle was then removed from each observation by subtracting the monthly mean 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.

Temperature Cross-Section

The vertical cross-section of temperature and their anomalies for April of 2000 and 2001 based on the multi-species survey data is shown in Fig. 2. 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 reasonably distributed across the complete transect (Fig. 1).

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 generally range from 2°C at approximately 125 - 150 m depth to 5° - 6°C near the bottom. At the edge of the continental shelf on the southeastern St. Pierre Bank the temperature field is marked by a strong gradient separating the warmer slope water from the Labrador Current water. 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 (Colbourne 2000).

During April of 2000 (Fig. 2) upper layer (0-75 m) temperatures ranged from 1° to 1.5°C near the coast and over Burgeo Channel and Bank and from 2° to 3°C over St. Pierre Bank. During April 2001 upper layer temperatures decreased compared to 2000 by over 1°C in most regions. Near the shelf edge an area of Labrador Current water with temperatures below 1°C was present during both 2000 and 2001, with an area of sub-zero °C water present during 2001. These values were generally above normal by 0.5° to 2°C during 2000 but by the spring of 2001 temperatures had decreased to 0.5 to 2°C below normal over most of the water column (Fig. 2). In the deeper waters of Burgeo and Hermitage Channels temperatures ranged from 0° to 2°C below normal during 2000 which increased to near-normal values in the deepest parts of Hermitage Channel during 2001. On the continental slope near the southwestern Grand Bank temperatures were mostly above normal in 2000 and mostly below normal in 2001. In general, temperatures over most of the water column during the spring of 2001 were below normal, reversing the warm trend of 1998-2000.

Bottom Temperatures Maps

The average bottom temperatures 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. On St. Pierre Bank bottom 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 (Colbourne 2000).

During April 2000 bottom temperatures were above average over Burgeo Bank and Channel. Hermitage Channel bottom temperatures were below 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. 3). In general, bottom temperatures over most areas during the spring of 2000 were above normal but there was an increase in areas with below normal values, particularly in Hermitage Channel and the deeper portions of the southeastern slopes of St. Pierre Bank. During the spring of 2001 bottom temperatures over St. Pierre Bank decreased significantly over 2000 values with a larger area of sub-zero ^{o}C water over the eastern side of the bank. As a result, below normal temperatures were more widespread during 2001, covering most of the bottom areas in the 3Ps region (Fig. 3).

Areal Index

Annual values of the areal extent of the bottom covered with water in the temperature ranges of <0^{o}C, 0-1^{o}C 1-2^{o}C 2-3^{o}C and >3^{o}C are displayed in Fig. 4. Note the large increase in the percentage area of the bottom covered by sub-zero ^{o}C water in 1985 that persisted well into the mid-1990s. The percentage area covered by sub-zero ^{o}C water during the spring of 1998 decreased to pre-1985 levels and to less than 5% during 2000 but increased to over 20% during 2001. The bottom area covered with water between 0-1^{o}C, except for 1979 and 1988, has remained below 20%. The bottom area with temperatures >1^{o}C before 1985 was approximately 70-80% and from 1984 to 1995 had been nearly constant between 50-70%. Since 1995, except 1997 this area has been increasing and approached pre-1985 values during 1999 and 2000. During the spring of 2001 however this area decreased to 50-60%. During the spring of 1999 and 2000 sub-zero ^{o}C water had completely disappeared from the Banks but reappeared during 2001 reaching near 30% coverage. The area of near-bottom water on the banks with temperatures >1^{o}C was about 50% of the total area during 1998 the first significant amount since 1984. This increased to about 70% during 1999 and to 85% during 2000 but decreased to a very low value during 2001.

The average bottom temperature of the surveyed area in Division 3P ranged between 3^{o} - 4^{o}C from 1970 to 1984 and decreased to between 2^{o} - 2.5^{o}C from 1985 to 1997. During 1999 and 2000 the average near-bottom temperature increased to over 3^{o}C but decreased to near 2^{o}C in 2001 (Fig. 4, bottom panel). On the banks, in water depths generally <100-m, the average temperature from 1970 to 1985 ranged between approximately 0.5^{o} to 1^{o}C. The average temperature decreased significantly during 1985 and has slowly recovered to about 1^{o}C by 1998, 1.6^{o}C during 1999 and to 1.7^{o}C during 2000. During the spring of 2001 the average temperature on the banks decreased to near 0^{o}C, the lowest since 1997.

Temperature Trends

Annual surface and bottom temperature anomalies from 1951 to 2001 on St. Pierre Bank bounded by the 100-m isobath (region B in Fig. 1) are shown in Fig. 5. The time series is characterised by large interannual variations with amplitudes ranging from ±1.5^{o}C from normal. The long-term trend shows amplitudes generally less than ±1^{o}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 significantly by over 1^{o}C in some years. This below normal trend continued until the mid-1990s, however since then temperatures began to warm and from 1997 to 2000 temperatures were above normal. During 2001 temperatures decreased significantly over 2000 values at both the surface and near-bottom reaching values typical of the early 1990s.

Salinity Cross-Section

Vertical cross-sections of salinity and salinity anomalies for April of 2000 and 2001 are shown in Fig. 6. In order to obtain enough data to construct the anomaly map the complete data set dating back to the mid-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 and over Burgeo Bank and Hermitage Channel ranges from about 32 to 32.2. Over St. Pierre Bank salinities generally range from 32.5 near bottom, to a low of 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 shelf 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 (Colbourne 2000).

During April of 2000 (Fig. 6) upper layer (0-75 m) salinities ranged from less than 31.5 to 32 near the coast and over Burgeo Channel and Bank and from less that 32 to 32.15 over St. Pierre Bank. At the edge of the shelf on the southeast corner of St. Pierre Bank salinities increased to about 32.5. This fresher-than-normal anomaly penetrated to below 200-m depth in Burgeo and Hermitage Channels and to 100-m depth on the southeast corner of St. Pierre Bank. In general, salinities over most of the water column during the spring of 2000 were below normal (Fig. 6). During the spring of 2001 however, upper layer salinities increased over 2000 values to between 32.25-32.5, which were generally saltier-than-normal.

Bottom Salinity 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 generally range from 33 to 34.5 (Colbourne 2000). During April of 2000 bottom salinities were below average (0.2-0.4) over most of St. Pierre Bank and parts of Hermitage Channel. Over Burgeo Bank and Hermitage Channel and the deeper slope regions of the banks salinities were generally above normal (Fig. 7). During the spring of 2001 near bottom salinities over

St. Pierre Bank increased to near 33, which were about 0.2-0.4 saltier-than-normal. Near-bottom salinities in general during 2001 were above normal in the 3P region.

Areal Index

Areal indices based on different salinity ranges were computed using the same method as was used for temperature. Shown in Fig 8 are time series of the areal extent of the bottom covered by water with salinities of ≤32.25, 32.25-32.5, 32.5-32.75 and >32.75. The areal index was only calculated for the banks with water depths ≤100-m, below that there does not appear to be any significant trend in the salinity data. The analysis is based on salinity data collected during the multi-species surveys from trawl-mounted CTD for the years 1990-2001.

The areal extent of bottom water with salinities ≤32.5 ranged from about 75 to 95% from 1990 to 1997. During 1998 it decreased to about 35% and increased to over 90% during 2000 but decreased to near 0% in 2001. The areal extent of bottom water on the banks with salinities >32.5 ranged from less than 10-25% from 1990 to 1997 but increased to about 65% in 1998 which decreased to less than 10% during the spring of 2000. During the spring of 2001 almost all of St Pierre Bank was covered by water with salinities >32.5 (Fig. 8 top panel).

The average bottom salinity of the surveyed area in Division 3P (Fig. 8, bottom panel) 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, but decreased again in 2000 to 33.38. During 2001 average salinities were similar to 1999 values. 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 increased to 32.6 in 1998 and to 32.48 in 1999. During the spring of 2000 salinities on the banks decreased to 32.14 the lowest in the 10 record. During April of 2001 however, salinities increased significantly over 2000 values and were similar to values during 1998. In general, this analysis showed significant variations in the water mass characteristics particularly on St. Pierre Bank during the past several years. During the mid-1980s up to 1997 a cold water mass with near constant salinity influenced most of the upper 100-m of the water column. This changed to much warmer and saltier conditions during 1998 and 1999 and to fresher but still warm conditions during 2000. During 2001 salinities increased to above normal values while temperatures generally decreased to below normal values.

Summary

Time series of temperature anomalies in the 3Ps (St. Pierre Bank) area show anomalous cold periods in the mid-1970s and from the mid-1980s to late 1990s. These conditions were similar to that observed on the continental shelf along the east coast of Newfoundland except the latter cold period lasted longer than on the eastern Newfoundland Shelf. During the most recent cold period, which started around 1985, 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 during all years show significant variations, but remaining relatively warm with temperatures in the 3-6°C range compared to much colder values (often sub-zero °C) on St. Pierre Bank. Beginning around 1996 temperatures on St. Pierre Bank started to moderate, decreased again during the spring of 1997 and returned to more normal values during 1998. During 1999 and 2000 temperature continued to warm reaching above normal values over most of the water column. During the spring of 2001 however, temperatures cooled significantly over the previous two years to values observed during the mid-1990s. The areal extent of <0°C bottom water increased significantly from the mid-1980s to mid-1990s but decreased to very low values during 1998-2000. During 2001 however it increased again, returning to values observed during the mid-1990s. Since 1995 the areal extent of bottom water with temperatures >1°C has been increasing, reaching pre-1985 values during 1999-2000. During 2001 the area of warmer water decreased significantly compared to the pervious 3-years. On St. Pierre Bank sub-zero °C water completely disappeared during 1999-2000 but increased to near 30% during 2001. The area of near-bottom water on the banks with temperatures >1°C was about 50% of the total area during 1998, the first significant amount since 1984. This subsequently increased to about 70% during 1999 and to 85% during 2000 but decreased to very low area during 2001. In general, this analysis showed significant variations in the water mass characteristics particularly on St. Pierre Bank during the past several years. During the mid-1980s up to 1997 a cold near constant salinity water mass influenced most of the upper 100-m of the water column. This changed to much warmer and saltier conditions during 1998 and 1999 and to fresher but still warm conditions during 2000. During 2001 salinities increased to above normal values while temperatures generally decreased to below normal values as cold water returned to the region.

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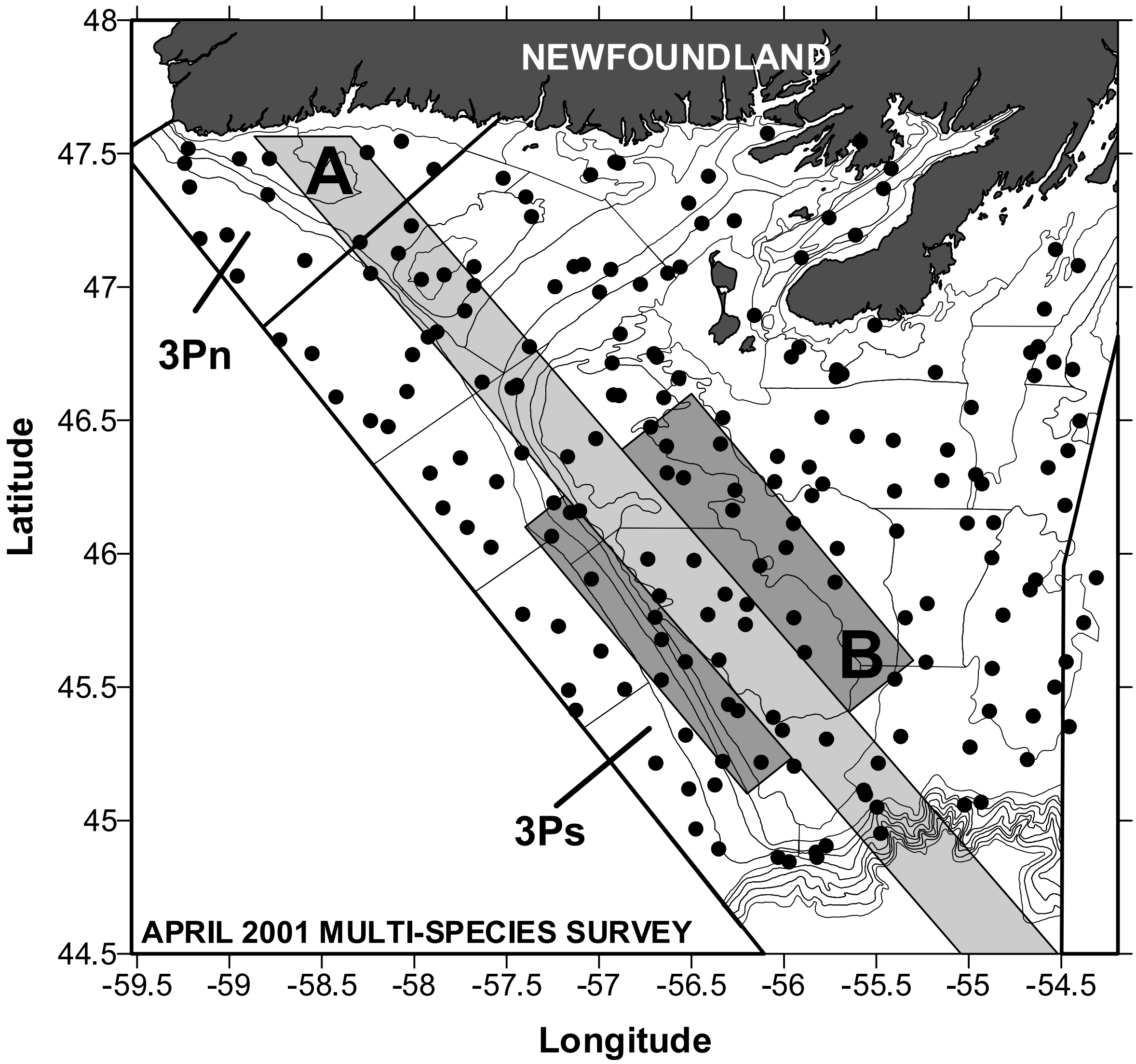


Fig. 1. Location map showing NAFO Subdivisions 3Pn and 3Ps and the areas A and B from which time series and cross-sections of temperature and salinity were constructed. The set positions where oceanographic measurements were available for the 2001 spring multi-species survey are also shown as well as the strata boundaries.

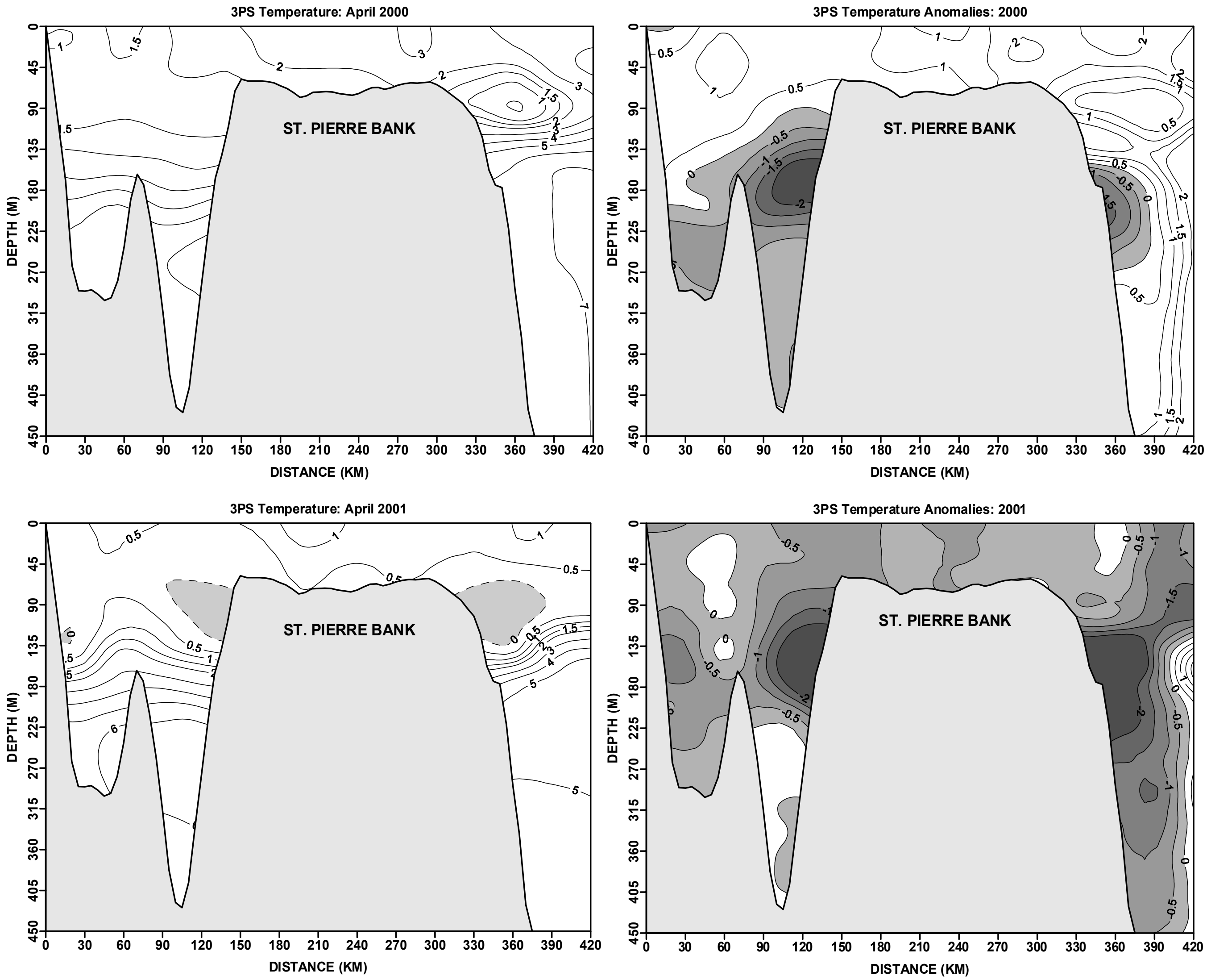


Fig. 2. The April 2000 and 2001 temperature and anomalies (in °C) along the transect constructed from the data in Box A of Fig. 1 for NAFO Subdivisions 3Pn and 3Ps. The anomalies are referenced to the 1971-2000 average.

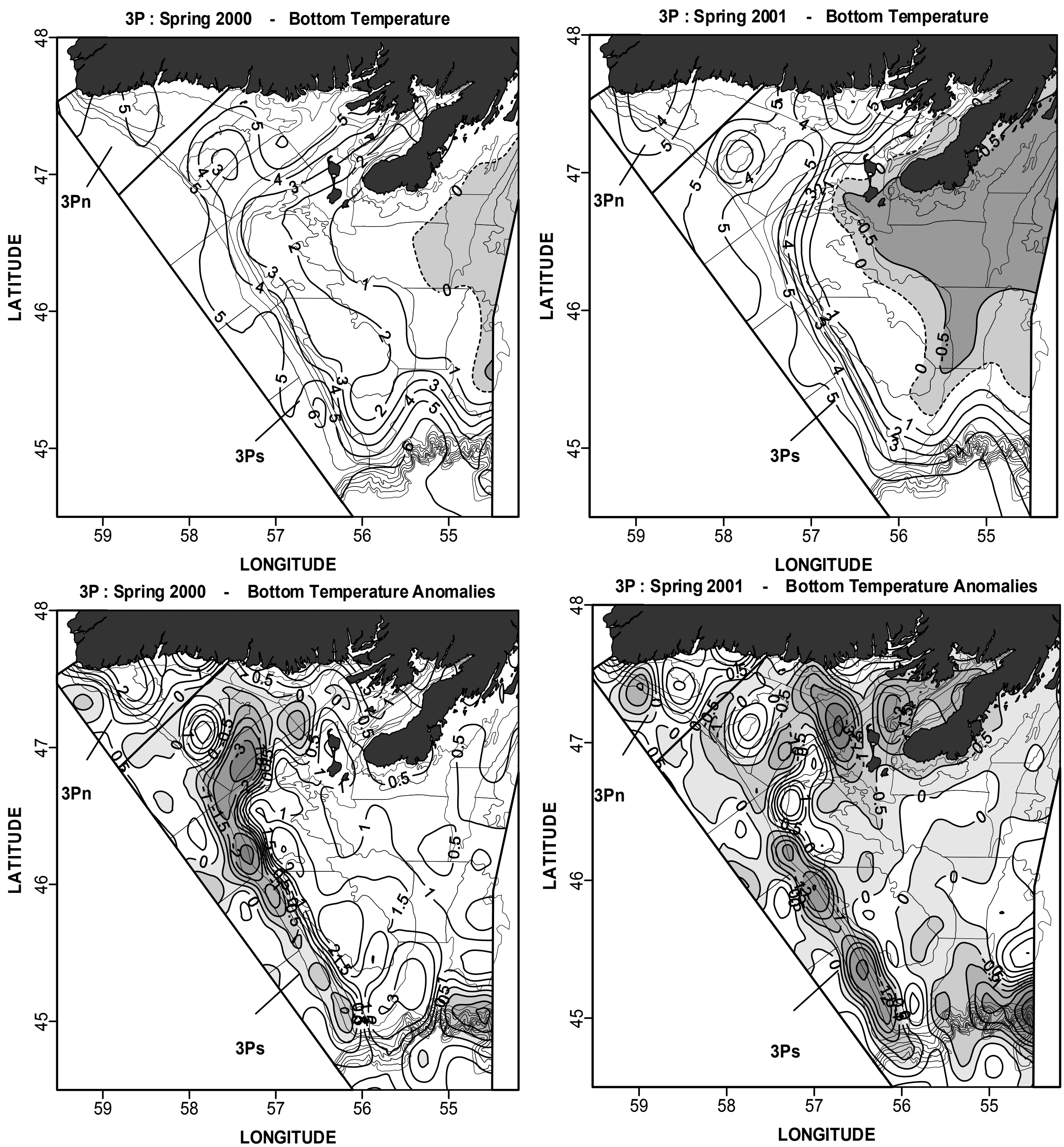
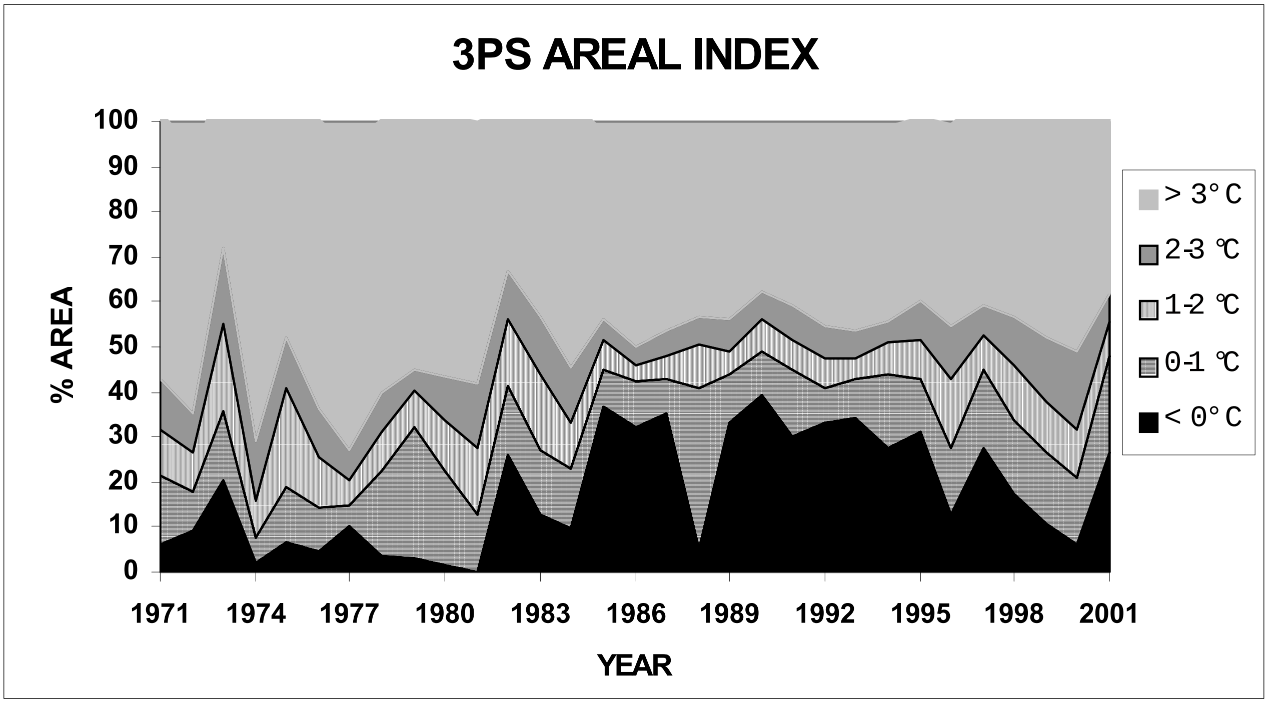


Fig. 3. The April 2000 and 2001 bottom temperature and anomalies (in °C) in NAFO Subdivisions 3Pn and 3Ps. The anomalies are referenced to the 1971-2000 average.



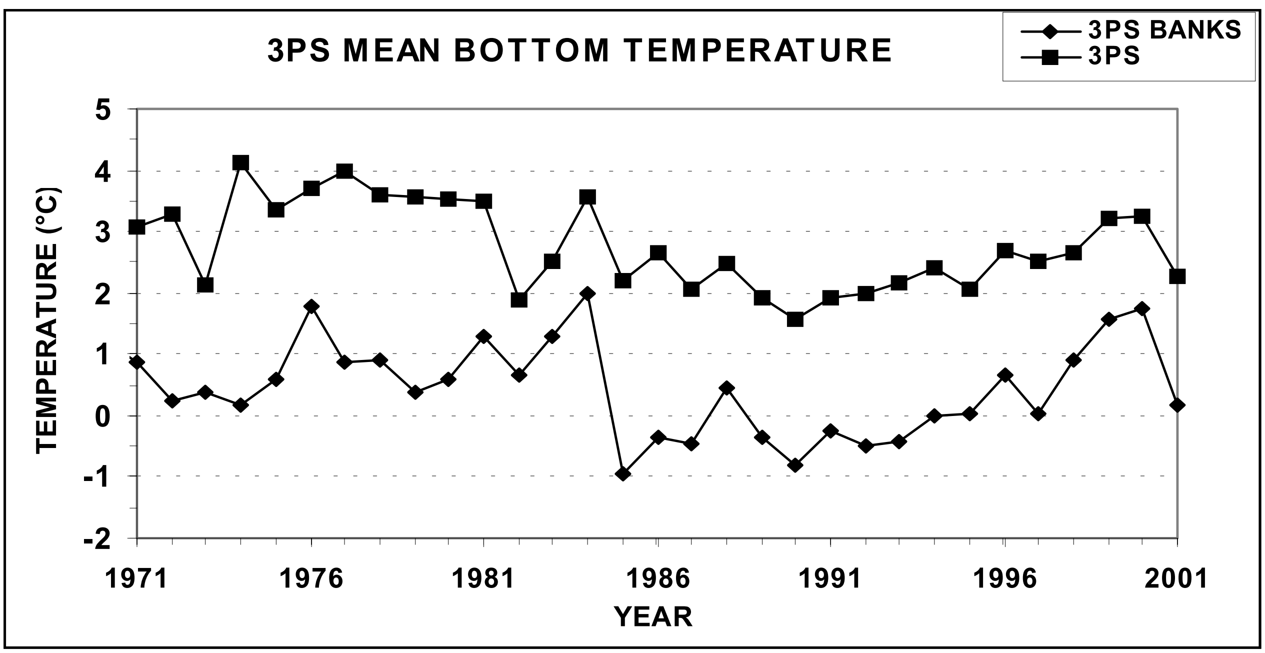


Fig.4. Time series of the percentage area of the bottom in NAFO Subdivisions 3Pn and 3Ps during the spring covered by water with temperatures ≤0°C, 0-1°C, 1-2°C 2-3°C and ≥3°C and the mean bottom temperature (in °C) for all strata and for strata with water depths <100 m.

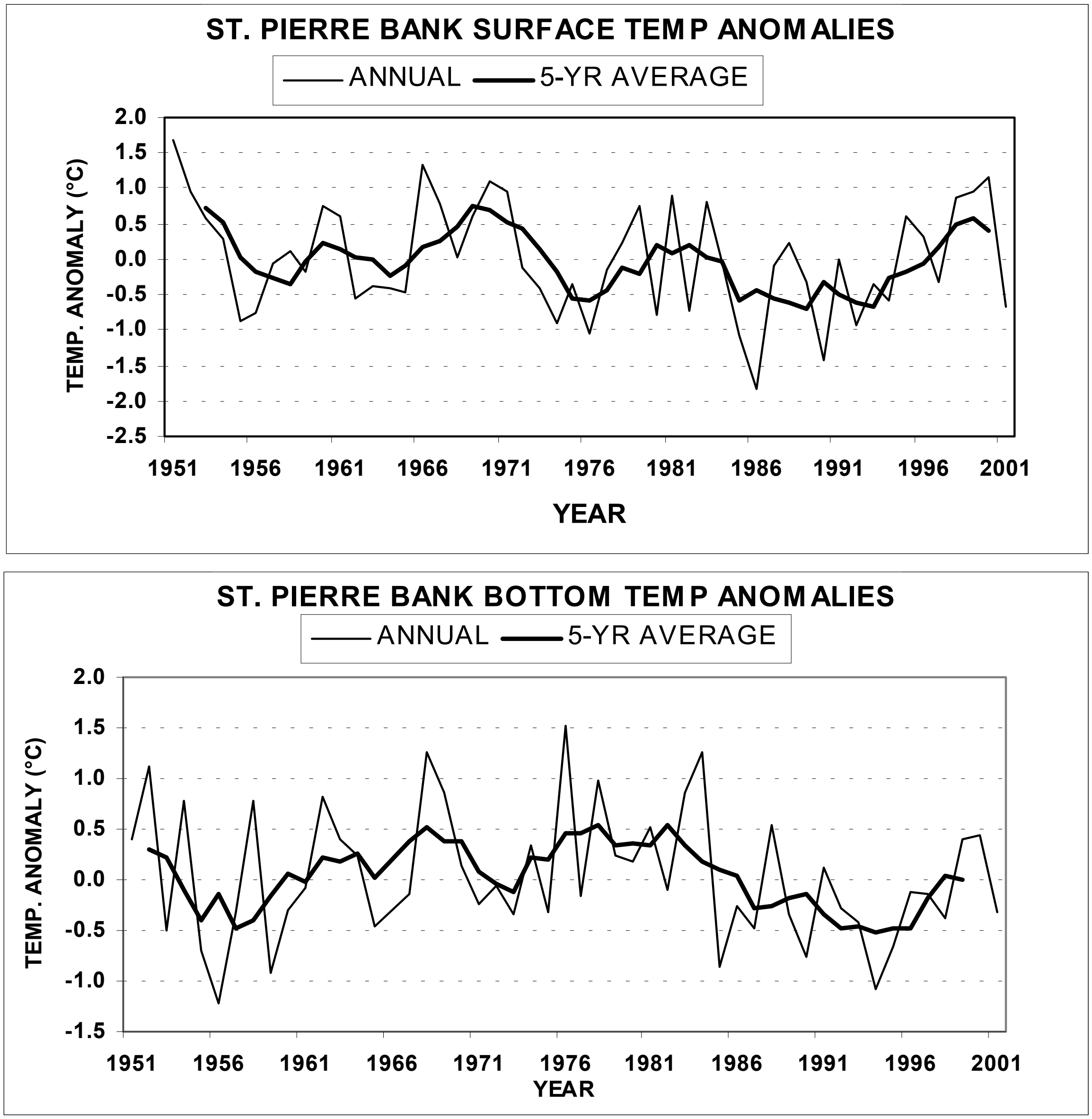


Fig. 5. Annual temperature anomaly time series (in °C) for the near-surface and near-bottom constructed from all historical data in Box B of Fig. 1. The heavy solid line represents the 5-year running mean.

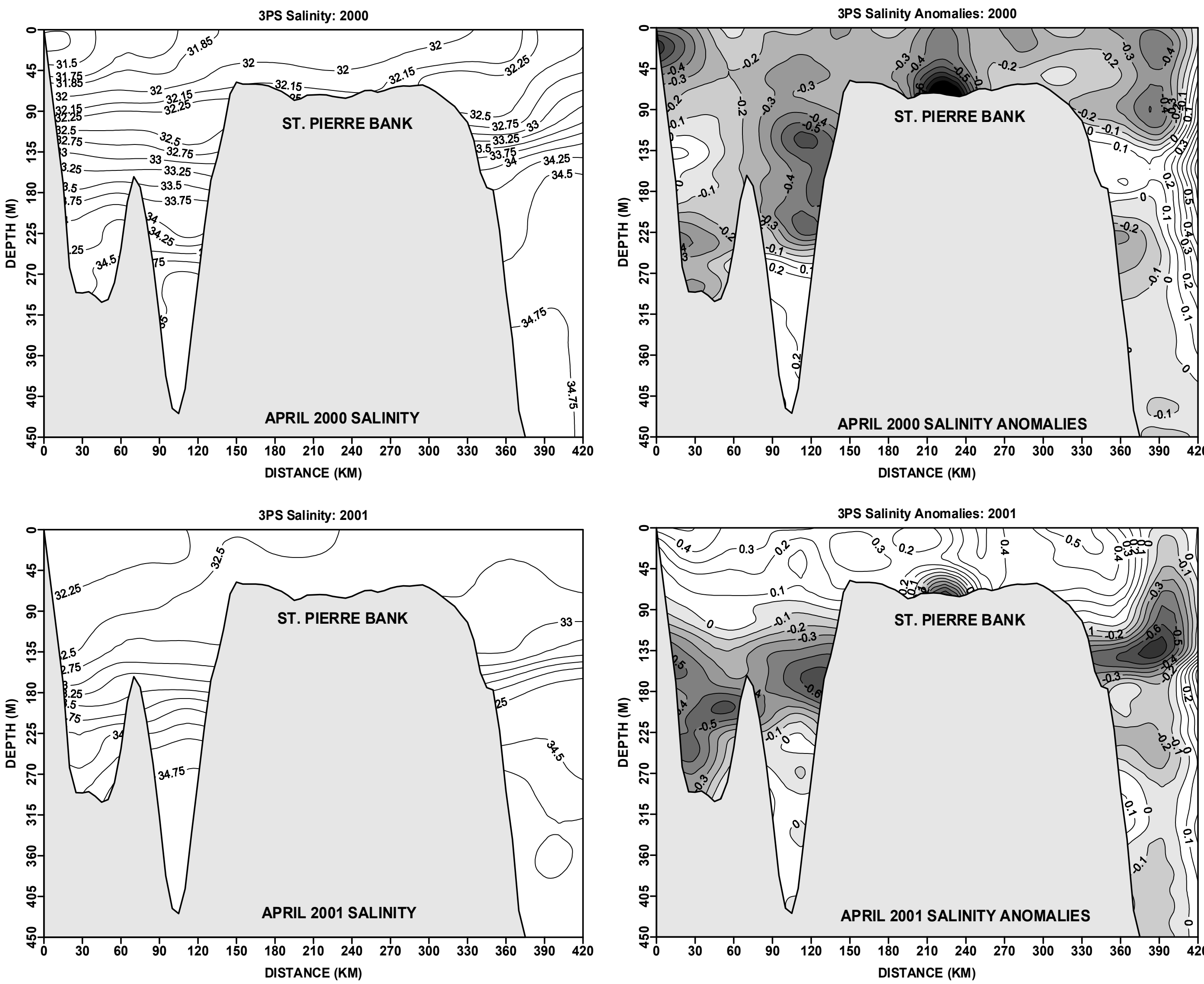


Fig. 6. The April 2000 and 2001 salinity and anomalies along the transect constructed from the data in Box A of Fig. 1 for NAFO Subdivisions 3Pn and 3Ps. The anomalies are referenced to the 1925 to 2000 average.

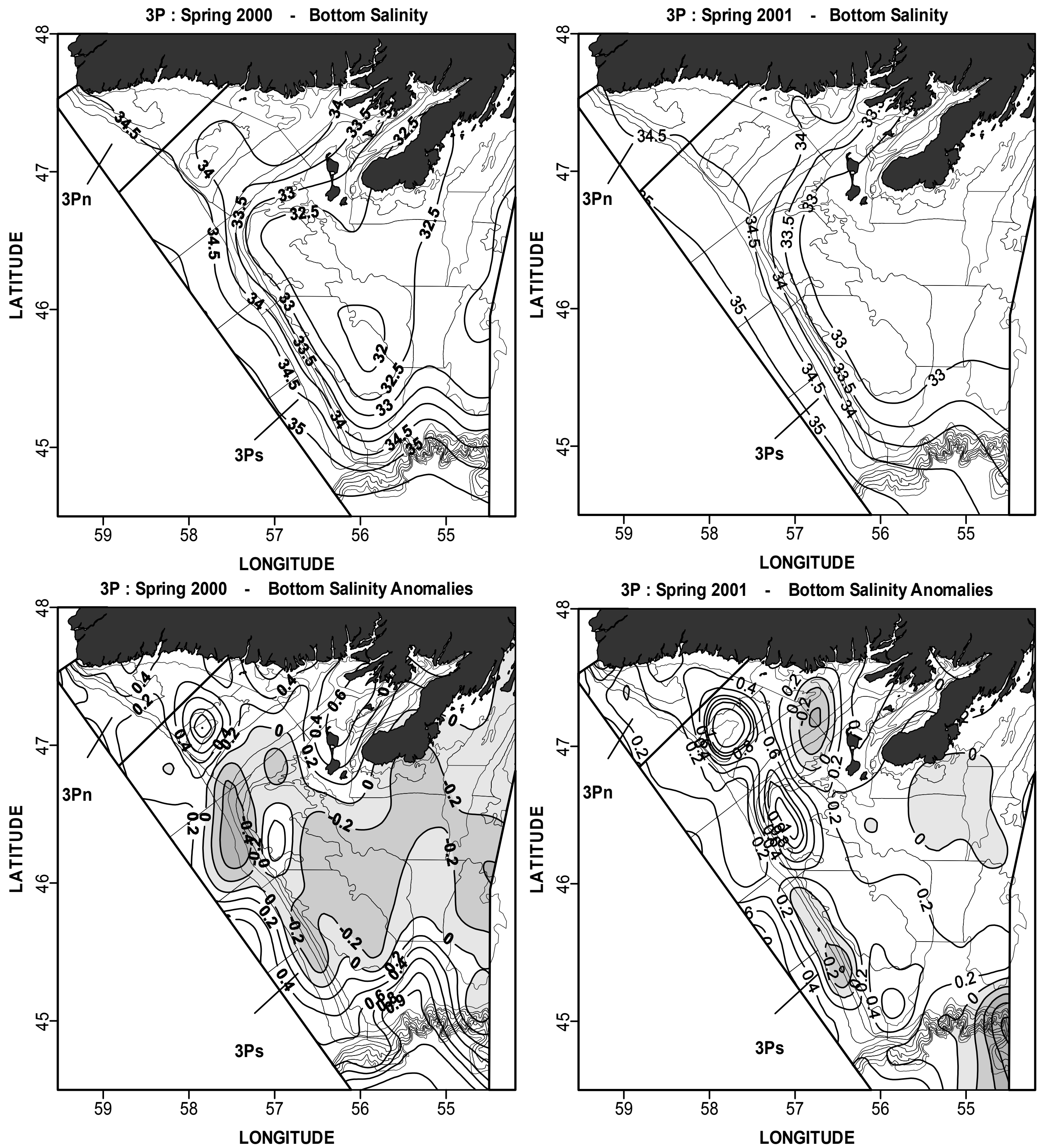
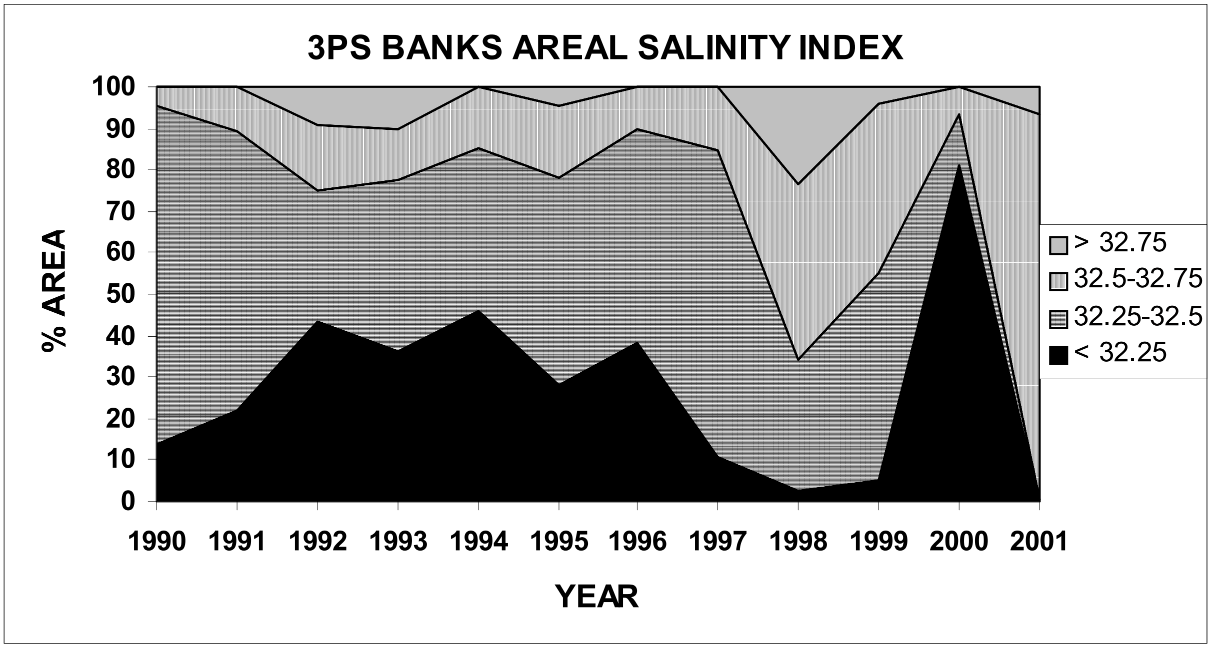


Fig. 7 The April 2000 and 2001 bottom salinity and anomalies in NAFO Subdivisions 3Pn and 3Ps. The anomalies are referenced to the winter/spring 1925-2000 average.



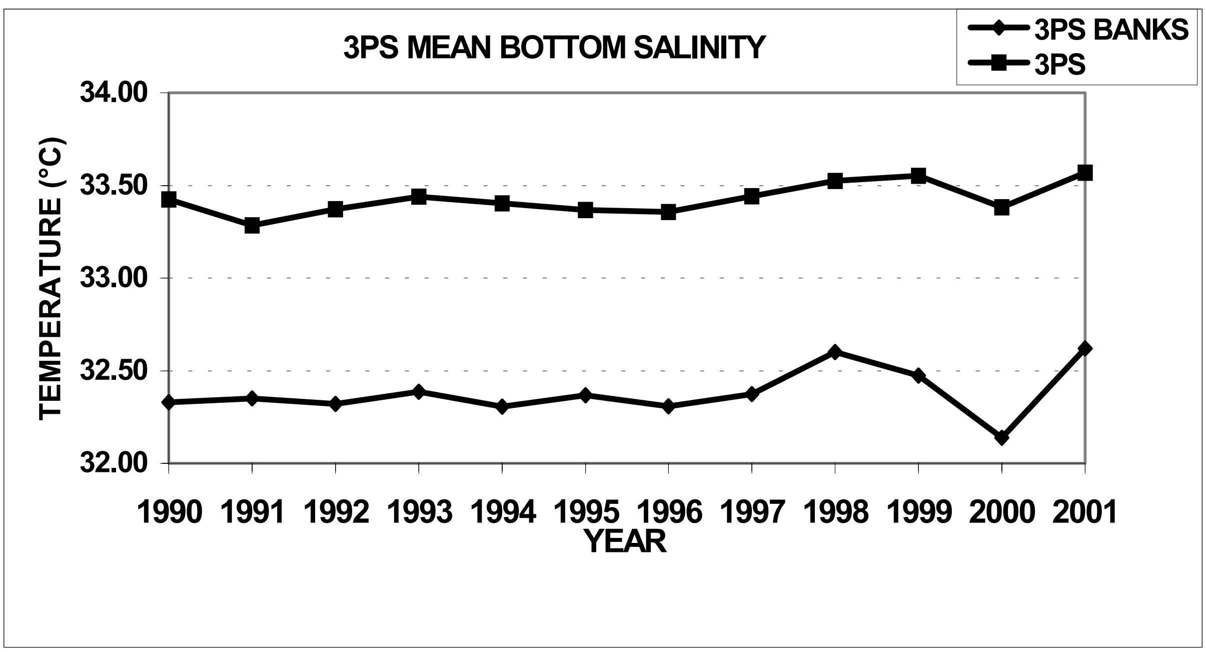


Fig. 8 Time series of the percentage area of NAFO Division 3P for strata with water depths <100 m covered by water in various salinities ranges (top) and the mean bottom salinity for all strata and for strata with water depths <100 m (bottom).