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Physical Oceanographic Conditions in NAFO Subareas 2 and 3 on the Newfoundland and Labrador Shelf During 2001

by

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Abstract

Oceanographic observations in NAFO Subareas 2 and 3 during 2001 are presented referenced to their long-term (1971-2000) means. The annual water column averaged temperature at Station 27 during 2001 warmed slightly compared to 2000, remaining above the long-term mean. Surface temperatures were above normal for 9 of the 12 months with anomalies reaching a maximum of near 1.6°C in October. Bottom temperatures at Station 27 were above normal (by ≈0.5°C) during 12 months of the year. Water column averaged summer salinities at Station 27 decreased to below normal values over the near-normal conditions of 2000. The cross-sectional area of <0°C (CIL) water on the Newfoundland and Labrador Shelves during the summer of 2001 decreased over 2000 values, except on the Grand Bank where there was a slight increase. Off Bonavista the CIL area decreased to the lowest value observed since 1978. Bottom temperatures on the Grand Banks during the spring of 2001 were generally above normal (up to 0.5°C) over most areas, except the southeast shoal of the Grand Bank where temperatures were slightly below normal. During the fall bottom temperatures were above normal on the northern Grand Bank (Div. 3L) and in Div. 2J and 3K. In general, over all areas of the Newfoundland Shelf the near-bottom thermal habitat continued to be warmer than that experienced from the mid-1980s to the mid-1990s. In summary, during 2000 and 2001 ocean temperatures were cooler than the 1999 values, but remained above normal over most areas continuing the warm trend established in 1996. Salinities during 2001 were generally fresher-than-normal in the inshore regions continuing the trend observed during most of the 1990s.

Introduction

This report presents an overview of the physical oceanographic conditions in the Newfoundland and Labrador Regions during 2001, with a comparison to long-term average conditions based on historical data. Where possible the long-term averages were standardized to a base period from 1971-2000 in accordance with the convention of the World Meteorological Organization and recommendations of the NAFO Scientific Council. Most of the data time series presented had good temporal coverage over the years 1971-2000. The information presented for 2001 is derived from the following sources; (1) observations made at Station 27 (Fig. 1a) throughout the year from all research and assessment surveys, (2) measurements made along standard cross-shelf transects during annual summer oceanographic surveys and (3) oceanographic observations made during the spring and fall multi-species research vessel surveys (Fig. 1b). Data from other sources are also used to help define the long-term means and conditions during 2001.

Data Sources and Analysis

Oceanographic data are available from archives at the Marine Environmental Data Service (MEDS) in Ottawa and maintained in databases at the Bedford Institute of Oceanography (BIO) in Dartmouth, Nova Scotia and at the Northwest Atlantic Fisheries Center (NAFC) in St. John's Newfoundland. Since 1977 (in Div. 2J), and from 1981 (in Div. 3KL) to 1989 the bulk of the fall data were collected during random stratified groundfish surveys. From 1971 to 1988 temperature data on these surveys were collected using bottles at standard depths and/or bathythermographs, mechanical or expendable (MBT/XBT), which were deployed usually at the end of each fishing set. Since 1989 net-mounted conductivity-temperature-depth (Seabird model SBE-19 CTD systems) recorders have replaced XBTs. This system records temperature and salinity data during trawl deployment and recovery and for the duration of the tow. 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°C in temperature and 0.005 in salinity. The XBT measurements are accurate to within 0.1°C.

Time series of temperature and salinity anomalies were constructed at standard depths from Hamilton Bank, Station 27 and the Flemish Cap. Anomaly time series were constructed by subtracting either the monthly mean or a fitted annual cycle from each observation. These anomalies are based on data collected over relatively large geographical areas and therefore may exhibit variability due to spatial differences. Additionally the annual values may be based on only a few monthly estimates for the year. Therefore caution should be used when interpreting short time scale features of these series, however the long-term trends generally show real features.

Bottom temperature grids for the Newfoundland Shelf were produced from all available data from 1971 to 2000 and for the spring and fall of 2001. All bottom-of-the-cast temperature values for each time period (except those for which the cast depths were not within 10% of the total water depth) were interpolated onto a regular grid and contoured using a geostatistical (2-diminsional Kriging) procedure. Bottom temperature anomaly maps were computed by subtracting the 2001 temperature grid from the average grid. Some temporal and spatial biasing may be present in the analysis given the large area and wide time interval over which the surveys were conducted. For example, the annual fall ground fish survey normally starts early to mid-October and finishes around mid-December, a time period when rapid cooling of the water column is taking place, particularly at the surface.

Near-bottom temperature data from the multi-species assessment surveys were used to compute a time series of the area of the bottom covered by water in selected temperature ranges. The mean near-bottom temperature for each grid element was calculated as described above and its area integrated to produce a yearly estimate of the percentage of the total area within each temperature range. The mean near-bottom temperature time series was also constructed for each region. The selected temperature ranges were ≤0°C, 0-1°C, 1-2°C, 2-3°C and ≥3°C. Potential sources of error in this analysis include temporal biasing arising from the wide time interval during which a typical survey is conducted. This source of error is probably small however, given the low magnitude of the annual cycle over most of the near-bottom depths encountered. An additional source of error that can potentially affect the results, particularly along the shelf edge, occurs when the spatial scales of temperature variations are shorter than the grid size. This effect however will probably be small, particularly over the Banks where the topography is relatively flat.

Time Trends in Temperature and Salinity

Station 27 (Division 3L)

A total of 57 temperature and salinity profiles were collected in the Avalon Channel at Station 27 off Cape Spear (Fig. 1a) during 2001. The data from this time series are presented in several ways to highlight seasonal and interannual variations over various parts of the water column. Depth versus time contour maps of the annual cycle in temperature and salinity and their associated anomalies for 2001 are displayed in Fig. 2. The monthly anomalies of temperature and salinity at selected standard depths are displayed in Fig. 3 and 4.

The cold near isothermal water column during the winter months has temperatures ranging from 0° to –1°C. These temperatures persisted throughout the year in the bottom layers. The surface layer temperatures ranged from about –1°-0°C from January to late April, after which the surface warming commenced. By mid-May upper layer temperatures had warmed to 1°C and to >13°C by August at the surface, after which the fall cooling commenced. Except for a near surface cold anomaly during the spring these values were about a 1/4° above normal for the winter months over most of the water column, but increased to 0.5°-1.0°C above normal in the upper water column by late May and into July. This warm anomaly continued during late summer and fall months with values reaching 1.5°C above normal in October. Temperatures at mid-depths (centred at 75-100 m) were below normal from August to December with values reaching 0.5°C below normal in November. Bottom temperatures ranged from 0° to 1/4°C above normal from January to December (Fig. 2).

Surface salinities reached a maximum of >32.2 by mid-February and decreased to a minimum of <30.8 by September. These values were about normal during the winter months but decreased to slightly below normal during the spring to late fall in the upper water column. In the depth range from 50-100-m, salinities generally ranged from

32.2 to 32.7 and near bottom they varied throughout the year between 32.8 and 33. Except for the near-normal values during the winter these values were generally below normal (by >0.2) during most of 2001 (Fig. 2).

The annual time series of temperature and salinity anomalies generally show three significant colder and fresher-than-normal periods at near decadal time scales since the early 1970s (Fig. 3 and 4). At the surface and intermediate depths of 50 and 100-m, the negative temperature anomalies that reached a minimum in the early-1990s began to moderate to near-normal conditions by the summer of 1994 and have continued above normal up to 2001. Near bottom at 175-m, temperatures were generally below normal from 1983 to 1994, the longest continuous period on record. During 1994 and 1995 bottom temperatures started to warm and by 1996 were above the long-term average. Bottom temperatures from 1998 to 2001 have remained above the long-term average. Annually, surface temperatures were above normal 9/12 months and near-bottom they were above normal during all 12 months of 2001 (Fig. 3 right panels).

Near-surface salinity anomalies (Fig. 4) show that the large fresher-than-normal anomaly that began in early 1991 had moderated to near normal conditions by early 1993 but returned to fresher conditions by the summer of 1995. Salinities approached near normal values during 1996 but decreased to mostly below normal values from 1997 to 2001. In general, during the past several decades cold ocean temperatures and fresher-than-normal salinities, were associated with strong positive NAO index anomalies, colder-than-normal winter air temperatures, heavy ice conditions and larger than average summer cold-intermediate-layer (CIL) areas on the continental shelf (Drinkwater, 1994; Colbourne *et al.*, 1994; Drinkwater *et al*., 1996; Drinkwater *et al.*, 1999). Annually, surface salinities were below normal for 10/12 months and near-bottom they were above normal during winter and fall but below normal from April to September of 2001 (Fig. 4, right panels).

Vertically averaged annual temperature and summer salinity anomaly time series for the depth ranges of 0-20, 0-50, 0-100 and 0-175 m are displayed in Fig 5. The temperature time series shows large amplitude fluctuations (exceeding 1^{o}C at 50 and 100 m) at near decadal time scales, with cold periods during the early-1970s, mid-1980s and early-1990s. During the time period from 1950 to the late-1960s the heat content of the water column was generally above the long-term mean. It reached a record low during 1991, a near record high during 1996, near normal in 1997 and 1998 and above normal during 1999 to 2001. During 2001 vertically averaged temperatures over all depth ranges increased over 2000 values (Fig. 5 left panels).

The salinity time series (Fig. 5 right panels), which are averages of the July-September values show similar trends as the heat content time series with fresher-than-normal periods generally corresponding to the colder-than-normal conditions up to at least the early-1990s. The predominance of fresher-than-normal salinities during the latter half of the 1990s corresponds to a warming trend, unlike previous time periods. The magnitude of negative salinity anomaly on the inner Newfoundland Shelf during the early 1990s is comparable to that experienced during the 'Great Salinity Anomaly' of the early-1970s (Dickson *et al*., 1988). During 1993 summer salinities started returning to more normal values but decreased again by the summer of 1995 to near record lows, then increased to near normal values in 1997 and 1998 but fell again to below normal values in 1999 and returned to normal conditions during 2000. During 2001 salinity averages decreased over 2000 values over all depth ranges to below normal conditions.

Flemish Cap (Division 3M)

Temperature anomalies on the Flemish Cap (Fig. 6) are also characterized by cold periods during the 1970s, mid-1980s and the late 1980s to the mid-1990s. The cold period, beginning around 1971, continued until 1977 in the upper layers, while temperature anomalies at 150-m depth were of a much lower magnitude. From 1978 to 1984 the temperature anomalies showed a high degree of variability in the upper water column with a tendency towards positive anomalies. By 1985 in the top 100-m of the water column, negative temperature anomalies had returned. This cold period moderated briefly in 1987 but returned again by 1988 and continued into the early-1990s. By 1995 temperatures moderated and were above normal at most depths from 1997 to 2001. In general, annual temperatures in 2001 decreased over 2000 values at most depths.

The time series of salinity anomalies (Fig. 6) show large fresher-than-normal conditions from 1970 to 1975 with peak amplitudes reaching near 1 PSU below normal at the surface. Negative salinity anomalies also occurred during the mid-1980s and mid-1990s, however the amplitude was much smaller than the great salinity anomaly of the early-1970s. The trend in salinity values during the latter half of the 1990s ranged from slightly above normal at the surface to near normal at deeper depths. In general, the long-term trends in temperature and salinity anomalies on the

Flemish Cap are very similar to those at Station 27 and elsewhere on the continental shelf over similar depth ranges (Colbourne and Foote, 2000). Annual salinity anomalies in 2001 decreased over 2000 values over all depths.

Hamilton Bank (Division 2J)

Time series of temperature and salinity anomalies from 1951 to 2001 on Hamilton Bank are shown in Fig. 7 at selected depths. The annual values show a high degree of variability that may indicate spatial variability over the bank at the same depth level. It should also be noted that these estimates are calculated from a variable number of observations. A low frequency trend was calculated by a 5-year running mean that suppresses the high frequency variations and gives a general indication of long-term trends.

The temperature anomaly time series is characterized by amplitudes ranging from near ±2°C and with periods ranging from 2-10 years. The cold periods of the early-1970s, the mid-1980s and the early-1990s are apparent, but the amplitude of the anomalies varied considerably with depth. The long-term trend indicates that temperatures on Hamilton Bank have moderated, particularly in the deeper layers, being above normal since the mid-1990s, similar to conditions further south at Station 27. During 2001 temperatures were about normal at the surface and at 75-m depth, but remained above normal below 100-m depth. The salinity time series show similar trends as elsewhere on the shelf with fresher-than-normal conditions in the early-1970s, mid-1980s and early-1990s. Salinities from 1995-2001 varied about the long-term mean with near-normal values during 2001.

Standard Monitoring Transects

In 1976 the International Commission for the Northwest Atlantic Fisheries (ICNAF) adopted a suite of standard oceanographic monitoring stations along transects in the Northwest Atlantic Ocean from Cape Cod (USA) to Egedesminde (West Greenland) (ICNAF, 1978). Several of these sections are occupied annually during mid-summer on an annual oceanographic survey conducted by the Department of Fisheries and Oceans (DFO) Newfoundland Region (Fig. 1a). The sections with the longest historical record include, the Seal Island transect on the southern Labrador coast and Hamilton Bank, the White Bay transect which crosses the relatively deeper portions of the northeast Newfoundland Shelf, the Bonavista transect off the east coast of Newfoundland and the Flemish Cap transect which crosses the Grand Bank at 47°N and continues eastward across the Flemish Cap. In this section the physical oceanographic data for these sections for the summer of 2001 are presented.

Sampling along the Flemish Cap section during the summer of 2001 was restricted to areas west of the Flemish Pass (Fig. 8). Near surface temperatures along this section ranged from 8-9°C during the summer while <0°C temperatures generally persisted from below 60-m depth to the bottom over most of the Grand Bank. The coldest water is normally found in the Avalon Channel and at the edge of the Grand Bank corresponding to the inshore and offshore branches of the Labrador Current. Except for some small isolated areas water column temperatures along this section were generally above normal during the summer of 2001. Bottom temperatures over most of the Grand Bank were also above normal. Salinities along the section on the Grand Bank are characterized by generally fresh conditions (<33), a strong horizontal gradient at the shelf break and generally salty (>35.25) water offshore of the Flemish Pass. Salinity anomalies during 2001 were quite variable along this section, but overall were slightly higher than average on the Grand Banks.

Bonavista

The dominant feature along the Bonavista section is the cold intermediate layer of <0°C water (CIL), which develops during early spring after intense winter cooling (Fig. 9). Temperatures along the Bonavista section shoreward of the shelf break in the upper water column reached a maximum of 7-8°C during the summer. Except for a colder-than-normal anomaly in the near-shore region and areas corresponding to the offshore core of the Labrador Current temperatures along this section were generally above normal in most areas (up to 2°C). Salinities along the Bonavista section ranged from <32 near the surface in the inshore region to >34 in the offshore region. Bottom salinities ranged from 32.5 in the inshore regions, to 34.75 at about 325-m depth near the shelf edge. In areas generally associated with the inshore and offshore Labrador Current salinities were fresher-than-normal (up to 0.5) at intermediate depths. For surface waters and at all depths over the central shelf regions salinities were predominantly saltier-than-normal.

White Bay

Along the White Bay section (Fig. 10) the CIL water mass during the summer is usually quite extensive, with a large area of water with <0°C temperatures extending from the coast and offshore to over 400 km. At about mid-shelf temperatures below 200 m increase from 0°C to >3°C at the outer edge of the shelf. Except at mid-shelf and near the surface, temperatures along this transect were generally below average during 2001. Surface salinities generally ranged from <31 in White Bay to near 34 in the offshore region. Bottom salinities ranged from 33 near shore to 34.75 at the edge of the shelf. These values were fresher-than-normal in areas corresponding to the locations of the inshore and offshore Labrador Current at intermediate depths and generally above normal elsewhere, similar to conditions along the Bonavista section.

Seal Island

Along the Seal Island section (Fig. 11) upper layer temperatures ranged from 0°C at approximately 50-m depth to between 3-4°C at the surface. Temperatures below 50-m depth were generally <0°C over most of the shelf, corresponding to the CIL, except near bottom where they range from 0.5°-1°C. Near the shelf break temperatures increase to 2°-3°C. Temperature anomalies in the surface layer were up to 1°C below normal over most of the shelf, but were up to 2°C above normal offshore of the shelf break. In water generally associated with the CIL, temperatures were above normal by up to 1°C in the inshore regions. Surface salinities along this section ranged from <31 inshore of Hamilton Bank to >34 in the offshore region. Bottom salinities ranged from 32.5 near shore to 34.75 at the edge of the shelf in water depths >400-m. Again similar to conditions along sections further south, intermediate water salinities were fresher-than-normal in areas corresponding to the locations of the inshore and offshore Labrador Current and generally above normal elsewhere, particularly at the surface. Offshore of the shelf break salinities were near normal at depth and above normal in the upper water column.

Makkovik Bank and Beachy Island (Nain Bank)

The Makkovik Bank and Beachy Island transects on the mid-Labrador Shelf were occupied in July of 2001 for the third consecutive year (Fig. 12 and 13). Along the Makkovik Bank section upper layer temperatures over the shelf ranged from 0°C at 30-m depth to between 2-3°C at the surface. Temperatures below 30-m depth were generally <0°C over the shelf but increased to above 0°C on the outer edge of the Bank and to >3°C on the shelf slope below approximately 200-m depth. Temperature anomalies in the upper layer were up to 1°C above average but near normal over the rest of the water column. Surface salinities along this section ranged from <30.75 inshore of Makkovik Bank, <32 on the bank and >34 in the offshore region. Bottom salinities ranged from 32.5 near shore to 34.75 at the edge of the Labrador Shelf in water depths >450-m. In general conditions along this section were fresher-than-normal over most of the water column, particularly near the surface. Offshore of the shelf break salinities were near normal at depths >150-m to above normal in the upper water column.

Along the Beachy Island transect, which crosses Nain Bank, temperatures were slightly warmer than that observed along the Makkovik Bank transect with surface values >4°C and the area of water with temperatures below –1°C was much less than that on Makkovik Bank. Offshore temperatures were very similar along both transects. Similar to the Makkovik Bank section temperature anomalies in the upper layer were above average but below average at the edge of the shelf. Surface salinities along this section ranged from <31 inshore of Nain Bank, <32 on Nain bank and >34 in the offshore region. Bottom salinities ranged from 32.5 near shore to 34.75 at the edge of the Labrador Shelf. These values were generally fresher than the average of the available data for this time period.

Cold Intermediate Layer (CIL) Time Series

As discussed above and shown in the cross-shelf contour plots (Fig. 8-13), the vertical temperature structure on the Newfoundland Continental Shelf during late spring through to the fall is dominated by a layer of cold <0°C water which remains isolated between the seasonally heated upper layer and warmer slope water near the bottom. This water mass is commonly referred to as the cold intermediate layer or CIL (Petrie *et al*., 1988). The cold, relatively fresh, shelf water is separated from the warmer saltier water of the continental slope by a frontal region denoted by a strong horizontal temperature and salinity gradient near the edge of the continental shelf. The spatial extend of this winter chilled water mass is evident in the section plots of the temperature contours. For example, along the White Bay transect (Fig. 10) the CIL extends offshore to over 400 km, with a maximum thickness of approximately 215 m in the White Bay area. This corresponds to a cross-sectional area of around 50 km^2. Figure 14 shows time series of the CIL cross-sectional area anomalies defined by the 0°C contour for the Flemish Cap, Bonavista, White Bay and Seal Island sections.

Along the Flemish Cap section the CIL was below the 1971-2000 normal, similar to conditions observed during the past 3-years but a slight increase over 2000. Off Bonavista the CIL area decreased to the lowest value observed since 1978 continuing the trend of below normal values observed since 1994. Similarly along the White Bay and Seal Island sections the area of <0°C water decreased over 2000 values continuing the recent below normal trend. This is in contrast to the near record high values measured during the early 1990s, which was a very cold period on the Newfoundland Shelf. Minimum temperatures (expressed as anomalies) measured in the core of the CIL for all four transects during the summer from 1951 to 2001 are also shown in Fig. 14. The minimum temperature observed along the Flemish Cap, Bonavista, White Bay and Seal Island transects during 2001 were -1.26°, -1.51°, –1.61°, and -1.34°C, respectively. These were all above normal and represent an increase over the 2000 values except on the White Bay section.

Multi-Species Survey Results

Canada has been conducting stratified random bottom trawl surveys in NAFO Subareas 2 and 3 since 1971. Each NAFO Div. has been stratified based on the depth contours of available standard navigation charts. Areas within each division with a selected depth range were divided into strata and the number of fishing stations in an individual stratum are based on an area weighted proportional allocation (Doubleday 1981). Temperature profiles of the water column are available for each fishing set in each stratum. Surveys have been conducted for the following NAFO Divisions, time periods and depth ranges: 3P in winter and/or spring from 1972 to 2001, in water depths down to 366 m until 1979 and to 548 m since then; 3L in spring from 1971-2001, except 1983 and 1984; 3NO in spring from 1971-2001, except 1983 in 3N and 1972, 1974 and 1983 in 3O, in water depths down to 366 m in most years and more recently to 548 m; 2J fall from 1977-2001; 3K in fall from 1978-2001; 3L in fall from 1981-2001, 3NO in fall from 1990-2001. These surveys provide 2 spatially comprehensive oceanographic data sets on an annual basis for the Newfoundland Shelf, one during the spring from 3Pn in the west to 3LNO on the Grand Banks and one during the fall time period from 2J in the north to 3NO in the south. In this section an analysis of the near-bottom temperature fields and their anomalies based on these data sets are presented for the spring and fall periods. Interannual variations are then examined by computing the areal extent of the bottom covered with water in various temperature ranges as described earlier. The objective of this analysis is to provide some indication of potential changes in any temperature dependent near-bottom habitat for various fish species.

3LNO Spring and Fall

Bottom temperatures and their anomalies for NAFO Div. 3LNO during the spring and fall are shown in Fig. 15. In the northern areas spring bottom temperatures ranged from <0°C in the inshore regions of the Avalon Channel to >3°C at the shelf edge. Over the central and southern areas bottom temperatures ranged from 1-2°C on the Southeast Shoal and >5°C along the slopes of the Grand Bank in Div. 3O. During the spring of 2001, <0°C water was mostly restricted to Div. 3L, with above normal temperatures over most areas except the southeast shoal of the Grand Bank where temperatures were slightly below normal. During the fall bottom temperatures generally ranged from <0°C on the northern Grand Bank and in the Avalon Channel to 3°C at the shelf edge. Over the central and southern areas bottom temperatures ranged from 1°C to >4°C on the Southeast Shoal and to >3°C along the edge of the Grand Bank. During the fall of 2001 bottom temperatures over the surveyed area were above normal on the northern portion and along the edge of the Grand Bank by up to 0.5°C but in 3NO they were quite variable fluctuating ±1°C about normal in most regions.

The areal extent of the bottom covered by water in various temperature ranges during spring and fall in 3LNO is displayed in Fig. 16. During the spring in this region from 1975-1983 most of the bottom area was covered by water with temperatures >0°C with only approximately 20% covered by <0°C water. From 1984-1997 there was a large increase in the area of <0°C water with percentages reaching near 60% in some years. Since 1997 there was a significant decrease in the % area of the bottom covered by <0°C water and a corresponding increase in the area covered by water ≥1°C. During the spring of 1998 and 1999 water with temperatures >1°C covered 50-60% of the bottom area on the Grand Bank, the largest area of relatively warm water on the Grand Bank since the late-1970s. During 1999 the area of <0°C water on the Grand Bank decreased to about 10%, the lowest since 1978. During the spring of 2000 and 2001 this area has increased to about 25%. During the fall of 2000 the area of <0°C water remained below the high values of the early-1990s but increased over 1999 values to near 40%. During 2001 the area of <0°C water decreased slightly over 2000.

The average bottom temperature for the Div. 3LNO region (Fig. 16, bottom panel) shows large interannual variations of about 1°C amplitude and a downward trend that started in 1984. This trend continued until the early-1990s. The highest temperature in the 25-year record occurred in 1983 when the average temperature was 3.2°C and the lowest temperature of 0.25°C occurred in 1990. Recently, temperatures have increased over the lows of the early-1990s with the average bottom temperature during the spring of 1999 and 2000 reaching 2°C. During the spring of 2001 the average bottom temperature decreased over the 2000 value to about 1.5°C. The average bottom temperature during the fall decreased from approximately 1.5°C during 1990 to 1°C during 1993 and 1994, then increased to approximately 1.8°C during 1995. These remained relatively constant up to 1998 but then increased to over 2.5°C during 1999, the highest in the 10-year record. During the fall of 2000 and 2001 the mean bottom temperature remained constant, a significant decrease over 1999 values, but was still above the cold condition of the early-1990s.

3K and 2J Fall

Bottom temperatures and their anomalies for NAFO Div. 3K and 2J during the fall of 2001 are shown in Fig 17. Most of Div. 3K has water depths >200-m, as a result relatively warm slope water floods through the deep troughs between the northern Grand Bank and southern Funk Island Bank and between northern Funk Island Bank and southern Belle Isle Bank. Bottom temperatures on these banks during the fall of 2001 ranged between 2-3°C, which were about 0.5-1°C above their long-term means. Near the edge of the continental shelf in water depths below 500-m temperatures were about normal, generally around 3.5°C. Bottom temperatures during the fall of 2001 ranged from <1°C inshore, to >3.5°C offshore at the shelf break. Bottom temperatures over Hamilton Bank ranged from <2°C on the inshore portion of the bank, to near 3°C on the southern portion. Bottom temperature anomalies were about 1-2°C above normal on Hamilton Bank and about normal along the edge of the shelf

The areal extent of the bottom covered by water in various temperature ranges and the mean bottom temperature during the fall for Div. 3K and 2J are displayed in Fig. 18. The % area of the bottom covered by <0°C water in this region is generally <30% and in many years <10%, with significant amounts appearing only during the cold periods of the early to mid-1980s and 1990s. For temperature >3°C, the bottom area in 3K covered has been relatively constant ranging from 20-35% from 1979 to 1995 after which it increased to near 50% from 1997 to 2001. The % area of the bottom covered by <0°C water in 2J is normally very low during the fall with significant amounts appearing only during the cold periods of the early- to mid-1980s and early-1990s, when it ranged between 20% to 30%. For temperatures >3°C in 2J the bottom area covered ranged from a low of 15% in 1992 to a maximum of near 50% during 1999 and 2001. Since 1996 the area of the bottom covered with <0°C water decreased to <10%.

The time series of the average bottom temperature in Div. 3K (Fig. 18, bottom panel) during the fall ranged from 1°C in 1982 to 2.3°C in 1986 with an overall average of about 2°C. From 1995-1999 they increased to above average values reaching about 2.7°C during 1999. During the fall of 2000 and 2001 bottom temperatures remained relatively warm but decreased over 1999 values to about 2.2°C. Bottom temperatures during the fall in Div. 2J generally average about 2°C but during the latter half of the 1990s they increased to about 2.5°C. During 2001 mean bottom temperatures continued above 2.5°C.

Summary

The annual water column averaged temperature at Station 27 for 2001 warmed slightly compared to 2000 remaining above the long-term mean. Surface temperatures were above normal for 9 months of the year with anomalies reaching a maximum of near 1.6°C in October. Spring (April to May) values were below normal. Bottom temperatures at Station 27 were above normal (by $\approx 0.5^{\circ}$C) during the entire year. Water column averaged summer salinities at Station 27 decreased to below normal values over the near-normal conditions of 2000. Annually salinities at Station 27 were above normal during the winter months, below normal from spring to early fall and slightly above normal during late fall below the surface layer.

The cross-sectional area of $<0^{\circ}$C (CIL) water on the Newfoundland and Labrador Shelves during the summer of 2001 decreased over 2000 values except on the Grand Bank where there was a slight increase. The CIL areas were below normal along all sections from the Grand Bank (Flemish Cap section), to the Seal Island section off southern Labrador. Off Bonavista the CIL area decreased to the lowest value observed since 1978. Minimum CIL core temperatures along the standard sections during the summer of 2001 increased over 2000 values except off White Bay, and were all above normal.

Bottom temperatures on the Grand Banks during the spring of 2001 were generally above normal (up to 0.5°C) over most areas except the southeast shoal of the Grand Bank where temperatures were slightly below normal. During the fall bottom temperatures were above normal on the northern Grand Bank (3L) but in Div. 3NO they were quite variable fluctuating $\pm 1^{\circ}$C about normal in most regions. Fall bottom temperatures in Div. 2J and 3K were above normal in most areas, up to 2°C on Hamilton Bank. Except during the spring on the Grand Bank mean bottom temperature in all regions increased slightly over 2000 values. Correspondingly, the area of the bottom covered by warmer water increased slightly over 2000 except on the Grand Bank during the spring. In general over all areas of the Newfoundland Shelf the near-bottom thermal habitat continued to be warmer than that experienced from the mid-1980s to the mid-1990s.

In summary, the below normal trends in temperature and salinity, established in the late-1980s reached a minimum in 1991. This cold trend continued into 1993 but started to moderate during 1994 and 1995. During 1996 temperature conditions were above normal over most regions, however, summer salinity values continue to be slightly below the long-term normal. During 1997 to 1999 ocean temperatures continued to warm over most areas, with 1999 one of the warmest years in the past couple of decades. In summary, during 2000 and 2001 ocean temperatures were cooler than 1999 values, but remained above normal over most areas continuing the trend established in 1996. Salinities during 2001 were generally fresher than normal in the inshore regions, which is a continuation of the trend observed during most of the 1990s.

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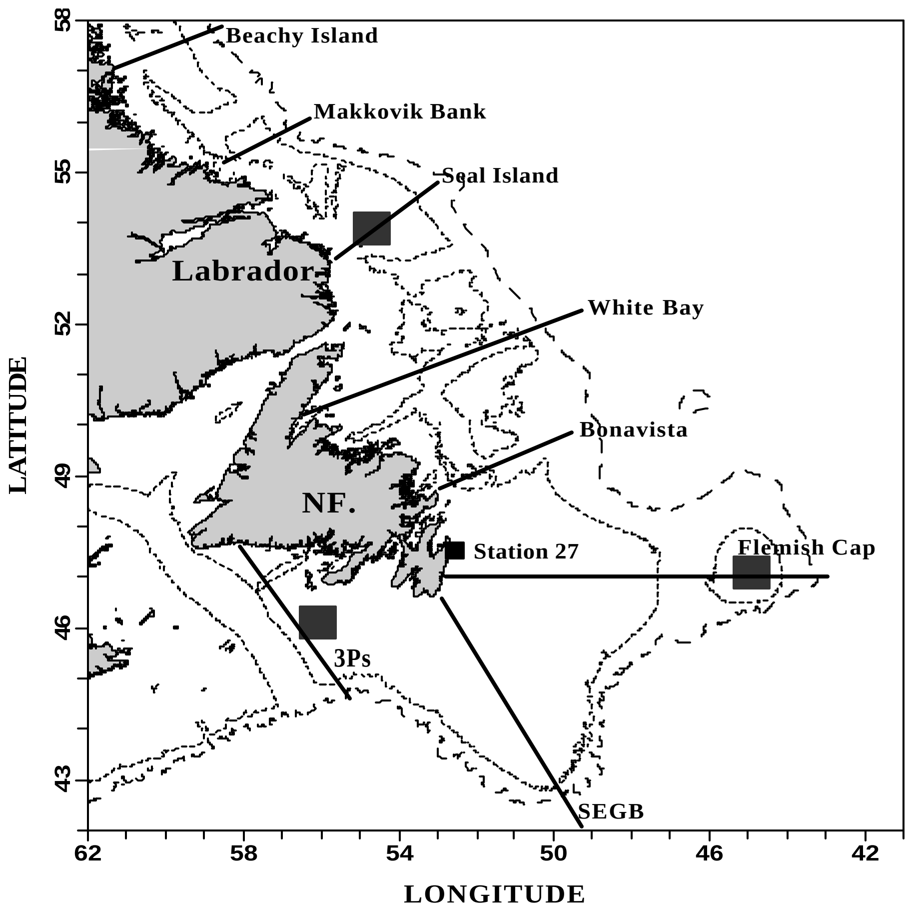
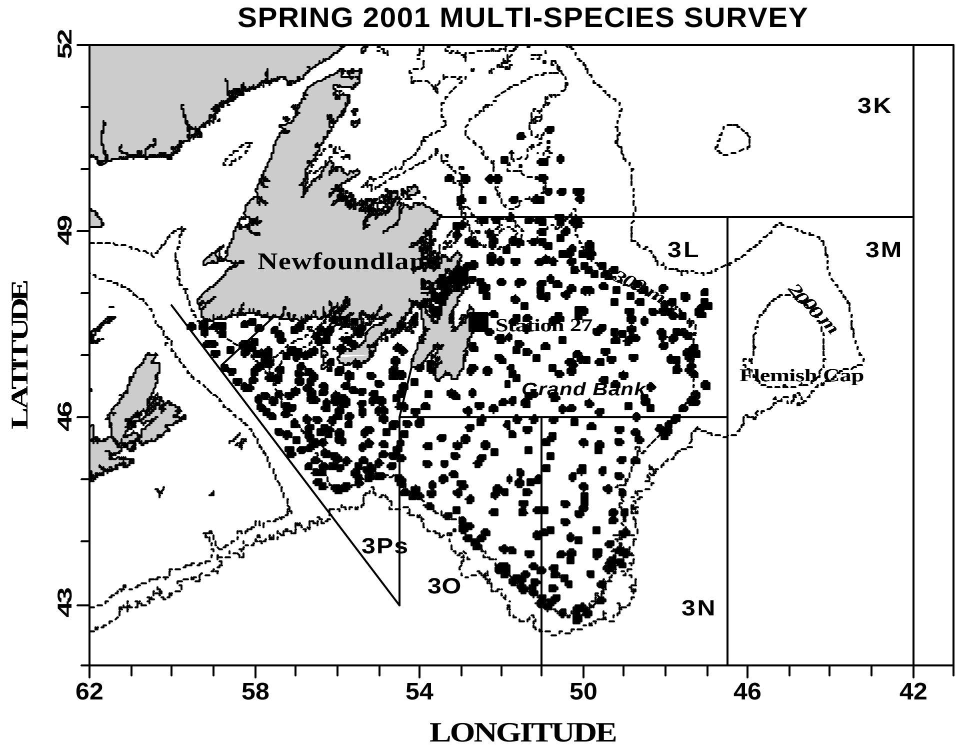


Fig. 1a. Location map showing the positions of standard sections, Station 27 and location boxes where temperature and salinity time series were constructed. Bathymetry contours are 300 and 1 000 m.



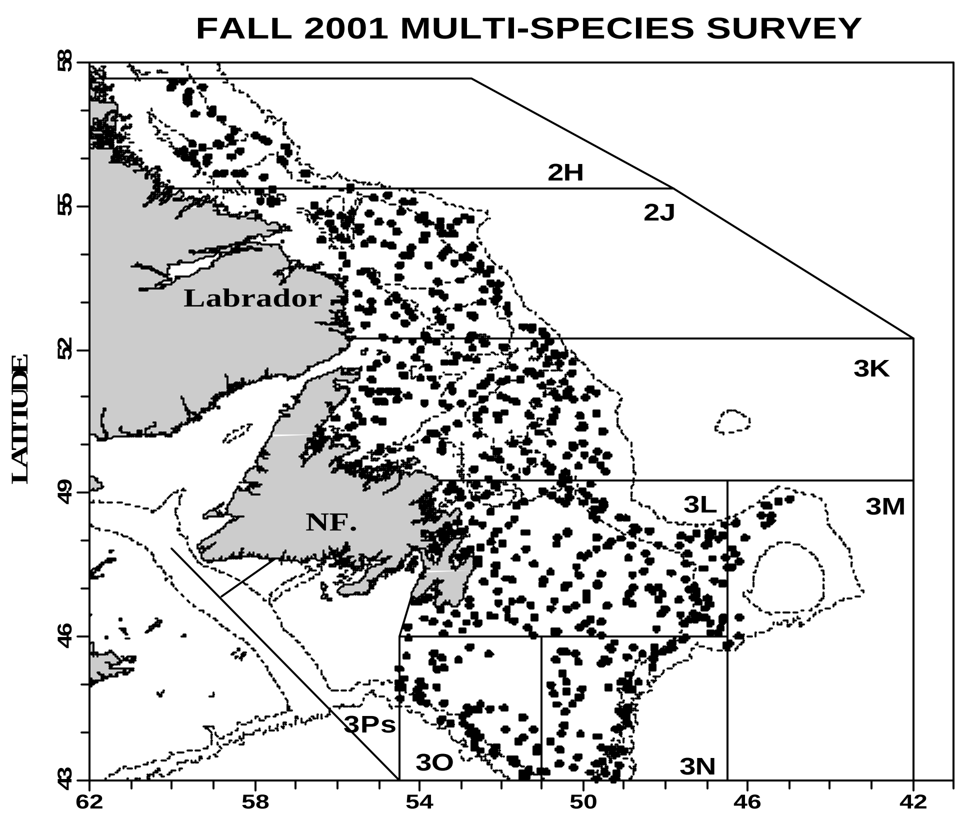


Fig. 1b. Location maps showing the position of sets with oceanographic data from the multi-species surveys during the spring and fall. Bathymetry contours are 300 and 1 000 m.

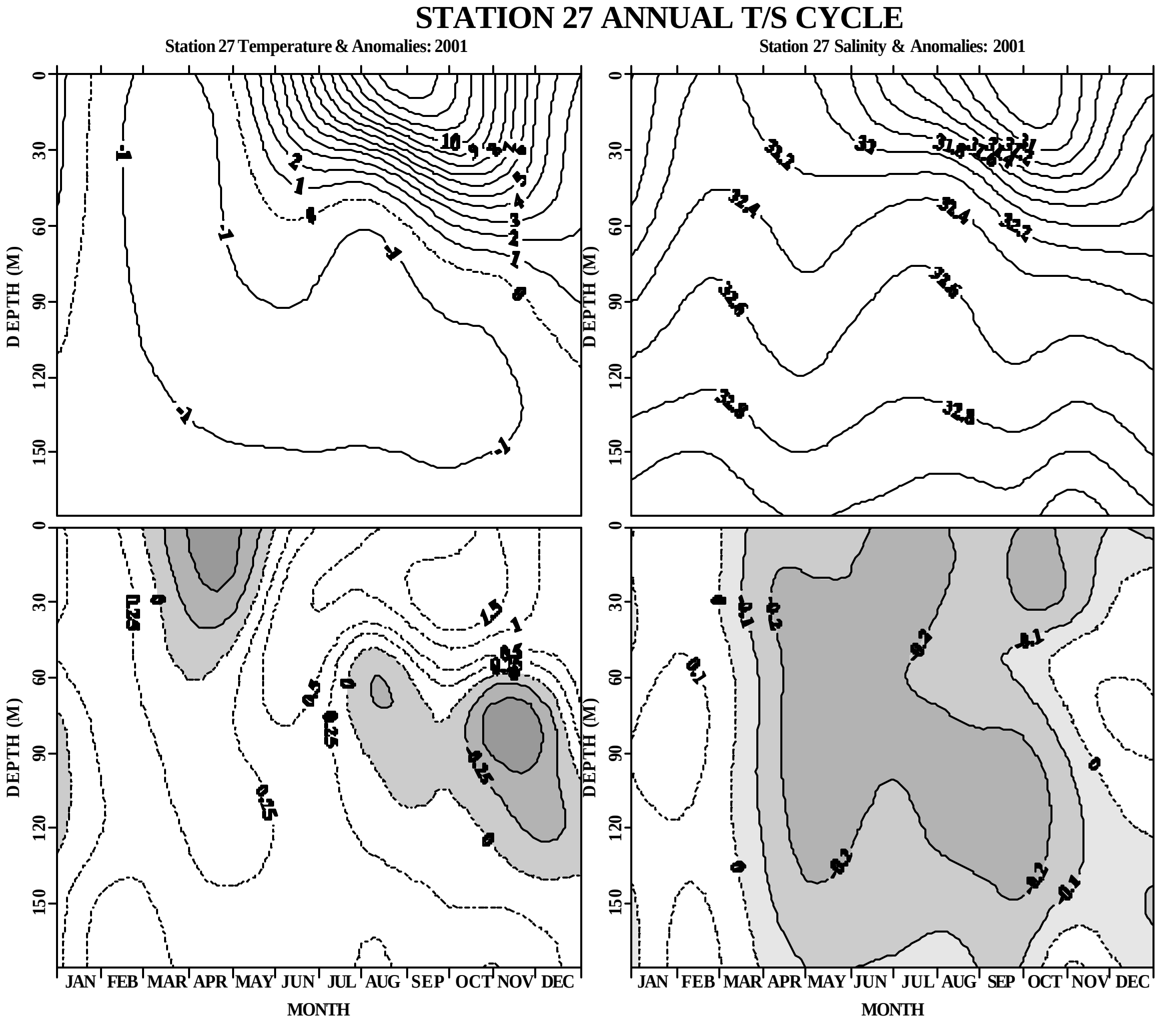


Fig. 2. Monthly temperatures (left panels) and salinity (right panels) and their anomalies (in °C) at Station 27 as a function of depth for 2001.

STATION 27 TEMPERATURE ANOMALIES

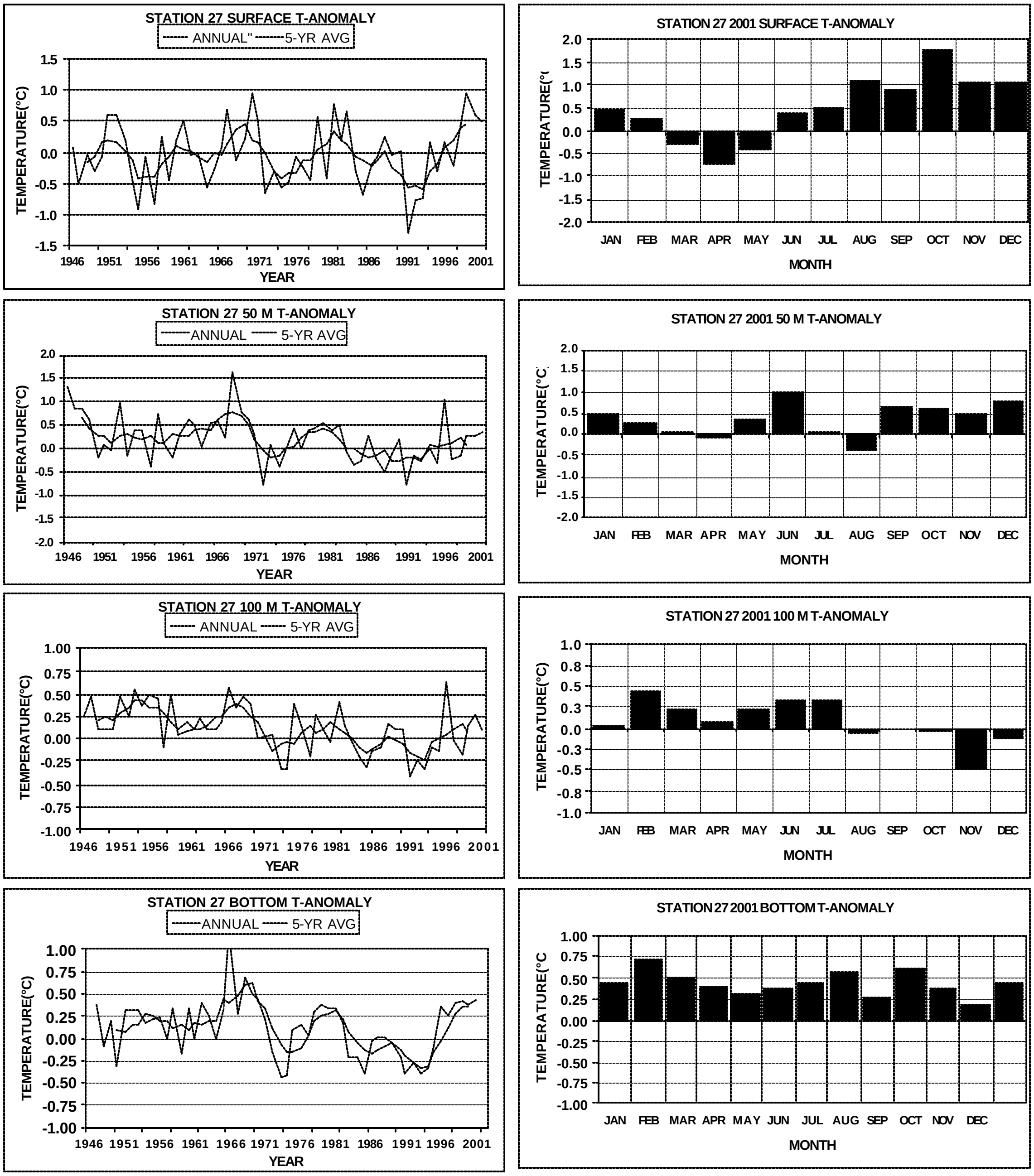


Fig. 3. Station 27 annual temperature anomalies and their 5-year running means at selected depths (left panels) and monthly temperature anomalies (right panels) for 2001.

STATION 27 SALINITY ANOMALIES

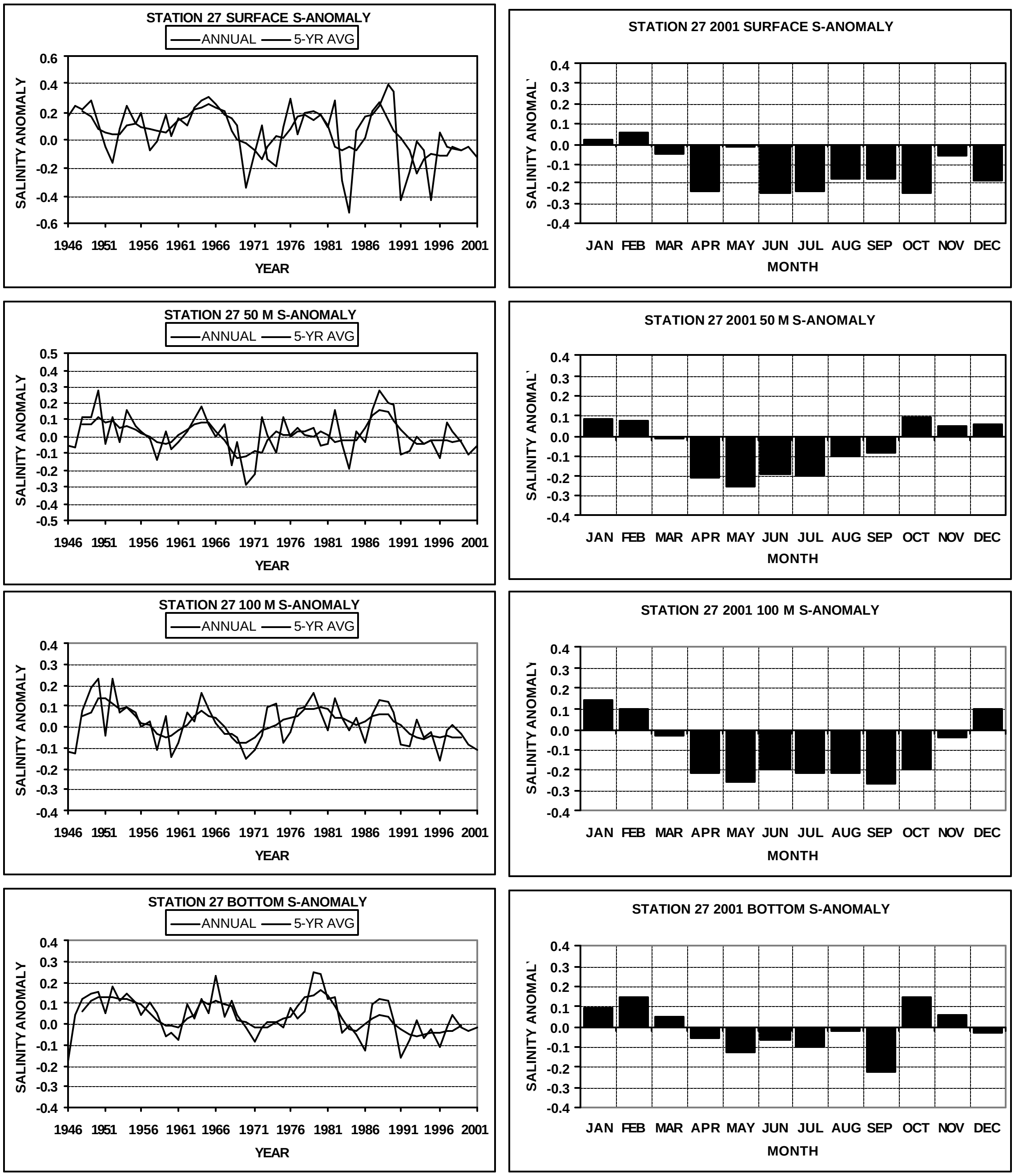


Fig. 4. Station 27 annual salinity anomalies and their 5-year running means at selected depths (left panels) and monthly salinity anomalies (right panels) for 2001.

STATION 27 WATER COLUMN AVERAGES

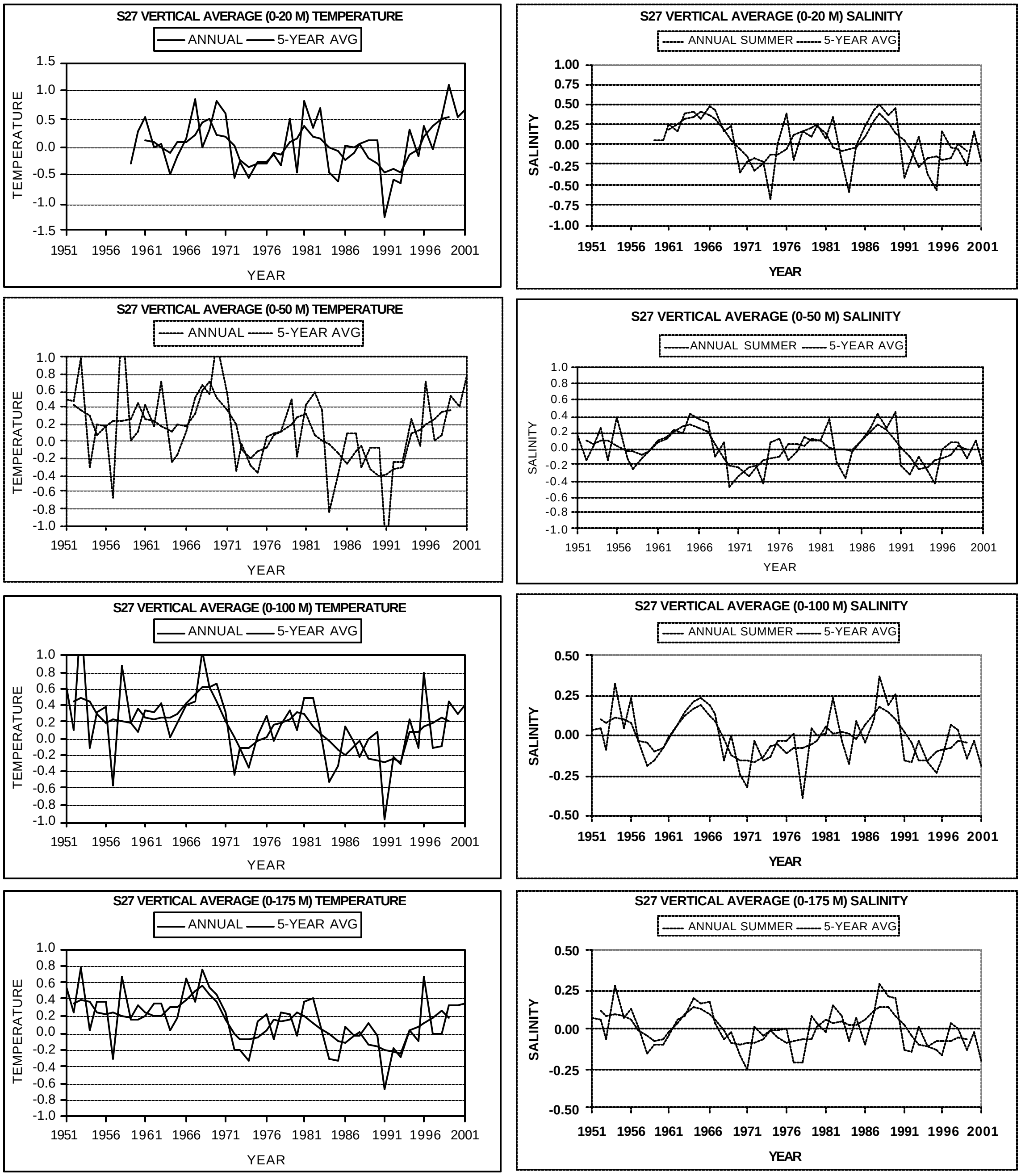


Fig. 5. Vertical averages over selected depth ranges of Station 27 temperature anomalies (left panels) and summer salinity anomalies (right panels). The heavy lines are the 5-year running means.

FLEMISH CAP TEMPERATURE AND SALINITY ANOMALIES

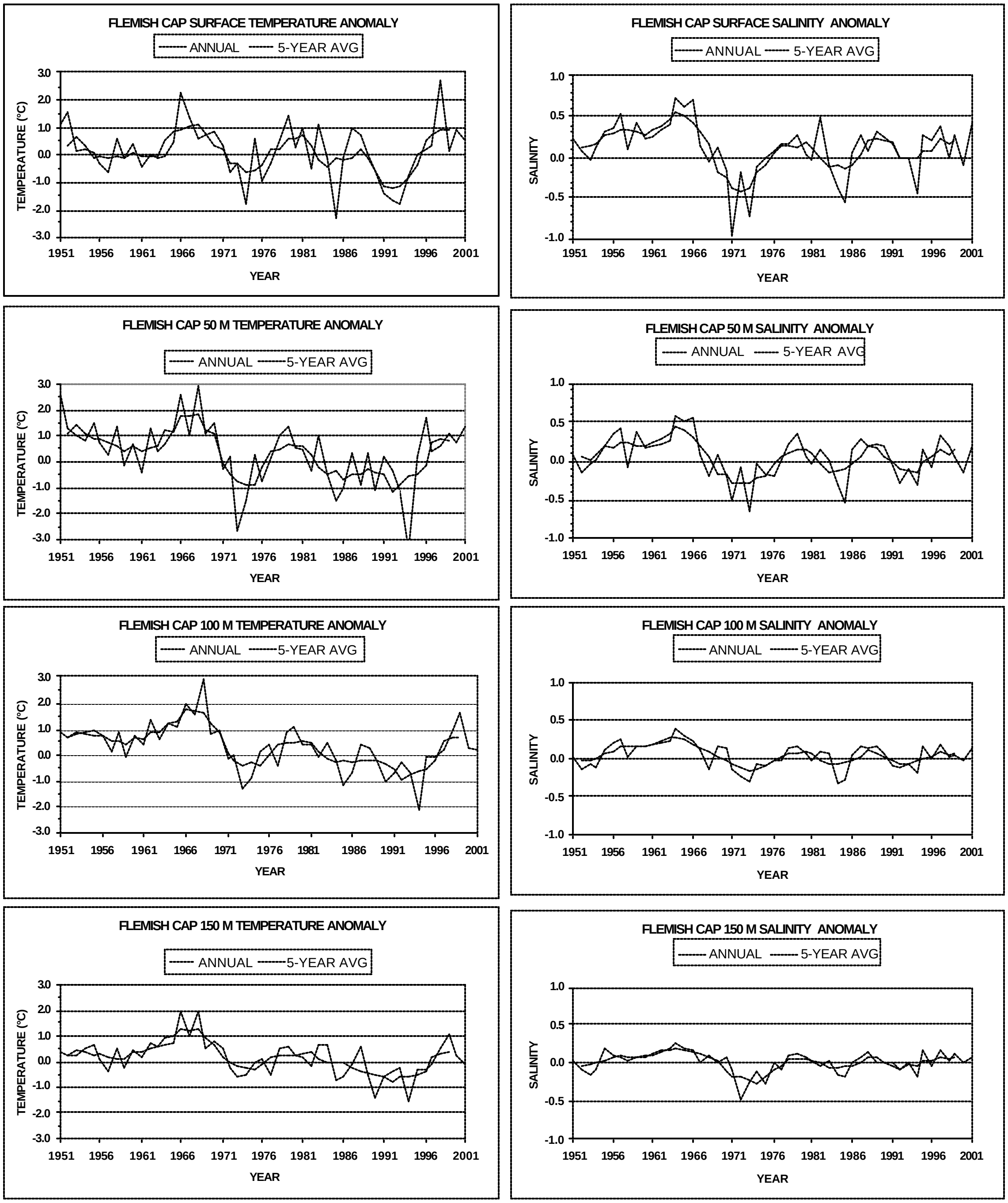


Fig. 6. Annual temperature (left panels) and salinity anomalies (right panels) on the Flemish Cap in NAFO Division 3M (within the box shown in Fig. 1a) at selected water depths. The heavy lines are the 5-year running means.

HAMILTON BANK TEMPERATURE AND SALINITY ANOMALIES

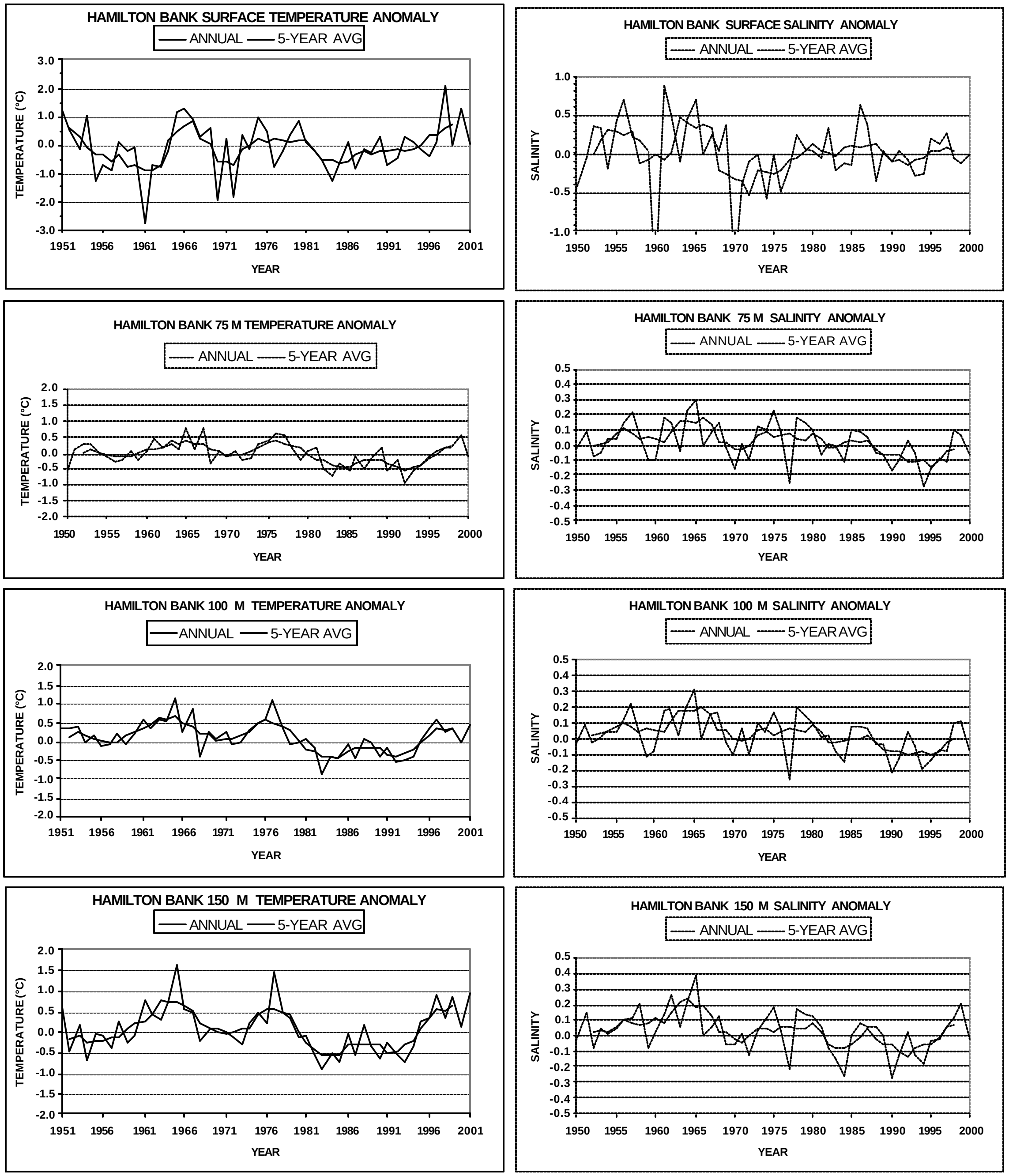


Fig. 7. Annual temperature (left panels) and salinity anomalies (right panels) on Hamilton Bank in NAFO Division 2J (within the box shown in Fig. 1a) at selected water depths. The heavy lines are the 5-year running means.

FLEMISH CAP TRANSECT (SUMMER 2001)

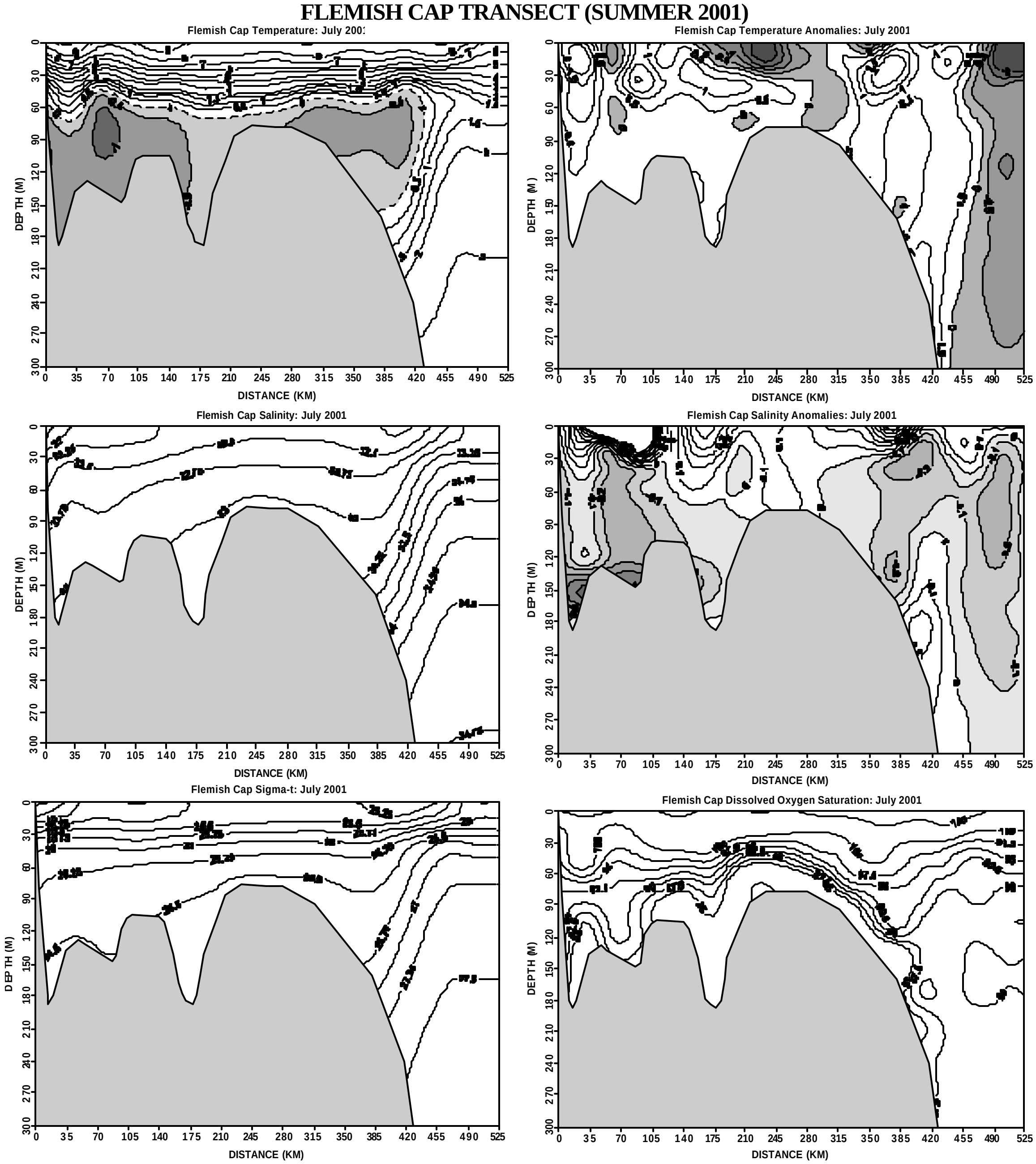


Fig. 8. Contours of temperature and salinity and their anomalies, sigma-t and dissolved oxygen saturation along the standard Flemish Cap section during the summer of 2001.

BONAVISTA TRANSECT (SUMMER 2001)

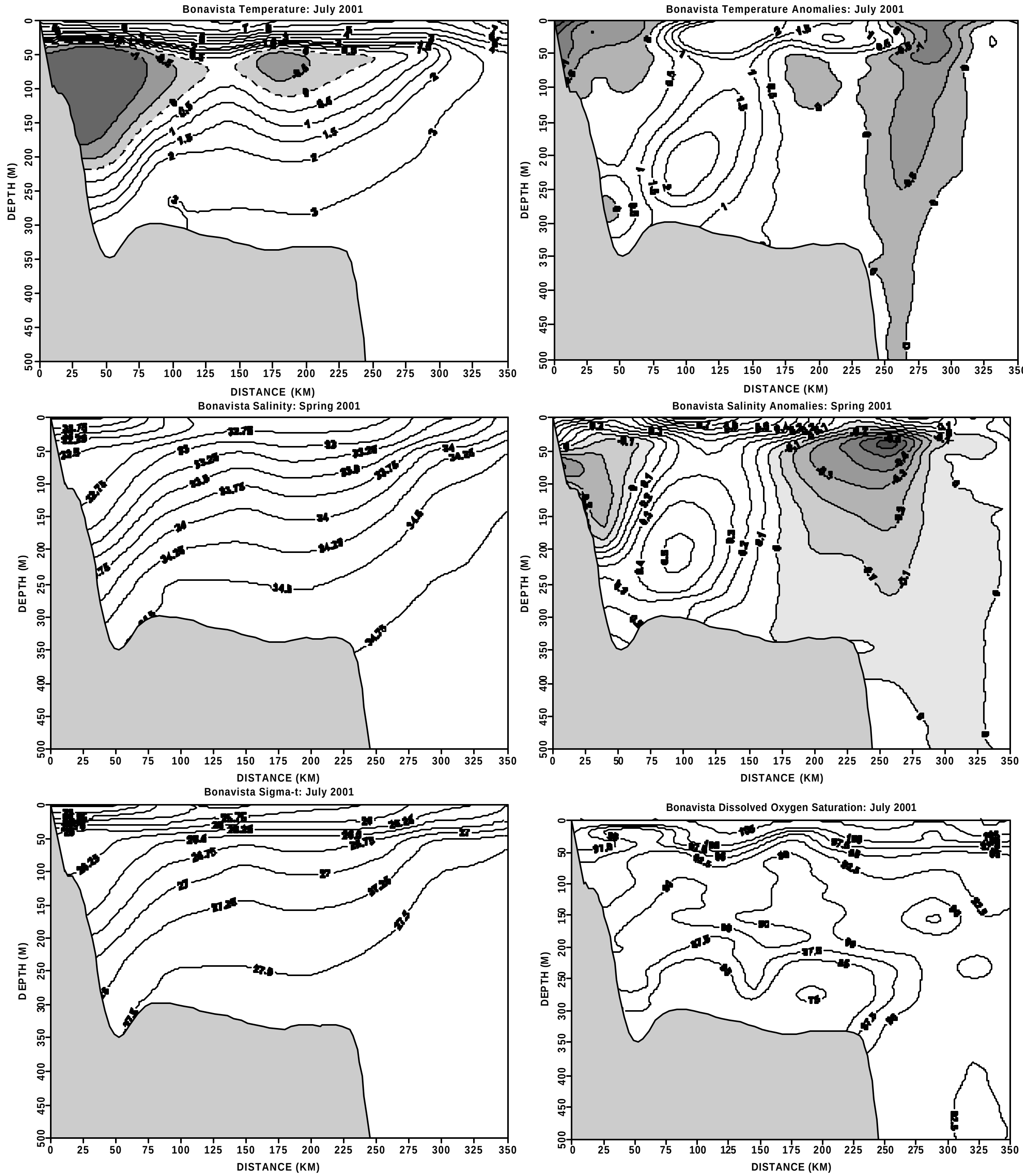


Fig. 9. Contours of temperature and salinity and their anomalies, sigma-t and dissolved oxygen saturation along the standard Bonavista section during the summer of 2001.

WHITE BAY TRANSECT (SUMMER 2001)

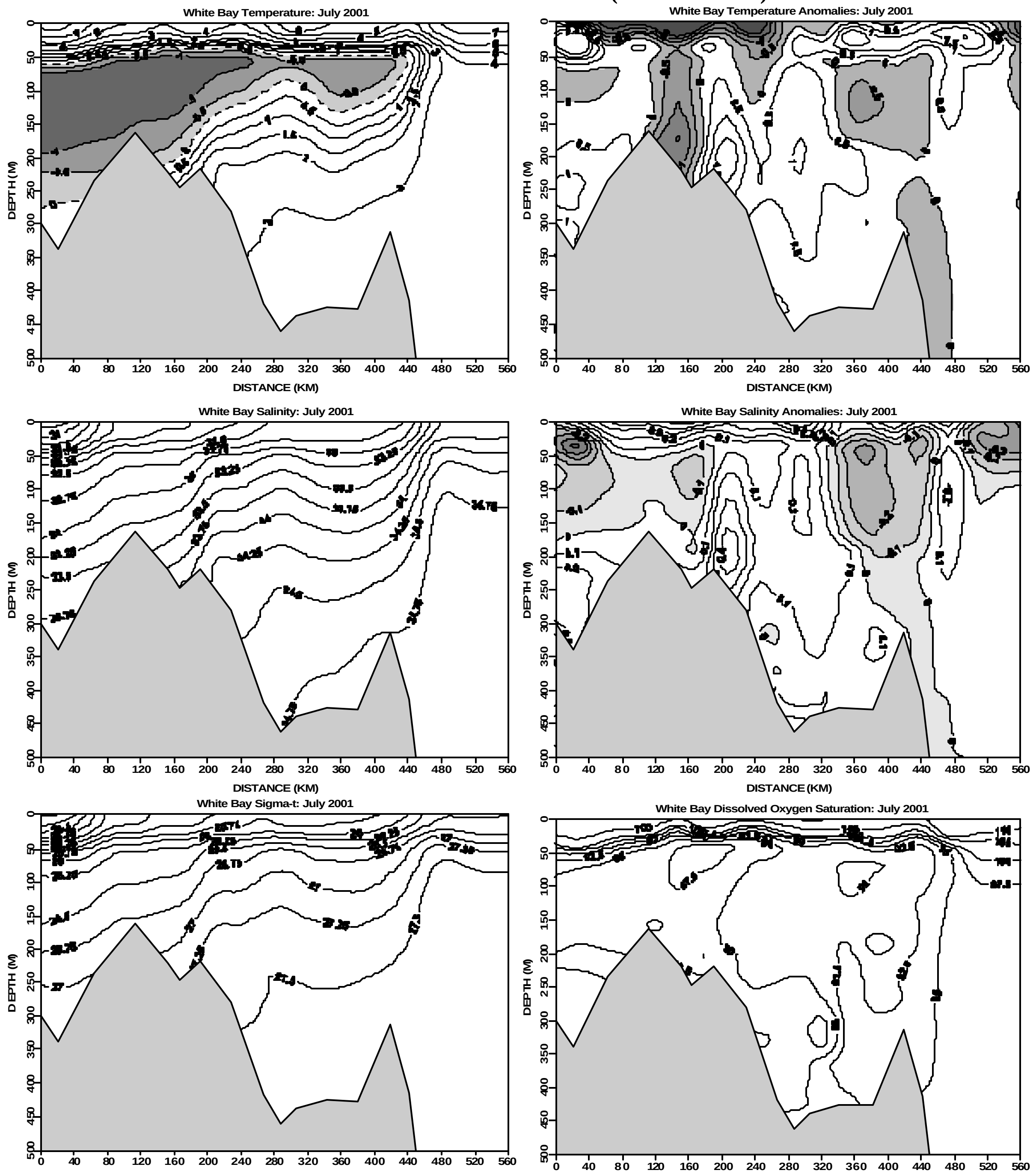


Fig. 10. Contours of temperature and salinity and their anomalies, sigma-t and dissolved oxygen saturation along the standard White Bay section during the summer of 2001.

SEAL ISLAND TRANSECT (SUMMER 2001)

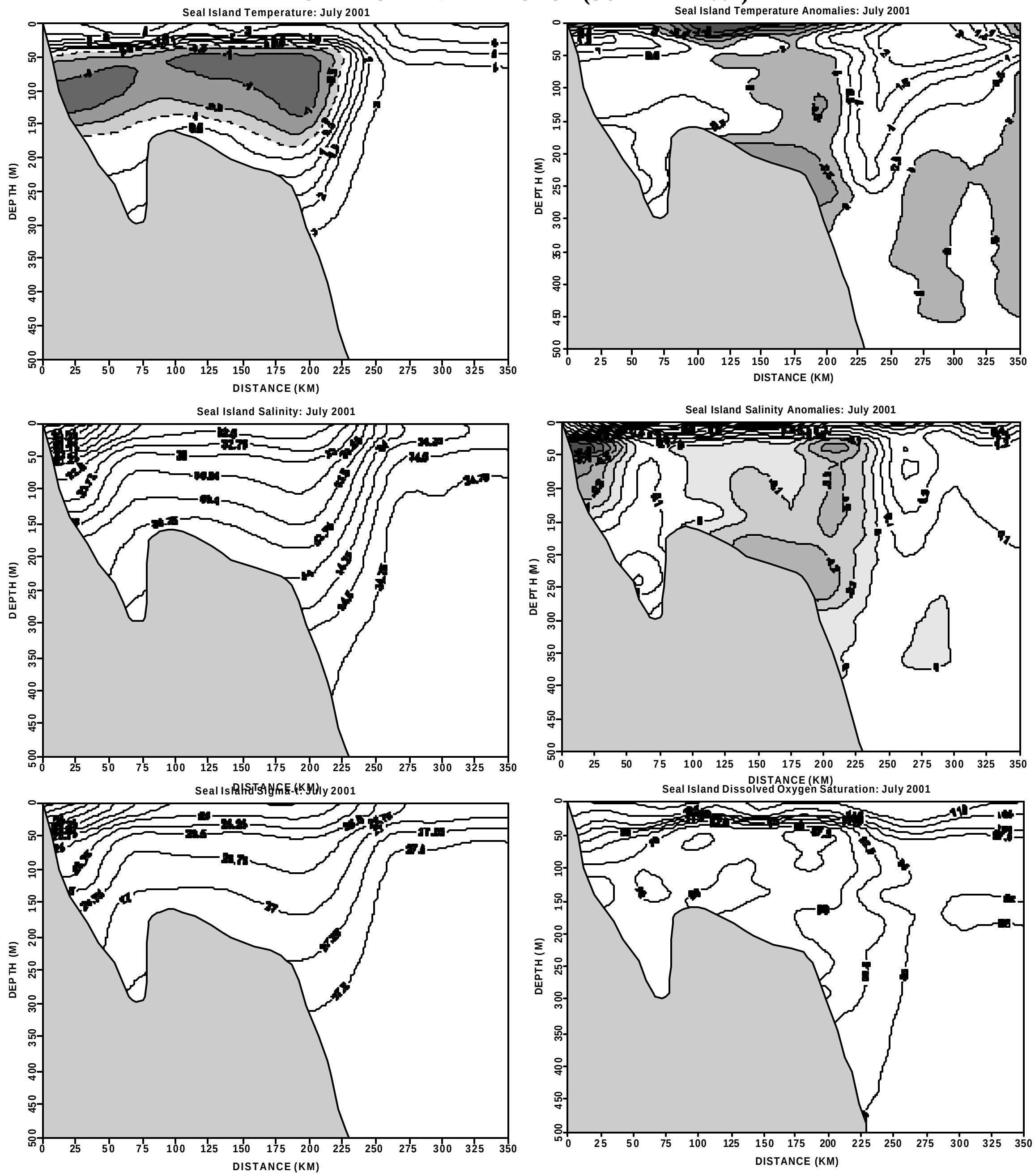


Fig. 11. Contours of temperature and salinity and their anomalies, sigma-t and dissolved oxygen saturation along the standard Seal Island section during the summer of 2001.

MAKKOVIK BANK TRANSECT (SUMMER 2001)

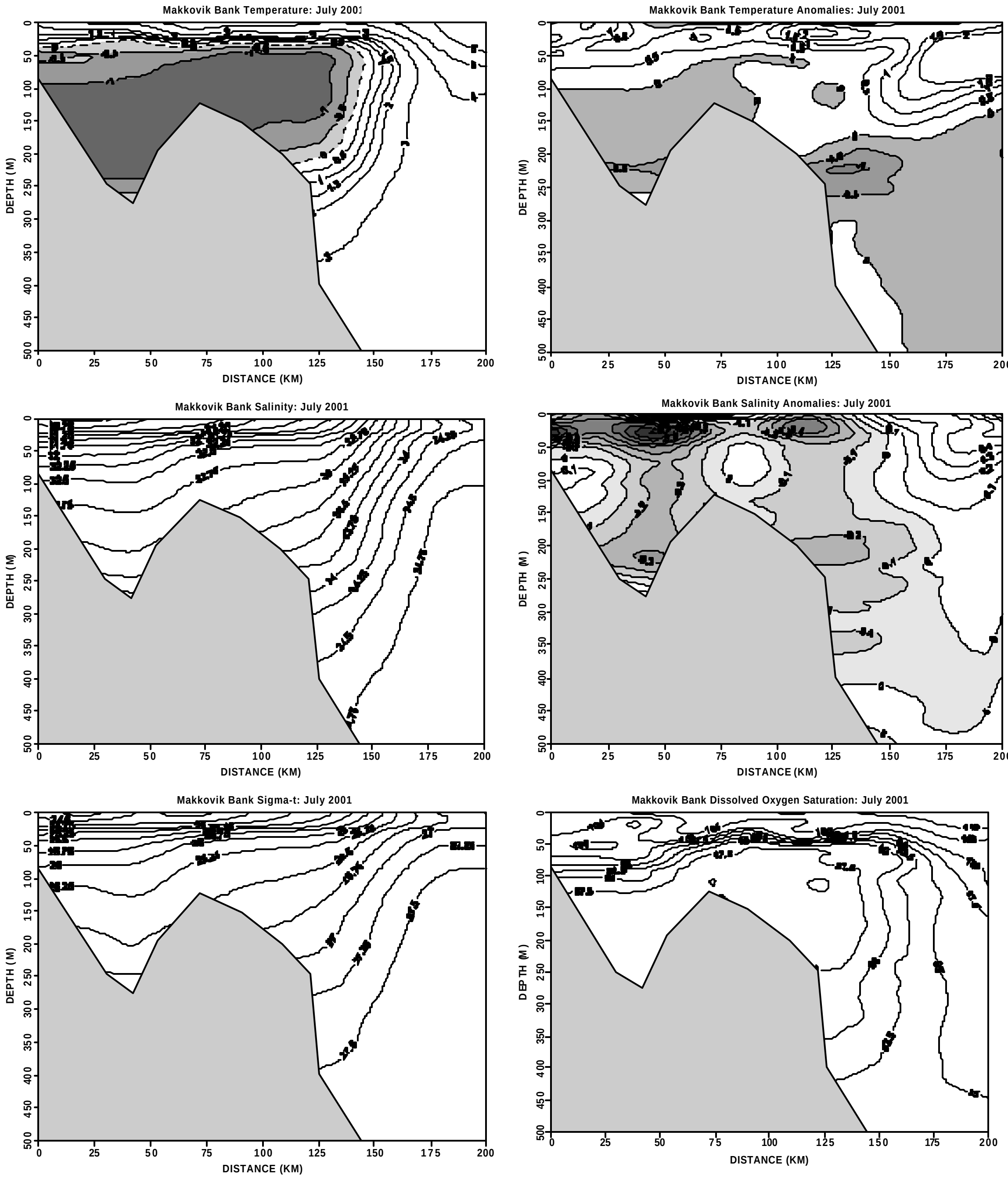


Fig. 12. Contours of temperature and salinity and their anomalies, sigma-t and dissolved oxygen saturation along the Makkovik Bank section during the summer of 2001.

NAIN BANK (BEACHY ISLAND) TRANSECT (SUMMER 2001)

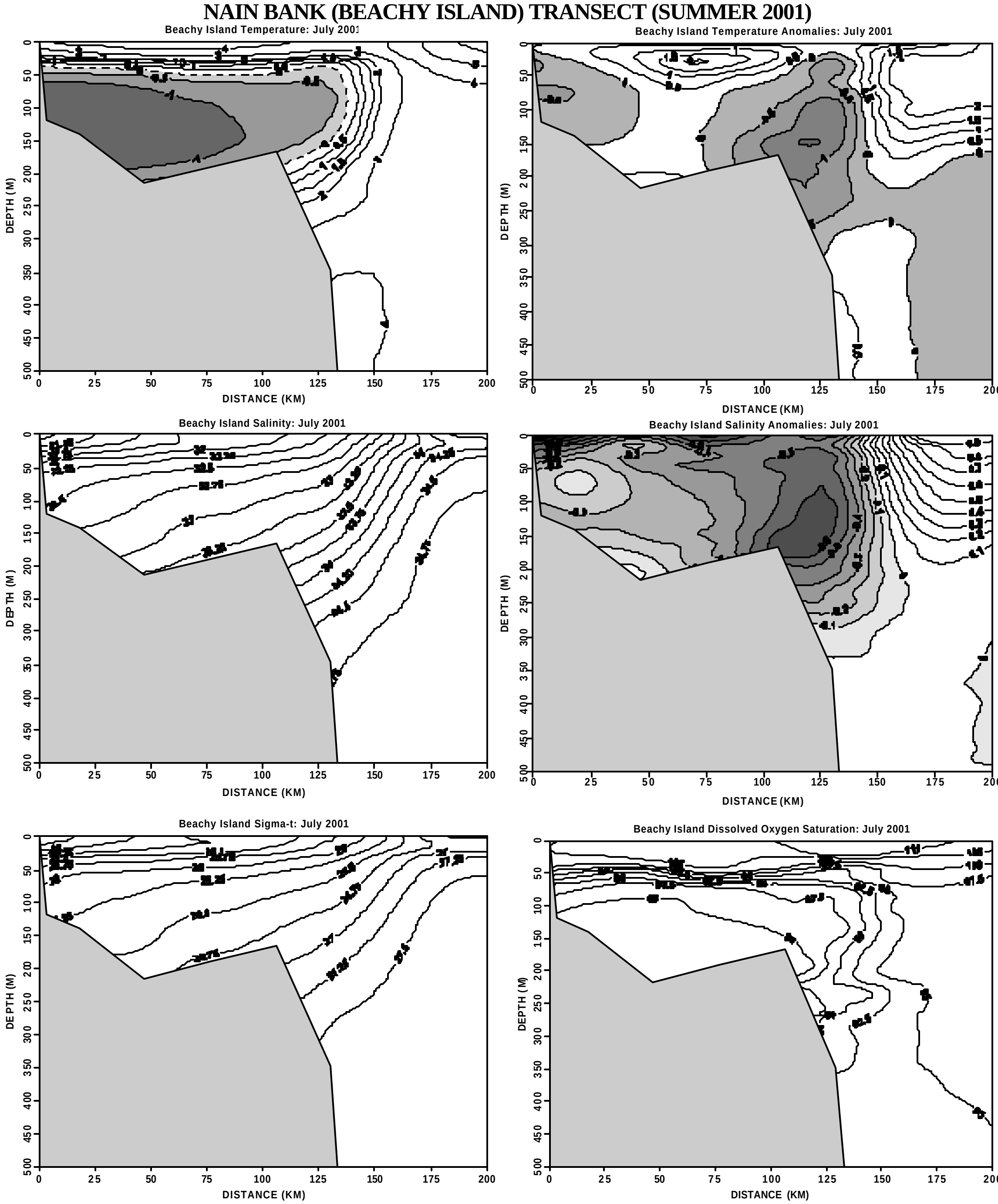


Fig. 13. Contours of temperature, salinity, sigma-t and dissolved oxygen saturation along the Standard Beachy Island section during the summer of 2001.

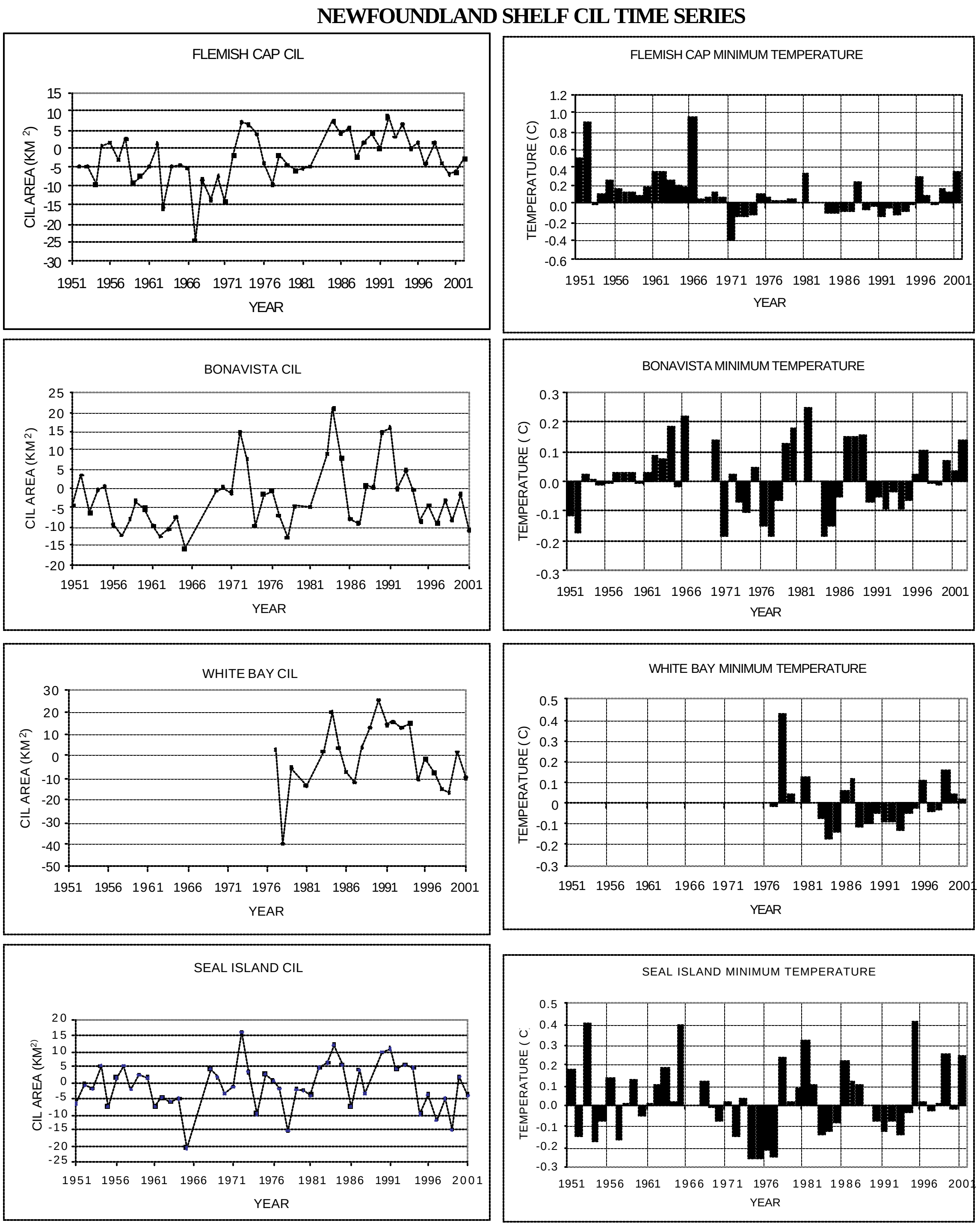


Fig. 14. Annual summer CIL cross-sectional area anomalies (left panels) and minimum temperature anomalies (right panels) along the Flemish Cap, Bonavista, White Bay and Seal Island transects. The anomalies are references to the 1971-2000 mean.

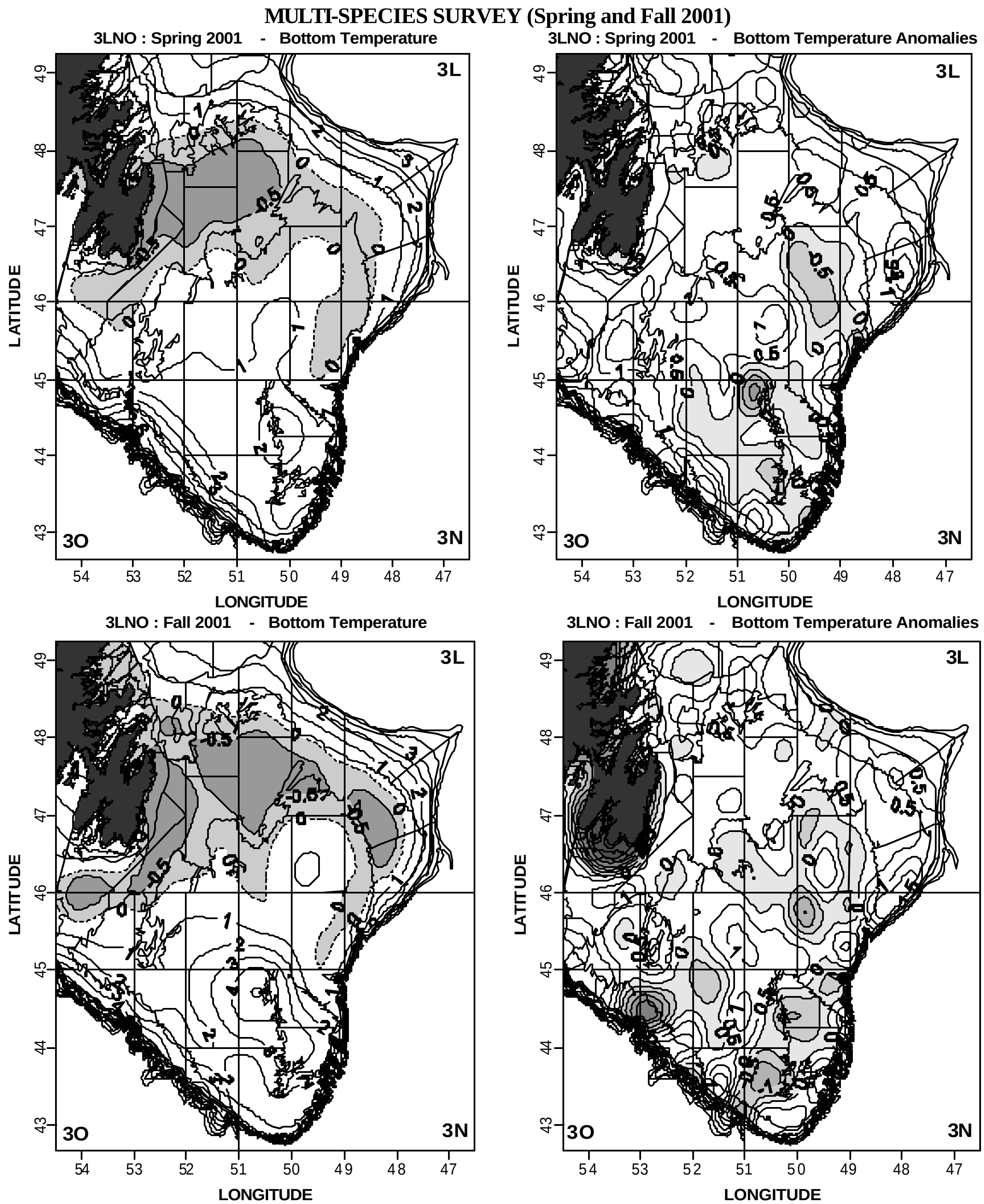


Fig. 15. Contours of bottom temperature and their anomalies (in °C) for the spring and fall of 2001 from the multi-species survey of NAFO Divs. 3LNO.

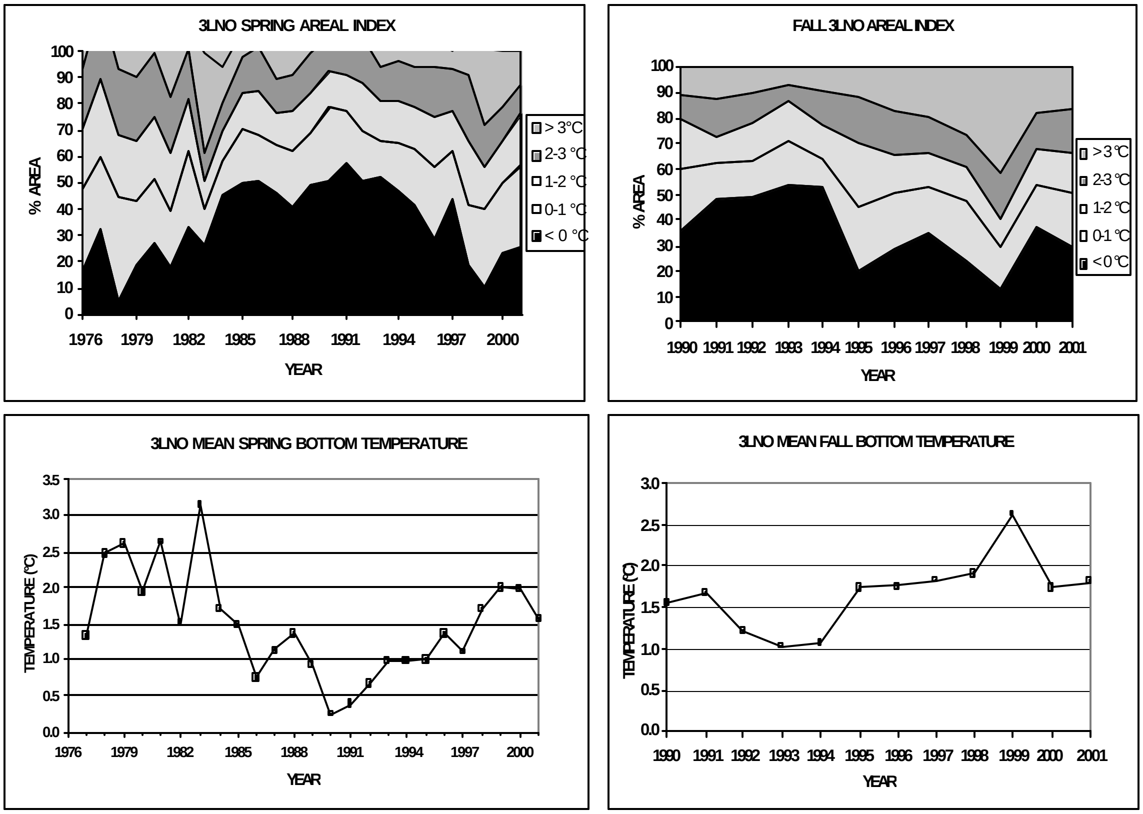


Fig. 16. Time series of the percentage area of the bottom in NAFO Divs. 3LNO covered by water with temperatures ≤ 0°C, 0-1°C, 1-2°C, 2-3°C and ≥3°C during spring and fall and the mean bottom temperature in °C (bottom panel).

MULTI-SPECIES SURVEY (FALL 2001)

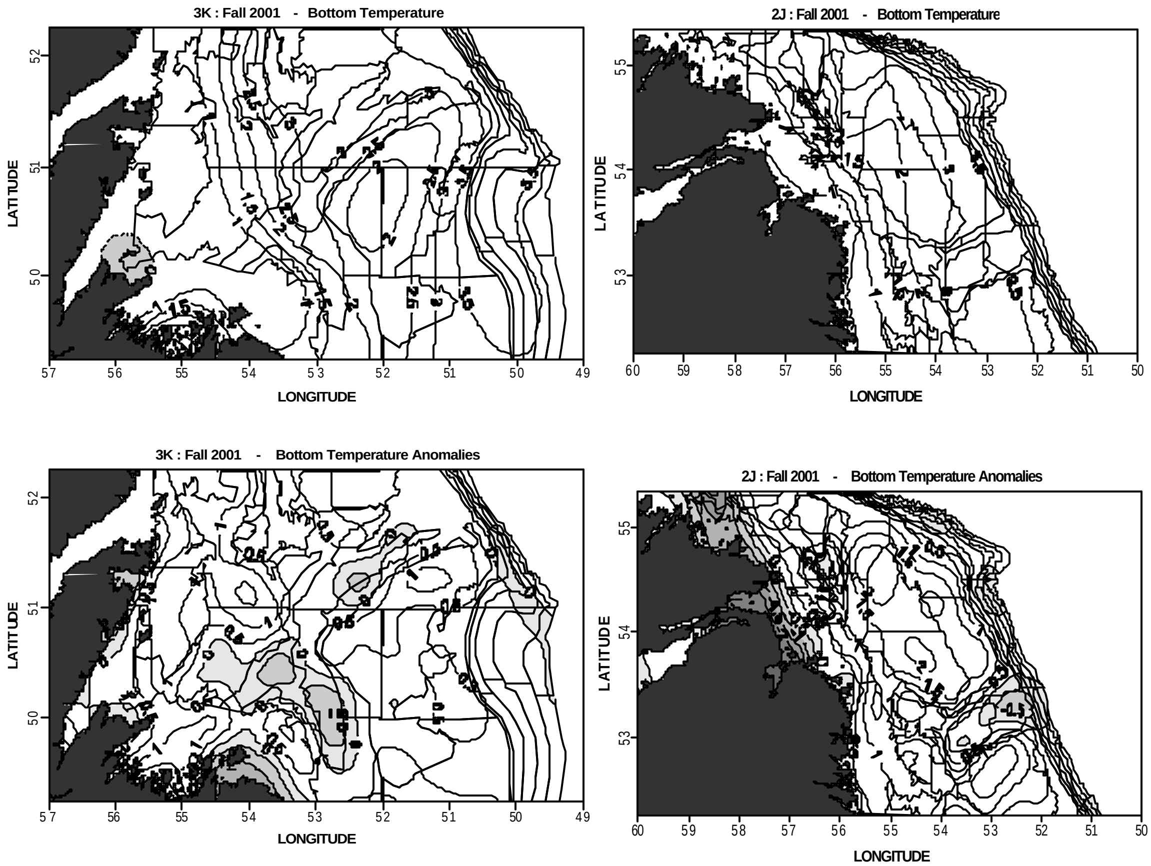


Fig. 17. Contours of bottom temperature and anomalies (in °C) for the fall of 2001, from the multi-species survey of NAFO Div. 3K and 2J.

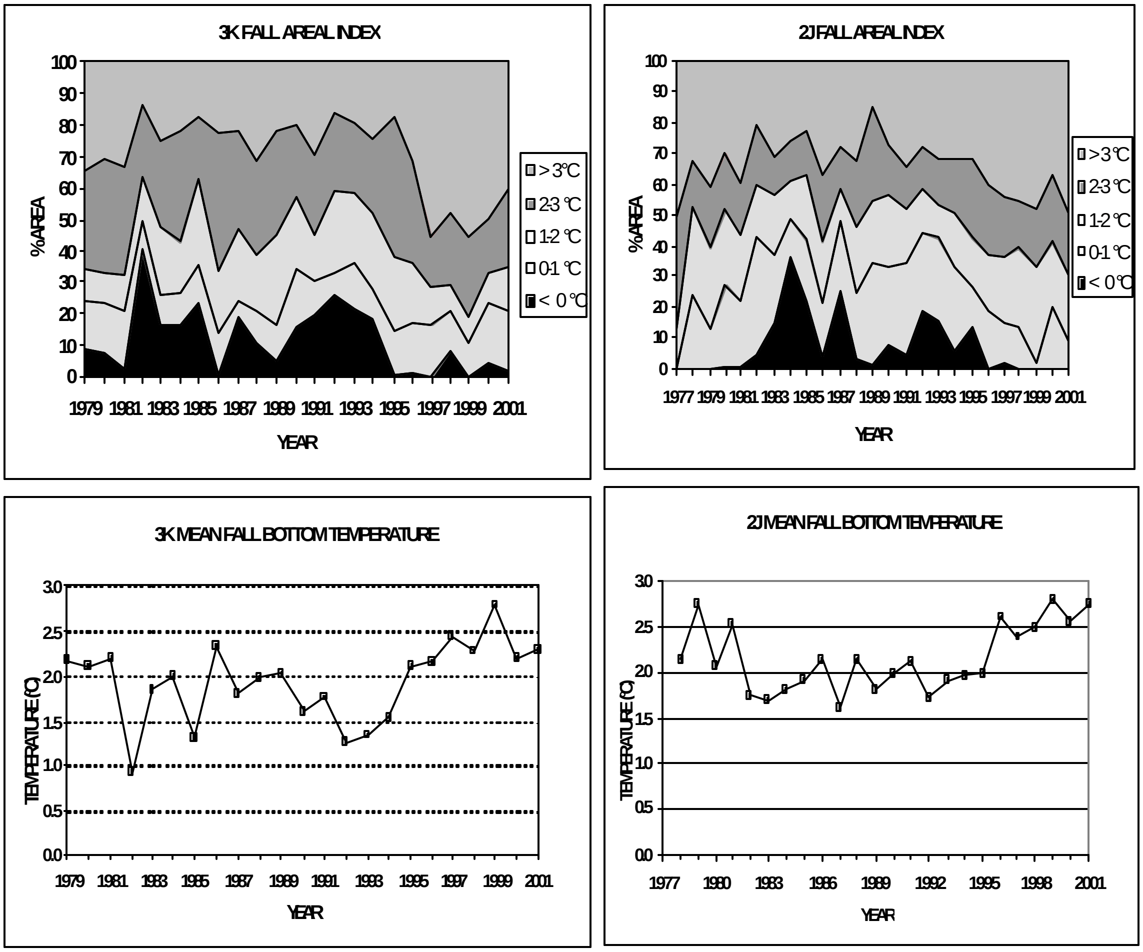


Fig. 18. Time series of the percentage area of the bottom in NAFO Div 3K and 2J covered by water with temperatures ≤ 0°C, 0-1°C, 1-2°C, 2-3°C and ≥3°C during the fall and the mean bottom temperature in °C (bottom panel).