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Physical Oceanographic Conditions in NAFO Subareas 2 and 3 on the Newfoundland and Labrador Shelf During 2002

by

E. B. Colbourne and C. Fitzpatrick

Department of Fisheries and Oceans, P. O. Box 5667
St. John's Newfoundland, Canada A1C 5X1

Abstract

Oceanographic observations in NAFO Sub-areas 2 and 3 during 2002 are presented referenced to their long-term (1971-2000) means. Water temperatures observed at Station 27 during 2002 decreased compared to 2001 values, but remained above the long-term mean over most depth ranges. Water salinity observed at Station 27 increased over 2001 values to above normal conditions and to the highest in about 12 years. The cross-sectional areas of <0°C (CIL) water 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 was very similar to 2001, below normal for the 8th consecutive year and among the lowest observed since 1978. Bottom temperatures on the Grand Banks during the spring of 2002 ranged from near normal to above normal (up to 0.5°C) over most areas. During the fall, bottom temperatures were generally above normal, except for the shallow waters of the southeast Grand Bank, where they were as low as 2°C below normal. Fall bottom temperatures in Div. 2J and 3K were above normal in most areas, up to 2°C on Hamilton Bank and up to 1°C on Funk Island Bank. 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. The below-normal trend in water temperatures, established in the late-1980s, reached a minimum in 1991 and continued below normal up to 1995. After 1995 temperatures began to moderate and by 1996 were above normal in many areas. During the latter part of the 1990s temperatures continued to increase reaching a maximum in 1999 and have continued above normal up to 2002. Water salinities on the Newfoundland Shelf also reached near-record lows in the early-1990s, remained below normal throughout most of the 1990s and up to 2001. During 2002 however, there was a significant increase with surface salinities the highest observed in over a decade.

Introduction

This manuscript presents an overview of physical oceanographic conditions in the Newfoundland and Labrador Regions during 2002, with a comparison to long-term average conditions based on historical data. Where possible the long-term averages were standardised to a base period from 1971-2000 in accordance with the recommendations of the World Meteorological Organization. Most of the time series presented had good temporal coverage between the years 1971-2000. The information presented for 2002 is derived from the following sources; (1) observations made at Station 27 throughout the year from all research and assessment surveys, (2) measurements made along standard NAFO cross-shelf sections during an annual summer oceanographic survey (Fig. 1), and (3) oceanographic observations made during the spring and fall multi-species research vessel surveys (Fig. 2). Data from other sources are also used to help define the long-term means and conditions during 2002.

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 Centre (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 these surveys collected temperature data 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 only on a few monthly estimates for the year. Caution therefore should be used when interpreting short time scale features of these series. The long-term trends however, 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. A potential source of error in this analysis is the 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 (NAFO Division 3L)

Station 27, located in the Avalon Channel off St. John’s (Fig. 1), was sampled a total of 55 times (49 CTD profiles, 6 XBT profiles) during 2002. The data from this time series are presented in several ways to highlight seasonal and interannual variations over various parts of the water column. 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. Surface layer temperatures ranged from about –1° to 0°C from January to late-April, after which the surface warming commenced. By mid-May upper layer temperatures had warmed to 2°C and to >12°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 0.25° to 0.5°C above normal for the winter months over most of the water column. Temperatures at depths from 25-75 m were below normal from July to August and from September to December a significant upper layer negative temperature anomaly developed which reached to 100 m depth by the end of the year. These values reached 1°C below normal in November and December. Bottom temperatures ranged from 0° to 0.5°C above normal from January to December (Fig. 3). Surface salinities reached their highest values >32.2 by mid-February and decreased to their lowest values <31.2 by September. These values were generally above normal throughout the year in the upper water column, reaching a maximum of about 0.4 above normal during the summer months. In the depth range from 50-100 m, salinities generally ranged from 32.2 to 32.8 and near bottom they varied throughout the year between 32.8 and 33.2. These bottom values were near normal during most of 2002 (Fig. 3).

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. 4 and 5). At the surface negative temperature anomalies reached a minimum in the early-1990s, began to moderate to near-normal conditions by the summer of 1994 and have continued at normal to above normal up to 2002. Near bottom at 175-m depth, 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 2002 have remained above the long-term average, however, during 2002 they decreased over 2001 values. Annually, surface temperatures were about normal during 2002, while at the bottom they were either normal or above normal in 8 months of 2002 (Fig. 4, right panels).

The depth averaged (0-175 m) annual temperature anomaly time series at Station 27 is displayed in the bottom panels of Fig. 4. The temperature time series shows large amplitude fluctuations 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 2002 the depth averaged temperature remained slightly above normal ($0.2^{o}C$) but decreased over 2001.

Near-surface salinity anomalies (Fig. 5) show 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 (Colbourne *et al*., 1994; Drinkwater, 1996). During the past several years (up to 2001) however, salinities have remained below normal during a time period of warm air temperatures and lower than normal ice conditions. During 2002 surface salinities were either normal to above normal for 11 of 12 months. Near-bottom however, they were slightly below normal for 6 of 12 months of 2002 (Fig. 5, right panels).

The depth averaged (0-50 m) salinity time series (Fig. 5, bottom panels) of the July-September values show similar variability 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 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). The spatial extent of the anomaly however, was mainly restricted to the inner Newfoundland Shelf. From 1996 to 2001 summer salinities varied considerably from about normal to below normal. During 2002 salinities increased over 2001 values and were the highest in about 12 years in the upper water column.

Flemish Cap (Division 3M)

Temperature anomalies on the Flemish Cap (Fig. 6) are also characterised 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. Surface temperatures during 2002 decreased to below normal values, while values at deeper levels were similar to 2001, generally above normal. It should be noted that the annual estimate for 2002 was based on only three observations.

The time series of salinity anomalies on the Flemish Cap (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 2002 were greater than those observed during 2000 and 2001 over all depth ranges, reaching 0.5 above normal at the surface.

Hamilton Bank (Division 2J)

Time series of temperature and salinity anomalies from 1951 to 2002 on Hamilton Bank are shown in Fig. 7 at selected depths. The annual values show a high degree of variability, which may in part be due to the different station locations between years coupled with the spatial variability of the hydrographic properties over the bank at the same depth level. It should also be noted that these annual 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 characterised by amplitudes ranging from near ±2^{o}C and with periods ranging from 2 to 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. Temperatures during 2002 were very similar to 2001 values, about normal at the surface and generally above normal at the deeper levels. The salinity time series, while very noisy, show similar trends as elsewhere on the shelf with fresher-than-normal conditions particularly in the early-1970s at the surface, and to some extent during the early-1990s. Salinities from 1995-2002 varied about the long-term mean with near-normal values during 2002, except at 150 m where they were above normal.

Standard Sections

In 1976 the International Commission for the Northwest Atlantic Fisheries (ICNAF) adopted a suite of standard oceanographic monitoring stations along sections 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. 1). The sections with the longest historical record include, the Seal Island section on the southern Labrador coast and Hamilton Bank, the Bonavista section off the east coast of Newfoundland and the Flemish Cap section which crosses the Grand Bank at 47°N and continues eastward across the Flemish Cap. The temperature and salinity data along these sections for the summer of 2002 are presented. The anomalies are referenced to the 1971-2000 historical data sets.

Flemish Cap (47^o N)

Near surface temperatures along the Flemish Cap section during the summer of 2002 ranged from 7^o-8^{o}C while <0^{o}C temperatures were generally found 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 (Fig. 8). Temperatures were generally above normal over most areas along this section during the summer except for isolated areas near the surface and in the deeper waters of the Flemish Pass. Salinities along the section on the Grand Bank are characterised by generally fresh conditions on the bank (<33), a strong horizontal gradient at the shelf break separating the saltier (>34.5) slope water offshore in the Flemish Pass. Salinity anomalies during 2002 were higher than average in the upper layers and near normal below 50-m depth (Fig. 9).

Bonavista

The dominant water mass feature along this section during the summer months is the cold intermediate layer of <0^{o}C water (CIL) which develops during early spring after intense winter cooling. Temperatures along the Bonavista section during the summer of 2002 in the upper water column ranged from 7-8^{o}C. These values were generally above normal (up to 2^{o}C) in the offshore areas and below normal inshore. The offshore area of the Labrador Current appeared warmer-than-normal as did the near bottom areas across most of the eastern Newfoundland Shelf. Intermediate depth (50-200 m) waters corresponding to the CIL were colder than normal (Fig. 8). Salinities along the Bonavista section generally ranged from <32.5 near the surface in the inshore region to >34 in the offshore region (Fig. 9). Bottom salinities ranged from 32.5 in the inshore regions, to 34.75 at about 325-m depth near the shelf edge.

Salinities were similar to those observed along the Flemish Cap section, generally above normal with the magnitude of the anomalies decreasing with depth. In general, salinities along the Bonavista section increased over values observed in 2001.

Seal Island

The Seal Island section, which crosses Hamilton Bank on the southern Labrador Shelf, was also sampled in July of 2002 (Fig. 8). Upper layer temperatures across the shelf in this region ranged from –0.5°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 water mass, except near bottom where they ranged from 0°-1°C due to the influence of warmer slope water. Near the shelf break in the Labrador slope water, bottom temperatures increase to 2°-3°C. Temperature anomalies in the surface layer were as low as 1°-2°C below normal over most of the shelf, but were up to 2°C above normal offshore off the shelf break. In water generally associated with the CIL, temperatures were above normal by up to 1°C over most of the shelf. 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, water salinities were saltier-than-normal in most areas over the shelf. Offshore of the shelf break, salinities were near normal at depth and above normal in the upper water column (Fig. 9).

Cold Intermediate Layer (CIL) Time Series

As discussed above with reference to the cross-shelf contour plots, 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 trapped 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 extent of this winter chilled water mass is evident in the section plots of the temperature contours. For example, along the Seal Island section (Fig. 8) the CIL extends offshore to >200 km, with a maximum vertical extent of approximately 150 m. This corresponds to a cross-sectional area of around 25 km^2. The annual summer CIL cross-sectional area anomalies defined by the 0°C contour for the Flemish Cap, Bonavista and Seal Island sections are displayed in Fig. 10. Along the Flemish Cap section during the summer of 2002 the CIL area was below the 1971-2000 normal, similar to conditions observed during the past 4-years but a slight decrease over 2001. Along the Bonavista section the CIL area was similar to that of 2001. It was among the lowest values observed since 1978, continuing the trend of below normal values observed since 1994. Similarly, along the Seal Island section the area of <0°C water decreased over 2001, continuing the below normal trend establish during the mid-1990s. This is in contrast to the near record high values measured during the early-1990s, which was an extremely cold time period on the Newfoundland Shelf.

Multi-Species Survey Results

Canada has been conducting stratified random bottom trawl surveys in NAFO Sub-areas 2 and 3 since 1971. 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 2002, in water depths down to 366 m until 1979 and to 548 m since then; 3L in spring from 1971-2002, except 1983 and 1984; 3NO in spring from 1971-2002, 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 1977-2002; 3K in fall from 1978-2002; 3L in fall from 1981-2002, 3NO in fall from 1990-2002. 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 Bank 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 surveys. Inter-annual 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 temperature dependent near-bottom habitats for various species of marine organisms.

Spatial Temperature Maps

Bottom temperatures during the spring of 2002 in NAFO Subarea 3P ranged from 5-6°C in the Laurentian, Burgeo and Hermitage Channels to about 3° to 5°C on Rose Blanche and Burgeo Banks. On St. Pierre Bank bottom temperatures ranged from 0°C on the eastern side to 2° to 4°C on the western side. In general, 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 2002, bottom temperatures were above average over Burgeo and Rose Blanche banks, while Hermitage Channel bottom temperatures were mostly below normal. Bottom temperatures anomalies over most of St. Pierre Bank varied considerably, being mostly below normal around the edges of the bank to above normal over the central portions of the bank (Fig. 11). In general, bottom temperatures in this area increased marginally over values observed during the spring of 2001.

Bottom temperature maps and their anomalies for NAFO Div. 3LNO during the spring and fall of 2002 are displayed in Fig. 12. In the northern areas of the Grand Bank 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°C to 2°C on the Southeast Shoal and to 4°-5°C along the slopes of the Grand Bank in Div. 3O. During the spring of 2002 <0°C water was mainly restricted to Div. 3L, with normal to above-normal temperatures over most areas. 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°-3°C during 2002 on the Southeast Shoal and to >3°C along the edge of the Grand Bank. During the fall of 2002 bottom temperatures over the surveyed area were above normal on the northern Grand Bank and along the edge of the Grand Bank by up to 1.0°C. In southern regions, particularly the southeast shoal of the Grand Bank, bottom temperatures were up to 2°C below normal.

In NAFO Div. 3K water depths are generally >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 2002 ranged between 2°-3°C, which were about 0.5°-1°C above their long-term means. Near the edge of the continental shelf near normal temperatures at about 3.5°C were observed in water depths below 500 m (Fig. 13). Bottom temperatures and their anomalies for NAFO Div. 2J during the fall of 2002 are shown in Fig. 14. Bottom temperatures in this region during the fall of 2002 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 near normal along the edge of the shelf.

Bottom Temperature Time Series

The spatially averaged spring bottom temperature of the surveyed area in NAFO Div. 3P ranged between 2° - 4°C from 1970 to 1984 and decreased to between 2° - 2.5°C from 1985 to 1997. During 1999 and 2000, the average near-bottom temperature increased to >3°C but decreased to near 2.5°C in 2001. During the spring of 2002 the average bottom temperature increased slightly over the 2001 value to 2.6°C (Fig. 15, top panel). The average spring bottom temperature time series for the 3LNO region shows large inter-annual 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 and 2002, the average bottom temperature decreased over the 2000 value to about 1.5°C (Fig. 15, top panel).

During the fall the average bottom temperature for all strata in Div. 3LNO decreased from approximately 1.5°C during 1990 to 1°C during 1993 and 1994, and 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 (Fig. 15, bottom panel). During the fall of 2000 to 2002 the mean bottom temperature decreased by nearly 1°C over the 1999 value, but was still above the cold condition of the early-1990s. The average bottom temperature in Div. 3K (Fig. 15, 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 to 1999 they increased to above-average values reaching about 2.7°C during 1999. During the fall of 2000 to 2002 bottom temperatures were lower than in 1999, but remained relatively warm between 2.2°-2.4°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^{o}C. During 2001 and 2002 mean bottom temperatures continued warm at >2.5^{o}C (Fig. 15 bottom panel).

Spring Thermal Habitat Index

The areal extent of the bottom covered by 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 for NAFO Div. 3P is displayed in the top panel of Fig. 16. Note the large increase in the percentage area of the bottom covered by <0^{o}C water in 1985 that persisted well into the mid-1990s. The percentage area covered by <0^{o}C water during the spring of 1998 decreased to pre-1985 levels and to less than 10% during 2000 but increased to >25% during 2001 and 2002. 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, with the exception of 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 between 50-60% but increased slightly again in 2002. During the spring of 1999 and 2000 <0^{o}C water had completely disappeared from the banks but re-appeared during 2001 and 2002, reaching near 30% coverage. The area of near-bottom water on the banks with temperatures >1^{o}C increased from about 50% in 1998 to near 85% during 2000, the first significant amount since 1984 (Colbourne, 2001).

The areal extent of the bottom covered by water in various temperature ranges during spring for the 3LNO region is displayed in the bottom panel of Fig. 16. In this region from 1975 to 1983 most of the bottom area was covered by water >0^{o}C with only approximately 20% covered by <0^{o}C water. From 1984 to 1997 there was a large increase in the area of <0^{o}C water with percentages reaching near 60% in some years. Since 1997 there was a significant decrease in the percentage area of the bottom covered by <0^{o}C water and a corresponding increase in the area covered by water ≥1^{o}C. During the spring of 1998 and 1999 water with temperatures >1^{o}C covered 50-60% of the bottom area on the Grand Bank. The 1998 and 1999 values represent the largest area of relatively warm water on the Grand Bank since the late-1970s. During 1999 the area of <0^{o}C water on the Grand Bank decreased to about 10%, the lowest since 1978. During 2000 the area of cold water began to increase reaching 30% by 2002.

Fall Thermal Habitat Index

The areal extent of the bottom covered by water in the selected temperature ranges during the fall for the 3LNO region is displayed in Fig. 17. In general, the percentage area of the bottom covered by <0^{o}C water decreased significantly during 1995 to roughly one-half the value during the first half of the 1990s. A corresponding increase in the areal extent of water ≥1^{o}C occurred during 1995. From 1995 to 1998 this remained relatively constant at about 50%, but increased to over 70% during 1999. During the fall of 2000 the area of <0^{o}C water remained below the values of the early-1990s but increased over 1999 values to near 40%. During 2002 the area of <0^{o}C water decreased slightly over 2000 and 2001.

The areal extent of the bottom covered by water in the selected temperature ranges during the fall for Div. 3K is displayed in Fig. 17. The percentage area of the bottom covered by <0^{o}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^{o}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 40-50% from 1997 to 2002. The areal extent of the bottom covered by water in the selected temperature ranges during the fall for Div. 2J is also displayed in Fig. 17. The percentage area of the bottom covered by <0^{o}C water in Div. 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%. In 2J for temperatures >3^{o}C the bottom area covered ranged from a low of 15% in 1992 to a maximum of near 50% during 2001 and 2002. Since 1996 the area of the bottom covered with <0^{o}C water decreased to <10%.

Summary

Annual water temperatures at Station 27 during 2002 decreased compared to 2001 values, but remained above the long-term mean over most depth ranges. The annual surface temperature at Station 27 was about normal during 2002, while the annual bottom temperature remained above normal by 0.2^{o}C. Surface salinities at Station 27 were above normal for 11 of 12 months, while bottom salinities were either near normal or slightly below normal. Salinities averaged over the entire water column however increased over 2001values to above normal and to the highest observed in about 12 years.

The cross-sectional area of <0^{o}C (CIL) water on the Newfoundland and Labrador Shelves during the summer of 2002 decreased over 2001 values along northern sections and along southern sections it remained very similar to 2001. The CIL areas were below normal from the Flemish Cap section on the Grand Bank to the Seal Island section off southern Labrador. Off eastern Newfoundland along the Bonavista section the CIL area was very similar to 2001, below normal for the eighth consecutive year. These values are among the lowest observed since 1978 on the eastern Newfoundland Shelf.

Bottom temperatures on the Grand Bank during the spring of 2002 ranged from near normal to above normal (up to 0.5^{o}C) over most areas. During the fall bottom temperatures were generally above normal except for the shallow waters of the southeast Grand Bank, where they were up to 2^{o}C below normal. Fall bottom temperatures in Div. 2J and 3K were also above normal, up to 2^{o}C on Hamilton Bank and up to 1^{o}C on Funk Island Bank. The spatially averaged bottom temperature during 2002 in all NAFO Divisions remained very similar to 2001 values, except in Div. 3K, where the mean bottom temperature increased slightly over 2001. 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 by 1995. During 1996 temperature conditions were above normal over most regions, however, summer salinity values continued to be slightly below the long-term average. 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. During 2000 to 2002 ocean temperatures were cooler than 1999 values, but remained above normal over most areas continuing the trend established in 1996. From 1997 to 2001 the trend in salinities on the Newfoundland Shelf was mostly below normal, however, during 2002 there was a significant increase with surface values the highest observed in over a decade.

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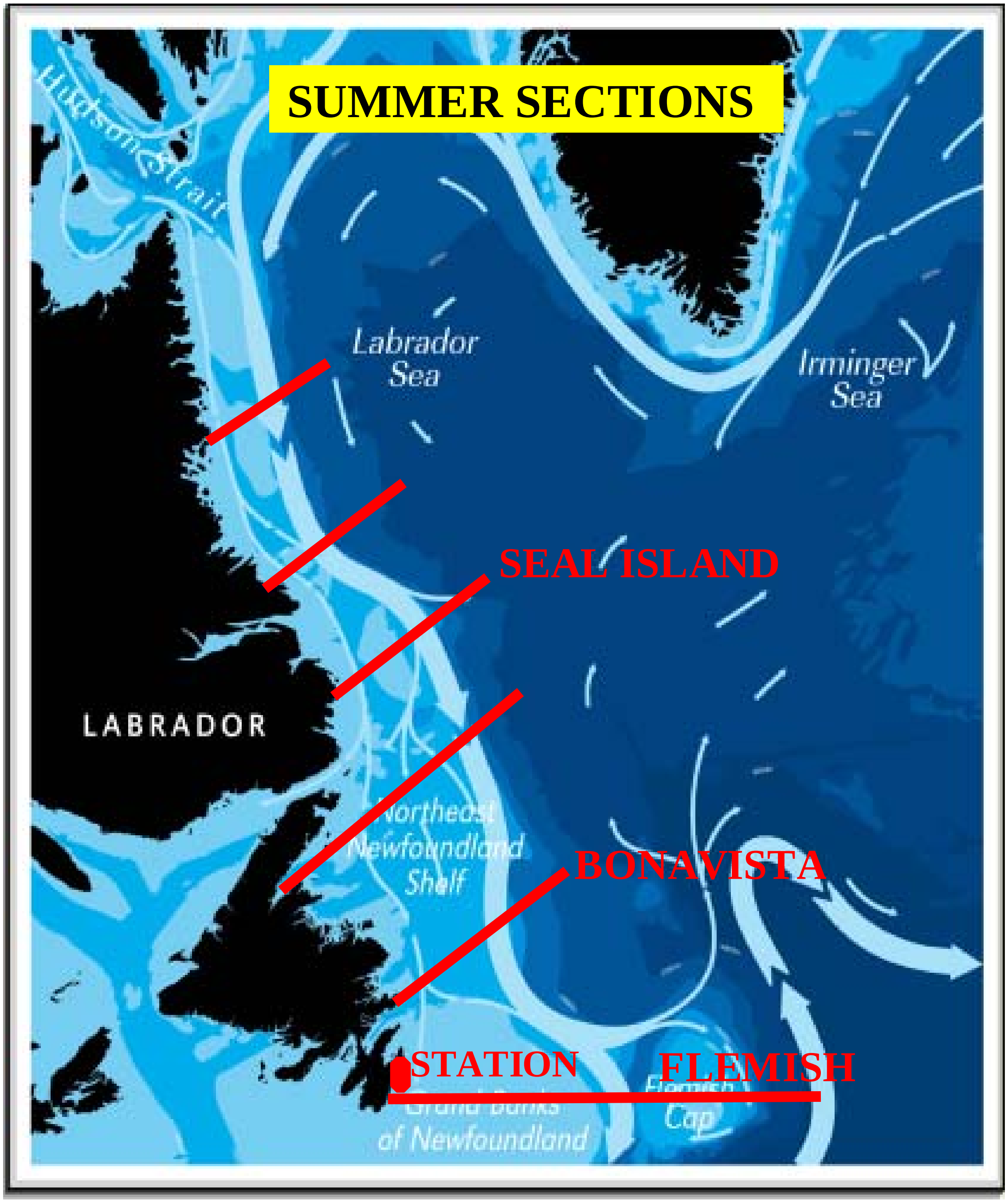
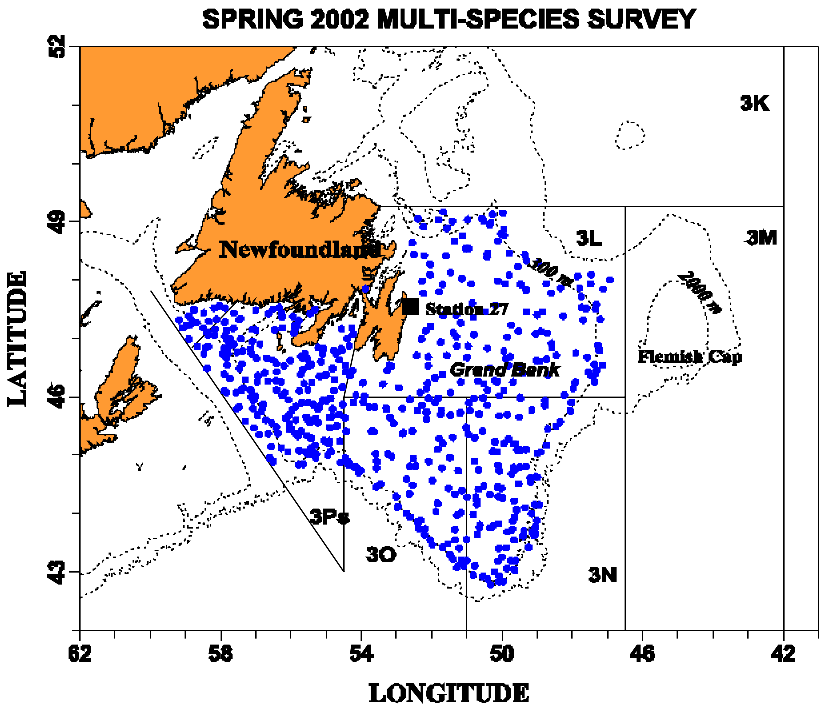


Fig. 1. Location map showing general circulation features of the Northwest Atlantic, the location of Station 27 and the standard monitoring sections on the Newfoundland and Labrador Shelf.



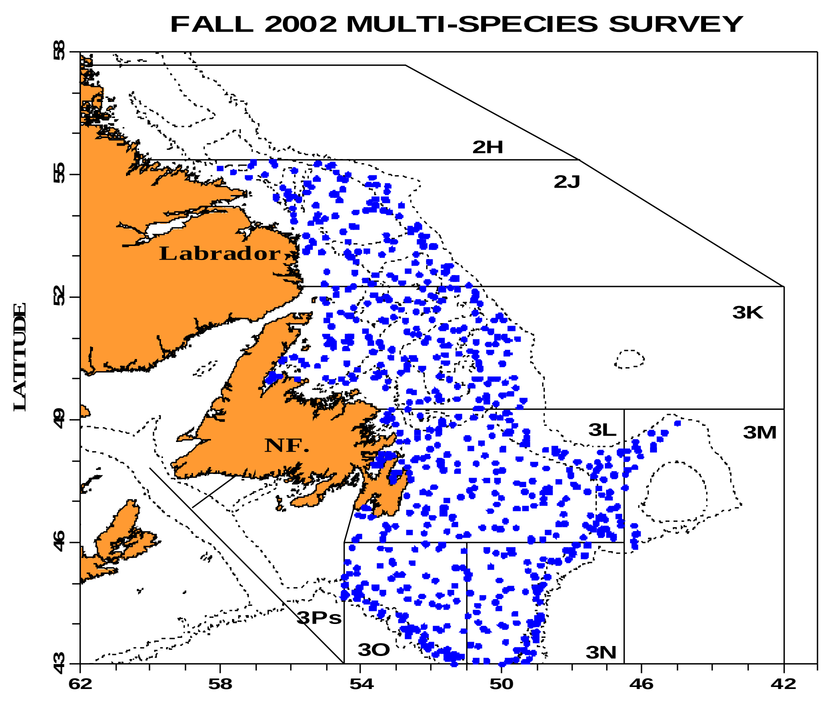


Fig. 2. Location maps showing the positions of sets with oceanographic data from the multi-species surveys during the spring and fall of 2002. Bathymetric contours are 300 and 1000 m

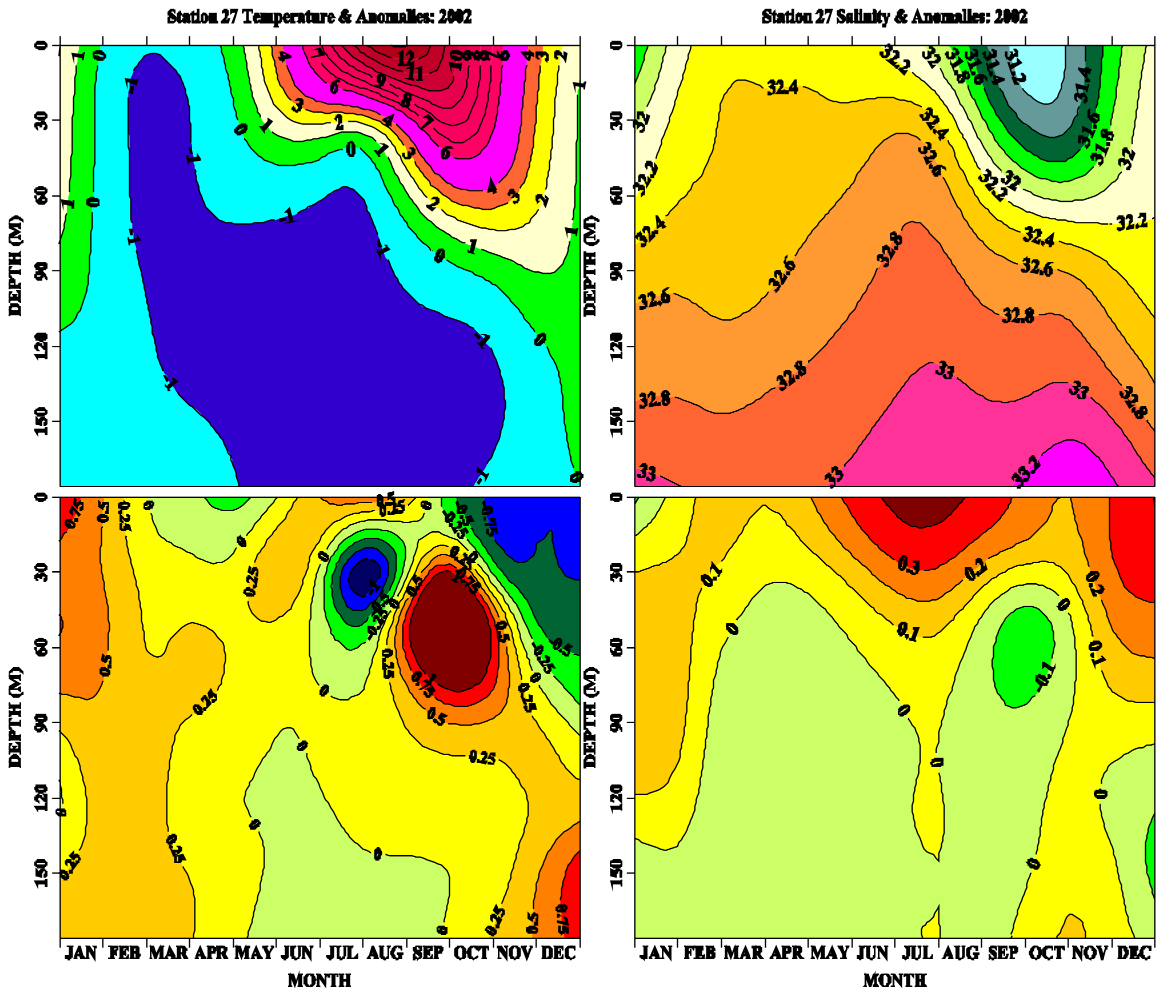


Fig. 3. Contours of the annual cycle of temperature and temperature anomalies (in °C) (left panels) and salinity and salinity anomalies (right panels) as a function of depth at Station 27 for 2002.

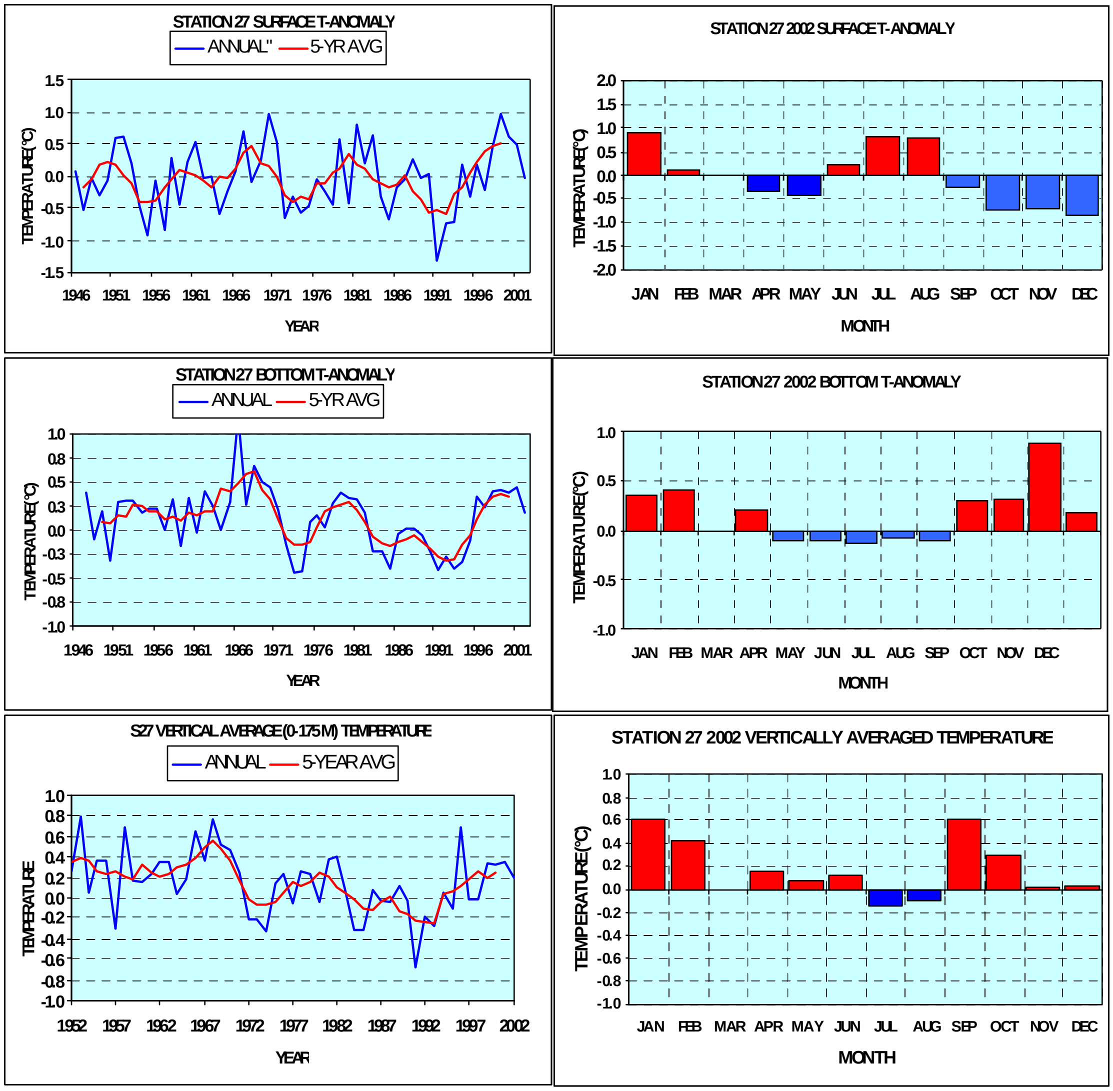


Fig. 4. Monthly surface, bottom and depth-averaged temperature anomalies at Station 27 during 2002 (right panels) and their annual anomalies with 5-year running means (left panels).

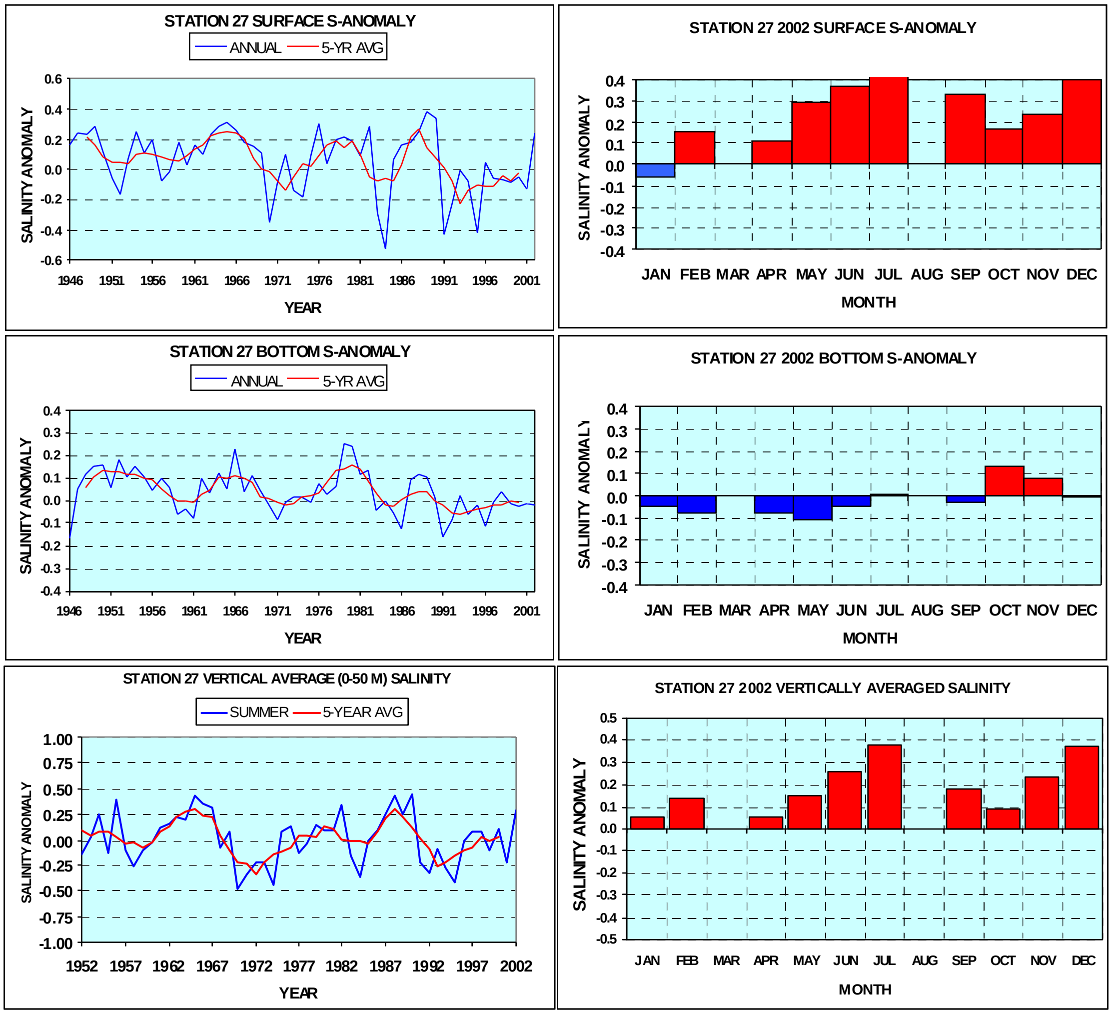


Fig. 5. Monthly surface, bottom and depth-averaged salinity anomalies at Station 27 during 2002 (right panels) and their annual anomalies with 5-year running means (left panels).

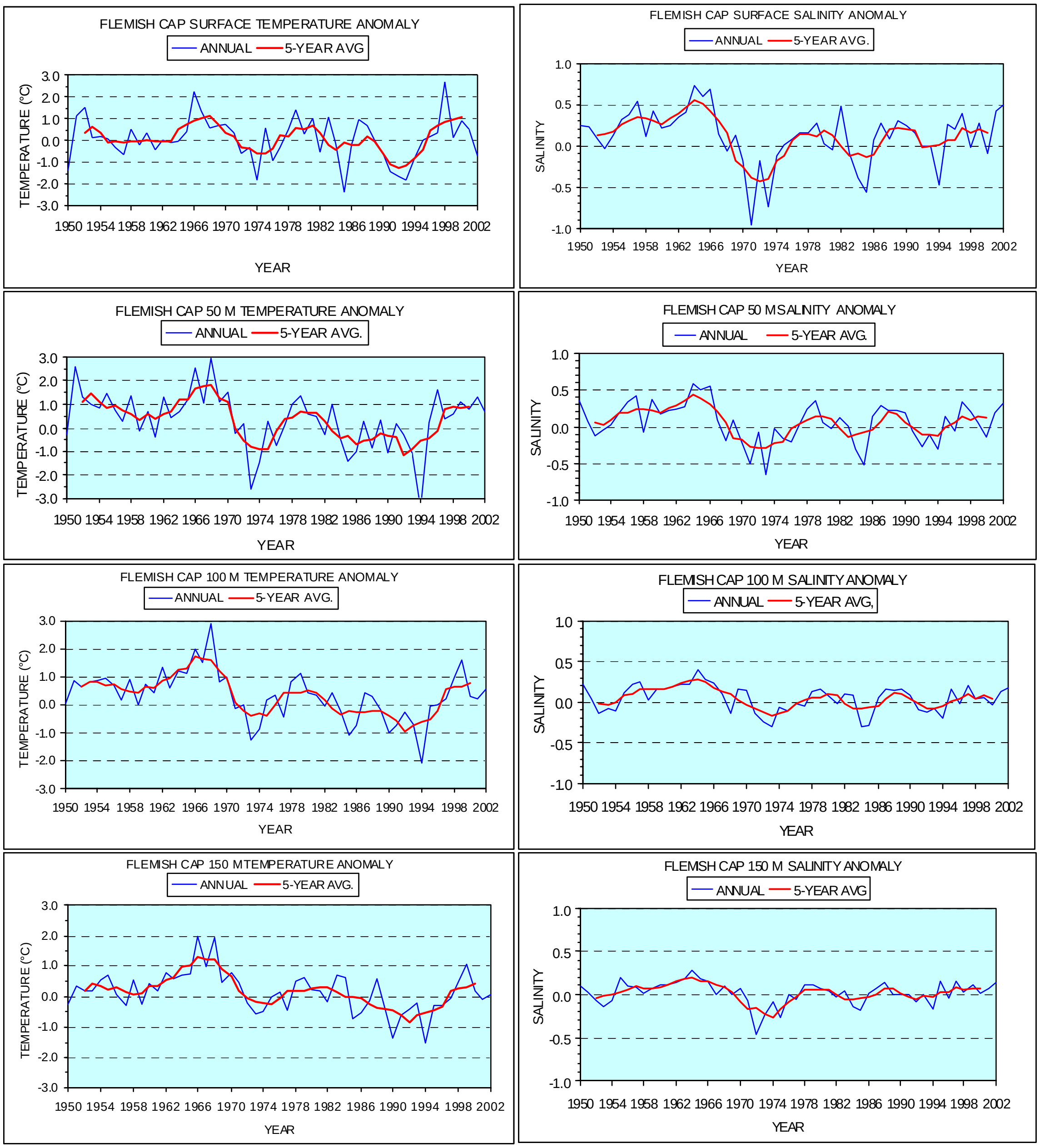


Fig. 6. Annual temperature anomalies (left panels) and salinity anomalies (right panels) on the Flemish Cap in NAFO Division 3M at selected water depths. The heavy lines are the 5-year running means

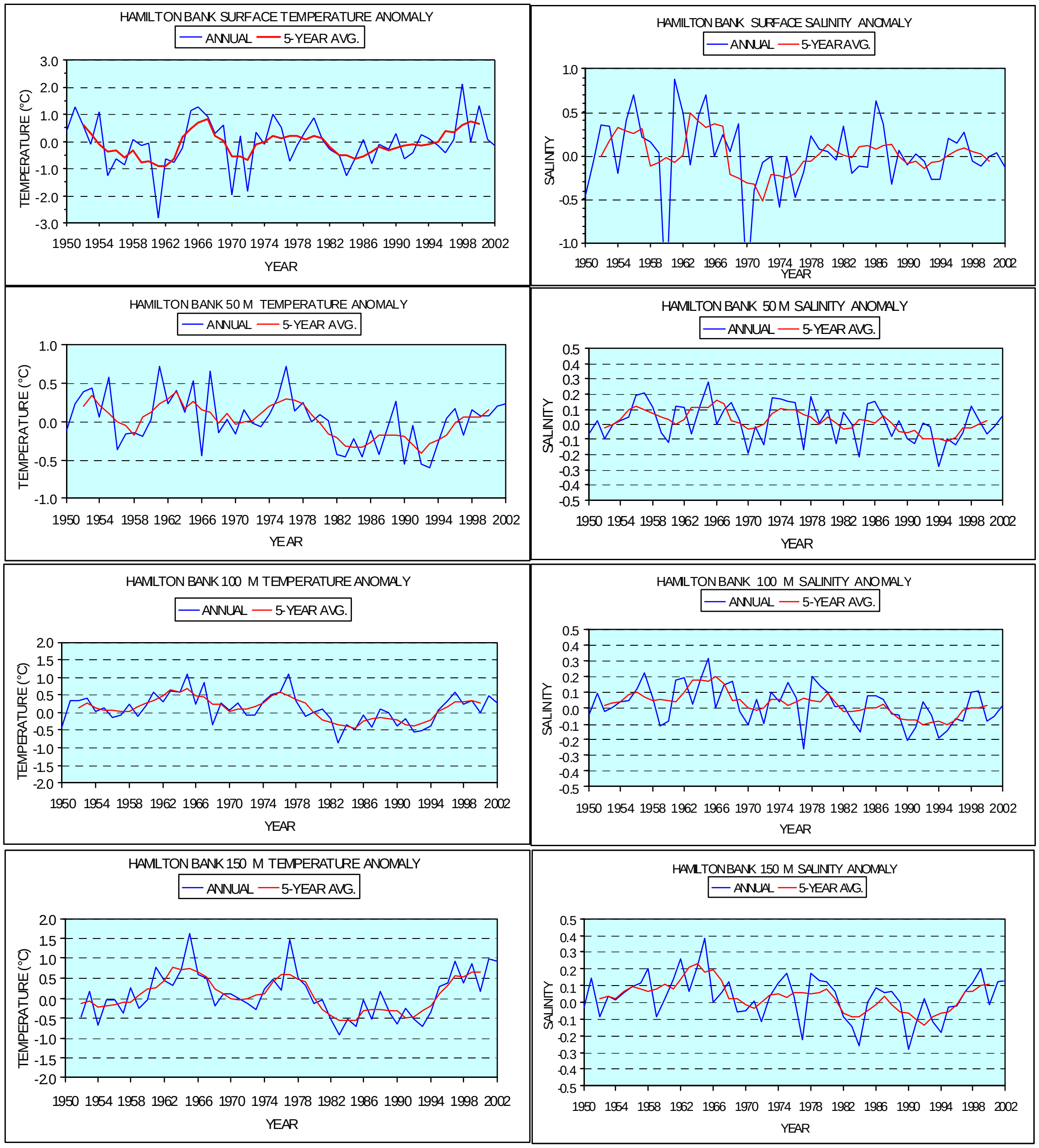


Fig. 7. Annual temperature anomalies (left panels) and salinity anomalies (right panels) on Hamilton Bank in NAFO Division 2J at selected water depths. The heavy lines are the 5-year running means.

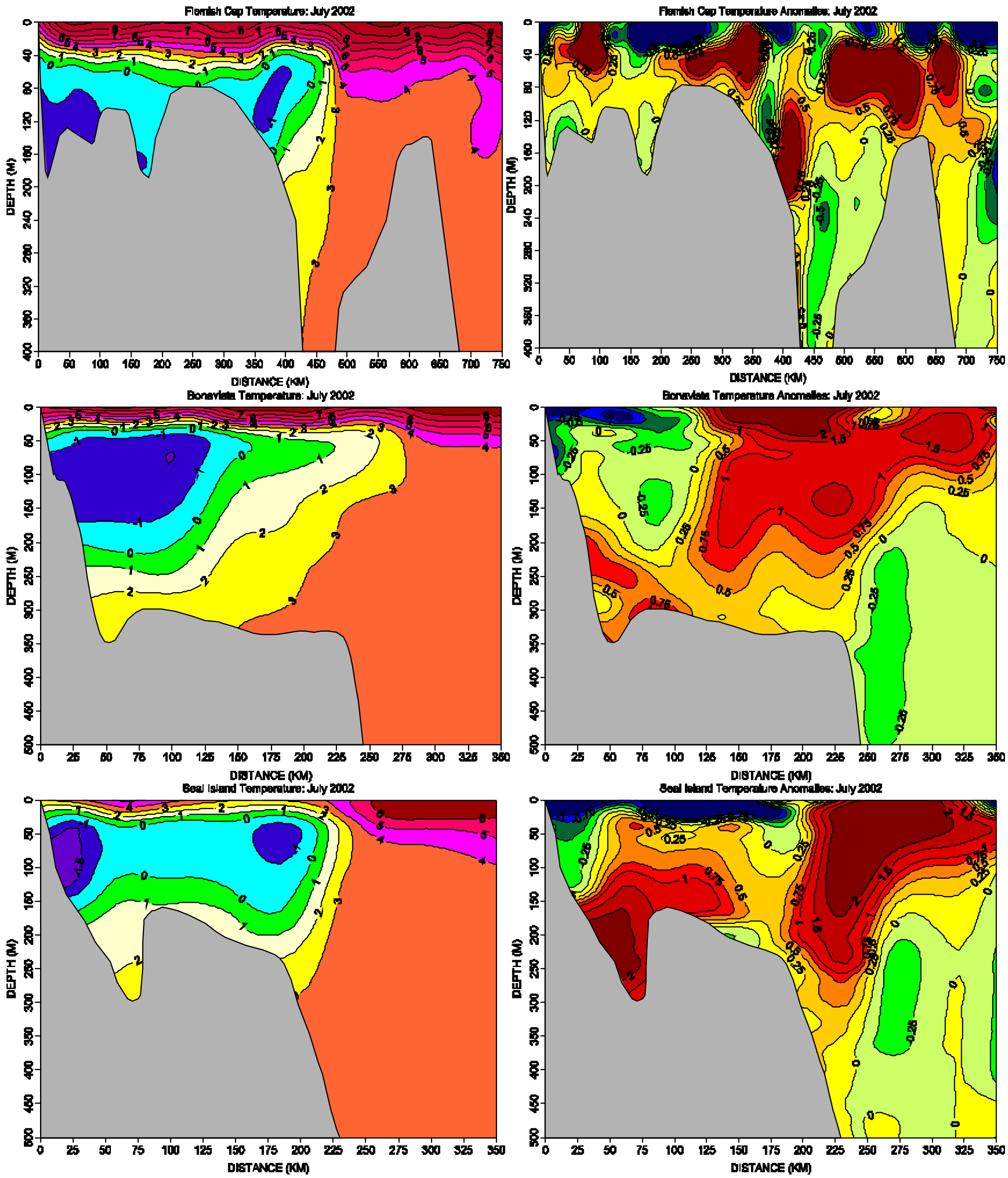


Fig. 8. Contours of temperature and temperature anomalies (in °C) along the Flemish Cap, Bonavista and Seal Island sections (Fig. 1) during the summer of 2002.

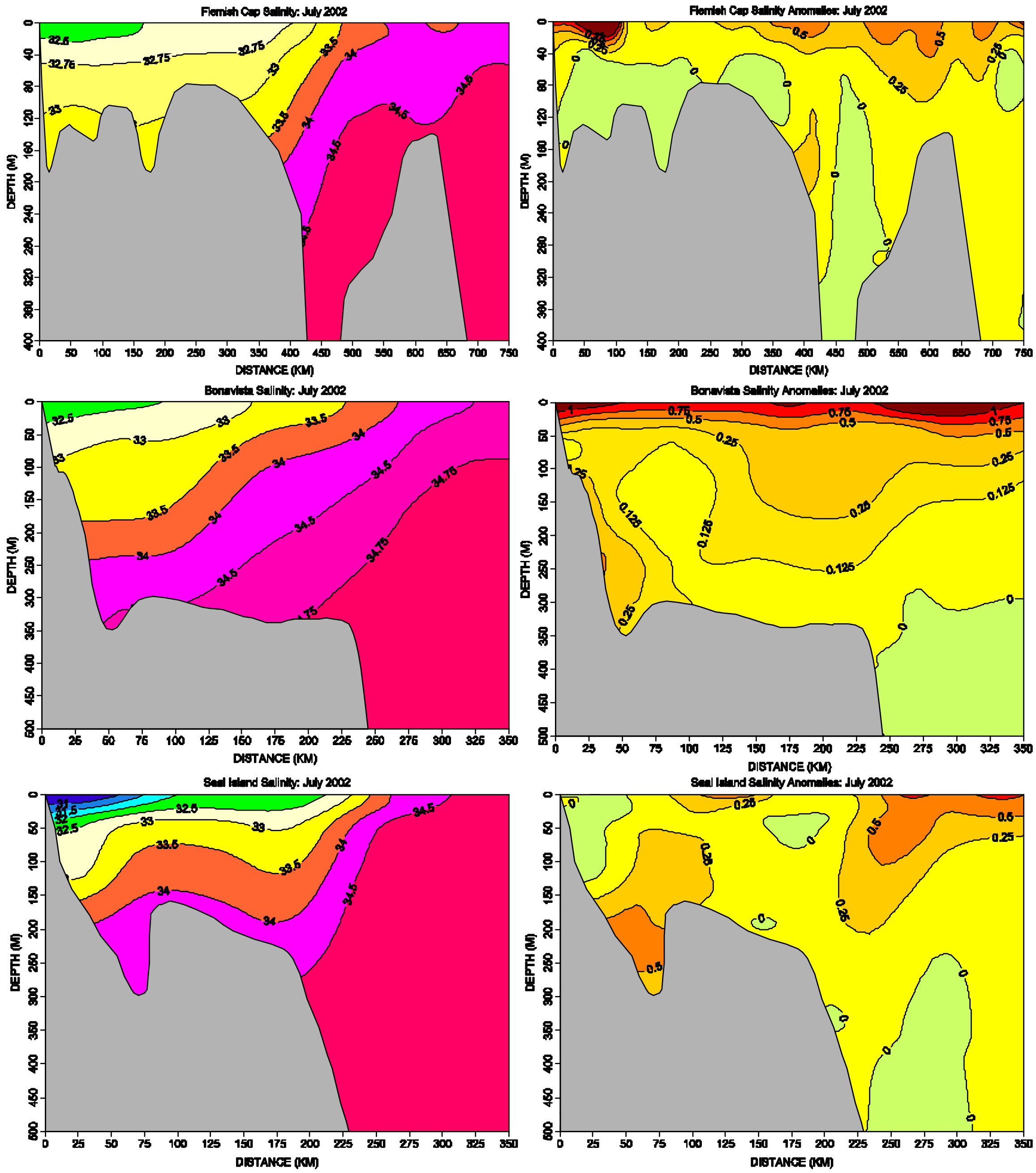


Fig. 9. Contours of salinity and salinity anomalies along the Flemish Cap, Bonavista and Seal Island sections during the summer of 2002.

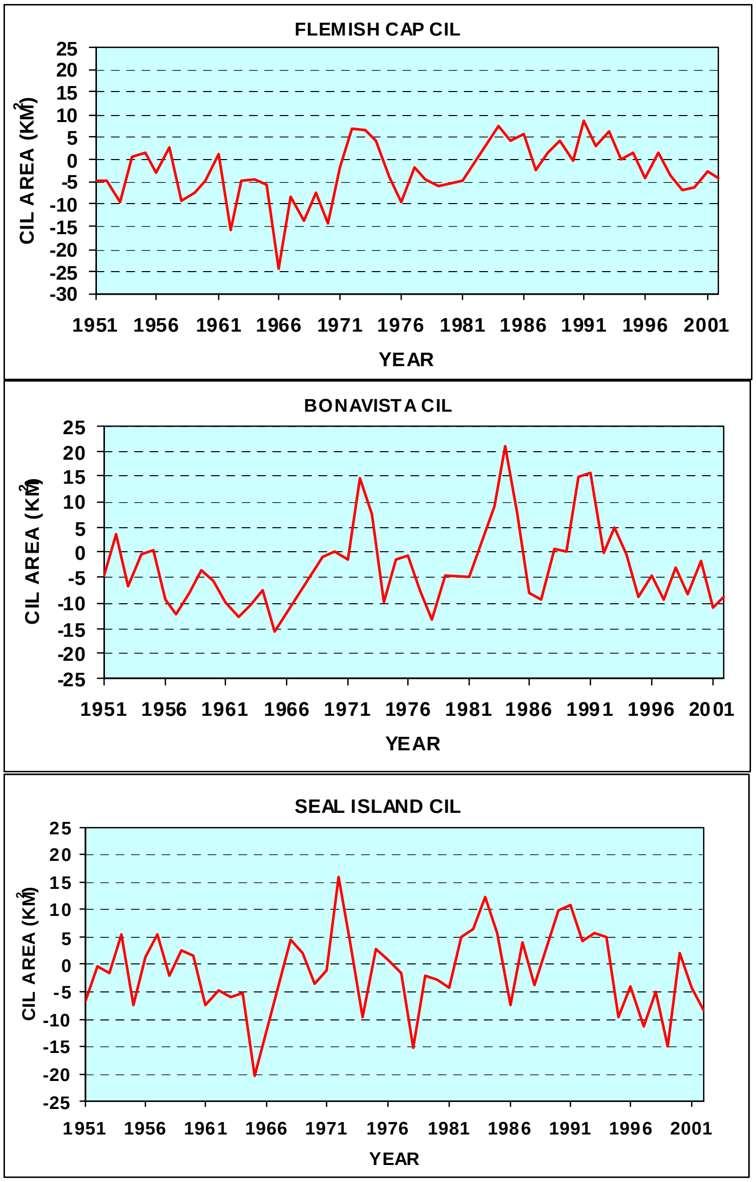
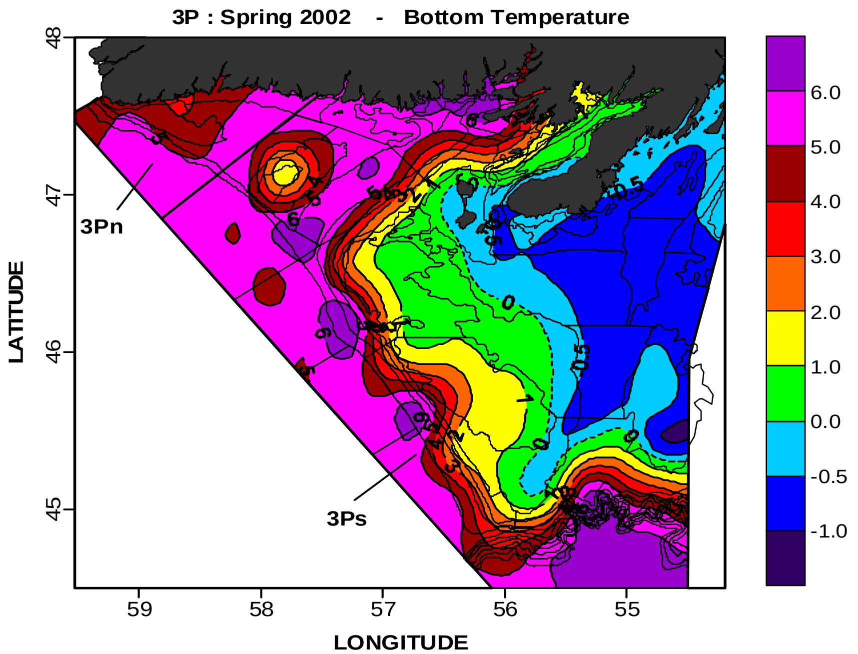


Fig. 10. Annual summer CIL cross-sectional area anomalies along the Flemish Cap, Bonavista and Seal Island sections. The anomalies are references to the 1971-2000 means.



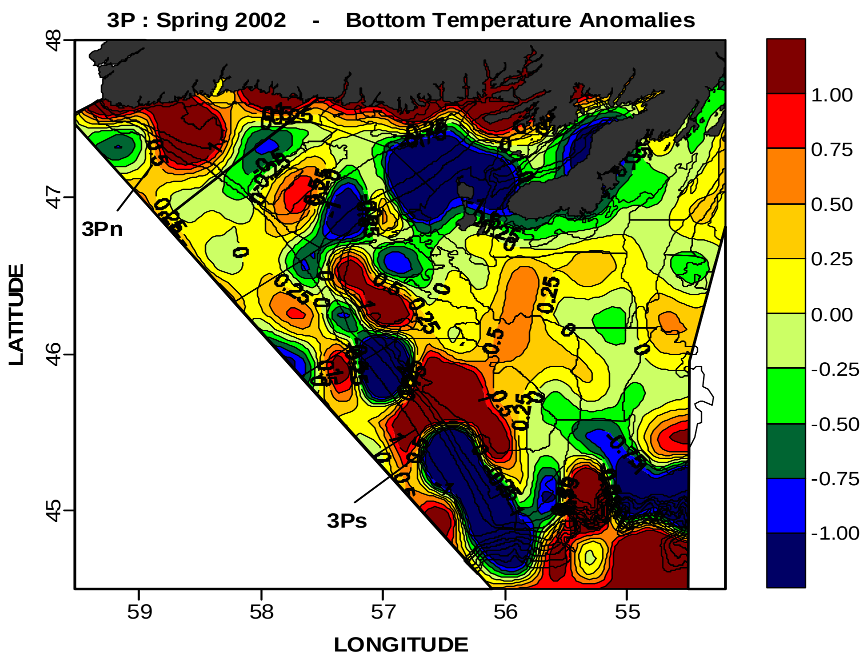


Fig. 11. The April 2002 bottom temperature and anomalies (in °C) in NAFO Subdivisions 3Pn and 3Ps. The anomalies are referenced to the 1971-2000 average.

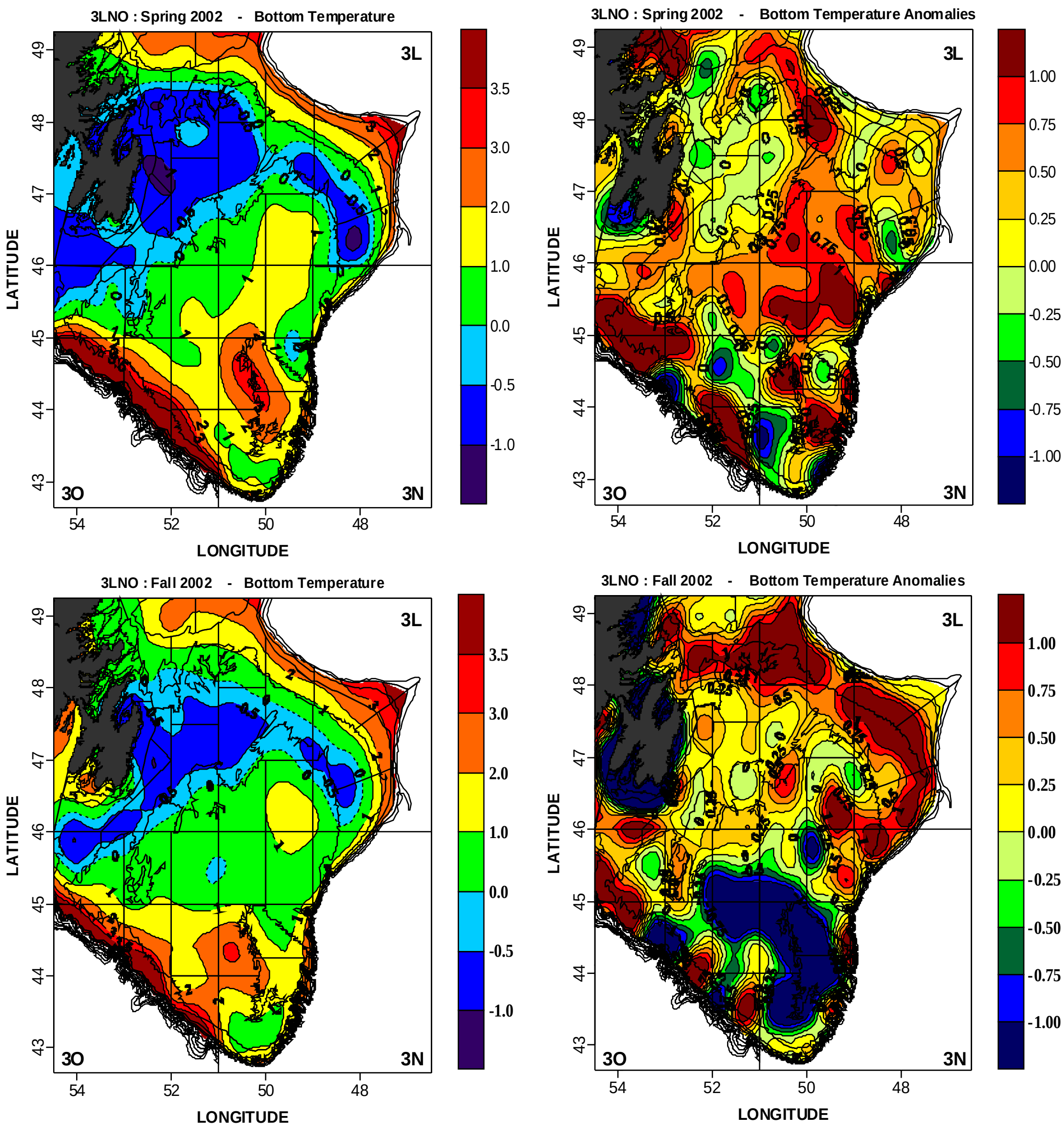


Fig. 12. Contours of bottom temperature and their anomalies (in °C) for the spring and fall of 2002 from the multi-species survey of NAFO Div. 3LNO.

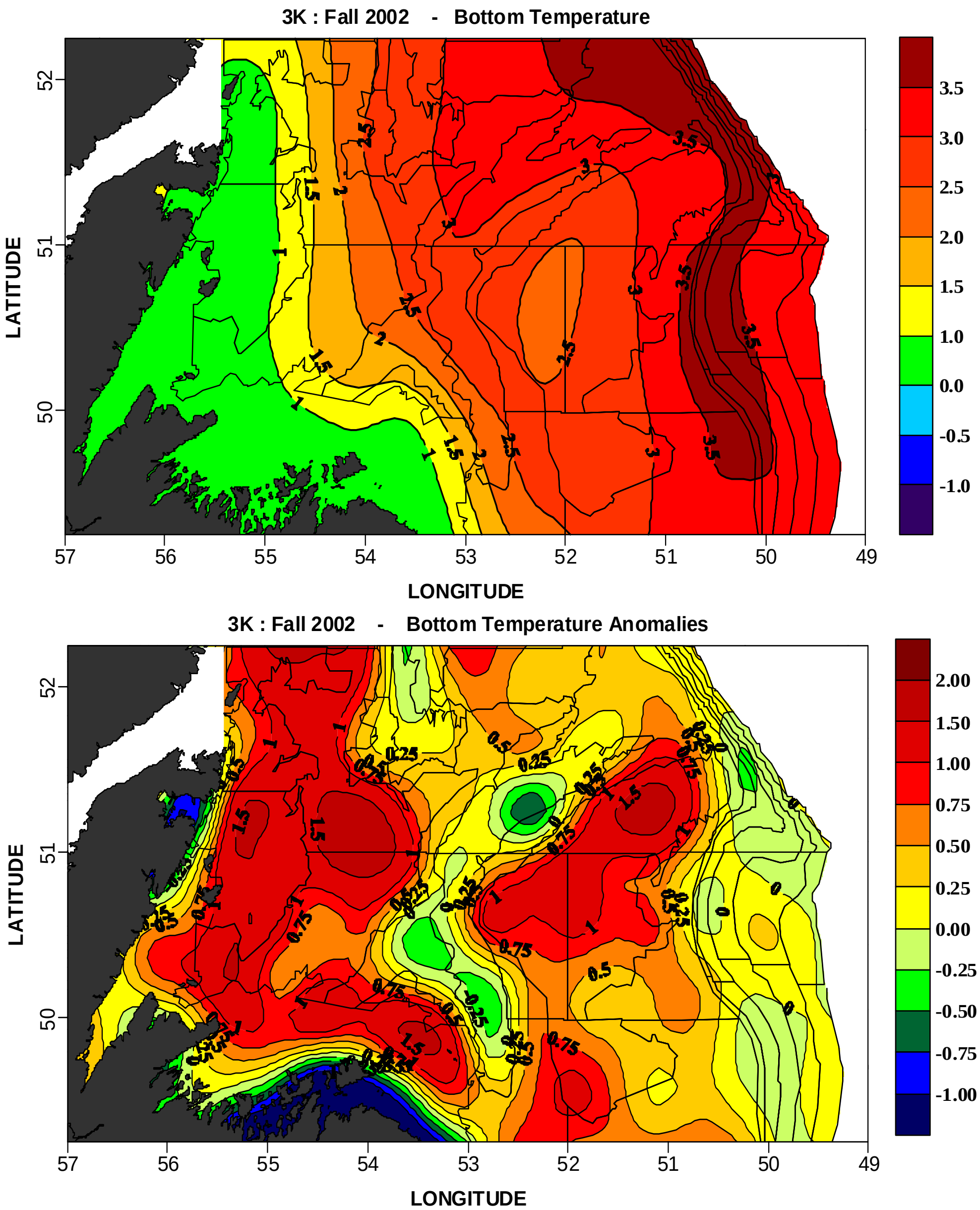
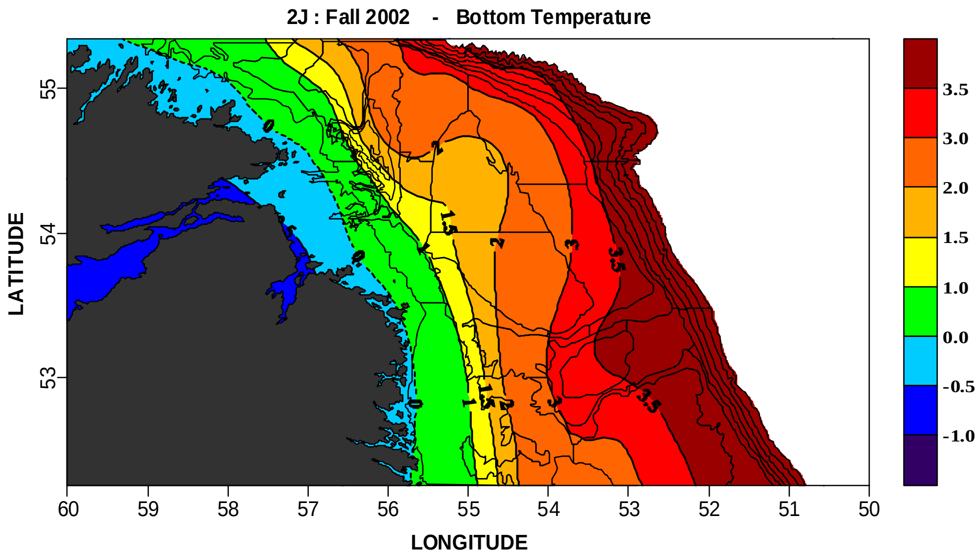


Fig. 13. Contours of bottom temperature and their anomalies (in °C) for the fall of 2002 from the multi-species survey of NAFO Div.. 3K.



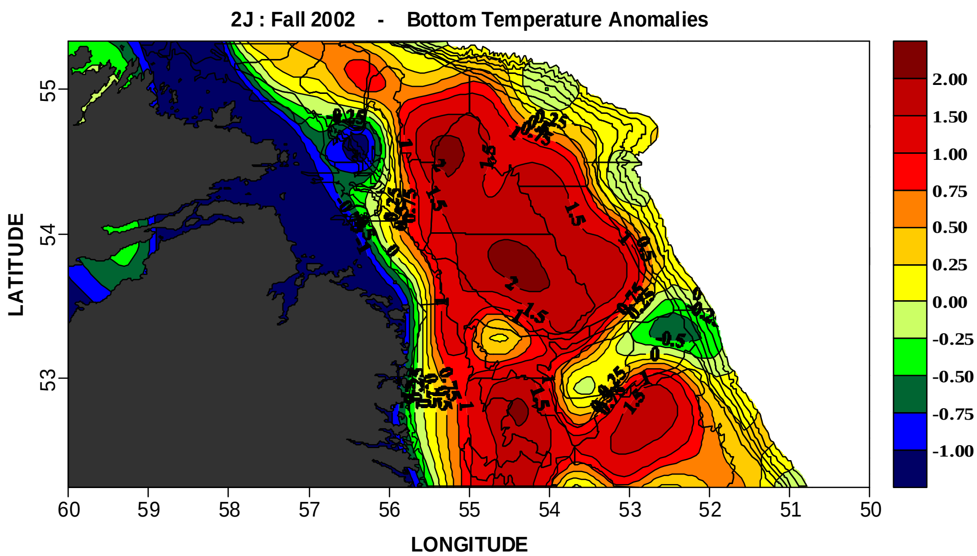


Fig. 14. Contours of bottom temperature and their anomalies (in °C) for the fall of 2002 from the multi-species survey of NAFO Div. 2J.

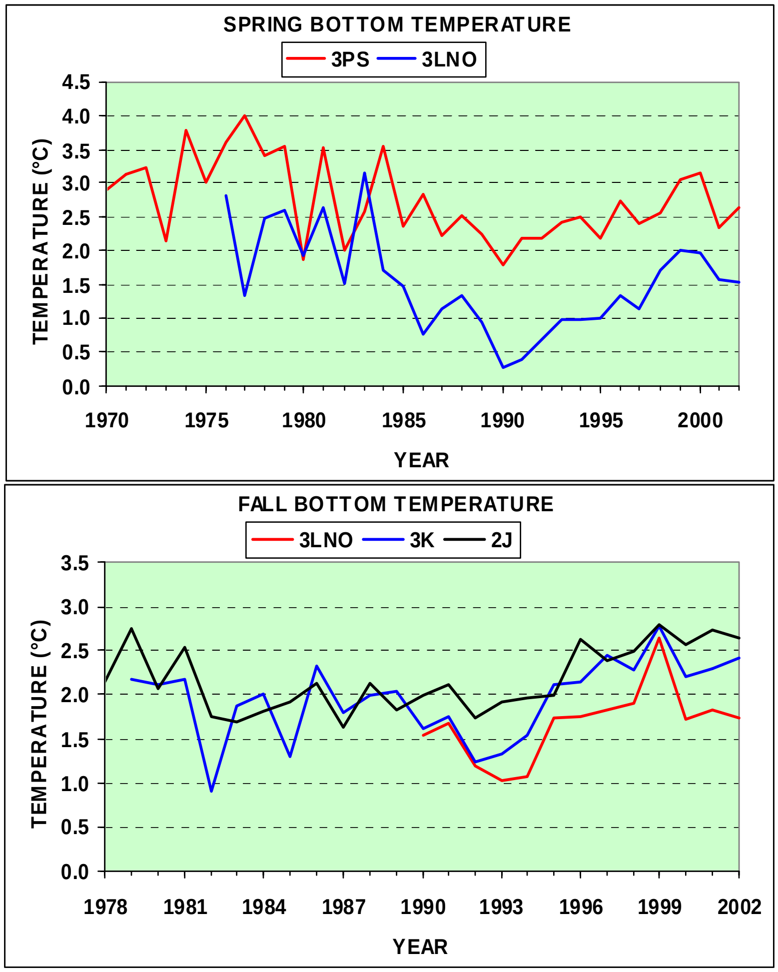


Fig. 15. Time series of the spatially averaged bottom temperatures during the spring (top panel) and fall (bottom panel) in NAFO Div. 3P, 3LNO, 3K and 2J.

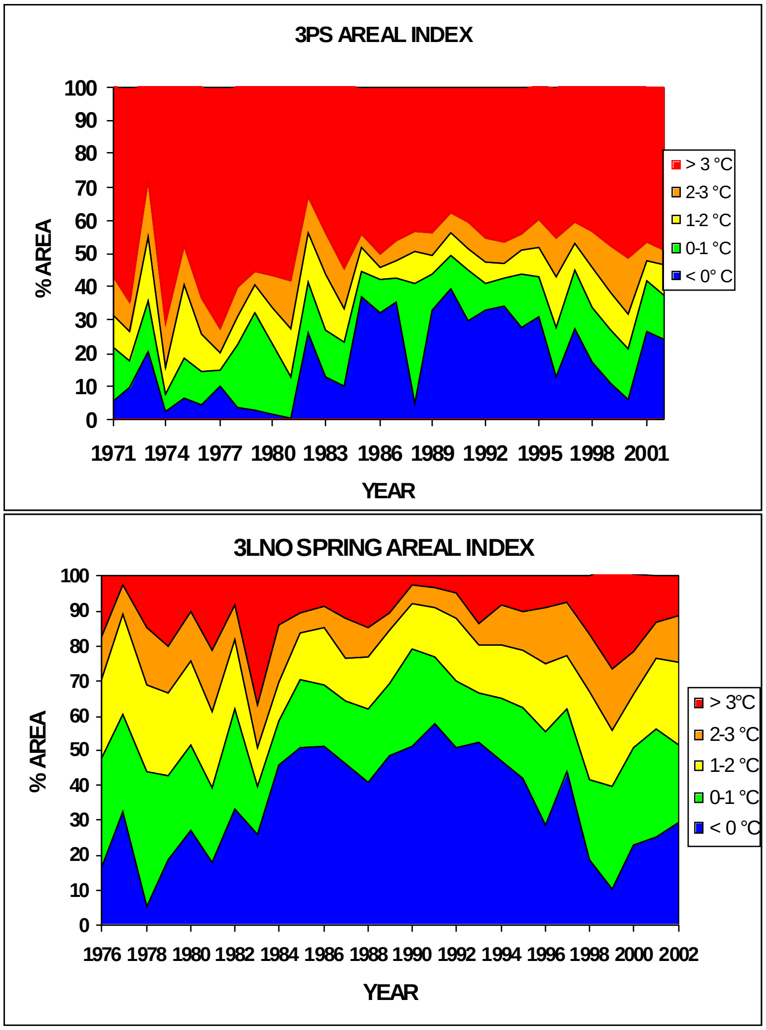


Fig. 16. Time series of the percentage area of the bottom in NAFO Div. 3P (top panel) and in Div. 3LNO (bottom panel) covered by water with temperatures ≤ 0°C, 0-1°C, 1-2°C, 2-3°C and ≥3°C during spring.

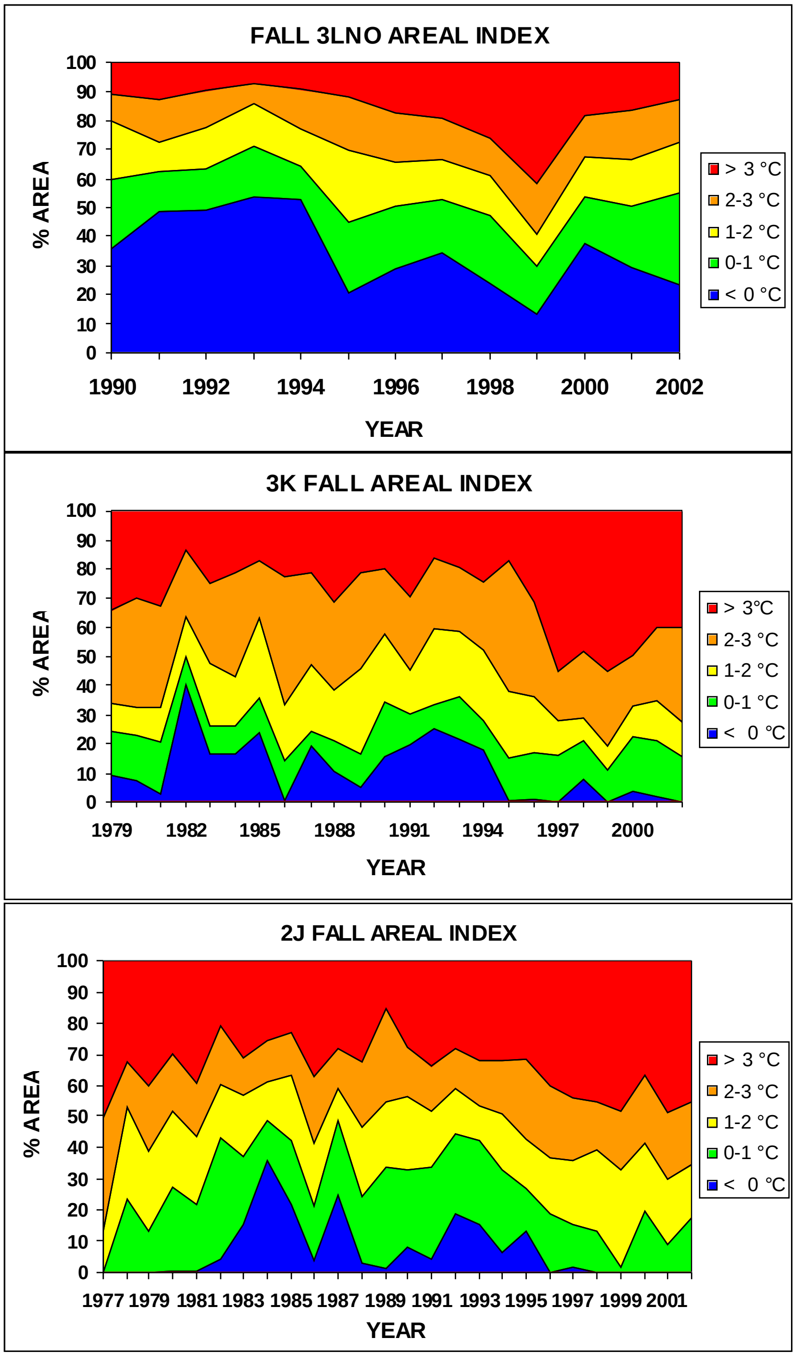


Fig. 17. Time series of the percentage area of the bottom in NAFO Div. 3LNO, 3K and 2J covered by water with temperatures ≤ 0°C, 0-1°C, 1-2°C, 2-3°C and ≥3°C during the fall.