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An assessment of the physical oceanographic environment on the Newfoundland and Labrador Shelf during 2003

Évaluation de l'environnement l'océanographique physique sur la plate-forme continentale de Terre-Neuve et du Labrador en 2003

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Abstract

Oceanographic observations from Nain Bank on the central Labrador Shelf to the Southern Grand Bank on the Newfoundland Shelf during 2003 are presented referenced to their long-term (1971-2000) means. The annual water-column averaged temperature at Station 27 for 2003 remained above the long-term mean and increased over 2002 values at all depth ranges. The annual surface temperature at Station 27 was 0.7^{o}C above normal, while the annual bottom temperature remained similar to 2002 at 0.2^{o}C above normal. Bottom temperatures were above normal during January and February, below normal during spring and above normal during the remainder of the year. Water-column averaged annual salinities at Station 27 remained above normal, similar to 2002. Surface salinities at Station 27 were above normal for 11 of 12 months, while bottom salinities were generally below normal, particularly during the period April to July. The cross-sectional area of <0^{o}C (CIL) water on the Newfoundland and Labrador Shelf during the summer of 2003 increased slightly over 2002 values but remained below the long-term mean for the ninth consecutive year in some areas. In general, the cold temperatures observed along standard sections off the east coast of Newfoundland during the spring moderated by summer and were generally above normal by fall. Bottom temperature anomalies on the Grand Bank during the spring of 2003 were highly variable, mostly positive in the northern areas of 3LNO during both spring and fall. However, fall bottom temperatures for the shallow waters of the southeast Grand Bank were similar to 2002, up to 2^{o}C below normal. Fall bottom temperatures in Divs. 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. In summary, 2003 was a year of extremes in many areas, with below normal temperatures in early spring, but increased to above normal values through the year. In general both 2002 and 2003 were cooler than 1999-2000 values, but remained above normal over most areas continuing the trend established in 1996.

Résumé

Des observations océanographiques effectuées en 2003 depuis le banc de Nain sur la partie centrale de la plate-forme du Labrador jusqu'à la partie méridionale du Grand Banc sur la plate-forme de Terre-Neuve sont présentées en regard des moyennes à long terme (1971 à 2000). En 2003, la température annuelle moyenne pour la colonne d'eau à la station 27 est restée supérieure à la moyenne à long terme et marquait une élévation par rapport à celle observée en 2002 à toutes les plages de profondeurs. La température annuelle en surface à la station 27 s'établissait à 0,7 ^{o}C au-dessus de la normale alors que la température annuelle au fond restait similaire à ce qu'elle était en 2002 et de 0,2 ^{o}C au-dessus de la normale. Les températures au fond ont été supérieures à la normale en janvier et en février, inférieures à la normale pendant le printemps et supérieures à la normale pendant le reste de l'année. La salinité annuelle moyenne pour l'ensemble de la colonne d'eau à la station 27 est restée au-dessus de la normale et similaire à celle observée en 2002. La salinité en surface à la station 27 a été supérieure à la normale pendant 11 des 12 mois alors qu'au fond elle était généralement inférieure à la normale, en particulier pendant l'intervalle d'avril à juillet. L'aire en coupe transversale mesurée pour l'eau à < 0 ^{o}C (CIF) sur la plate-forme continentale de Terre-Neuve et du Labrador pendant l'été de 2003 a légèrement augmenté par rapport à celle observée en 2002, mais est restée inférieure à la moyenne à long terme pour la neuvième année consécutive dans certains secteurs. En général, les températures froides observées pendant le printemps le long de coupes normalisées au large de la côte orientale de Terre-Neuve ont été tempérées pendant l'été et se situaient généralement au-dessus de la normale à l'automne. Les anomalies de température de fond sur le Grand Banc pendant le printemps de 2003 ont été très variables, principalement de valeur positive dans les régions septentrionales de 3LNO pendant le printemps et l'automne. Cependant, les températures au fond pendant l'automne dans la région peu profonde du sud-est du Grand Banc étaient similaires à celles observées en 2002 et jusqu'à 2^{o} C sous les normales. Les températures au fond pendant l'automne dans les divisions 2J et 3K étaient également au-dessus des normales, jusqu'à 2^{o} C sur le banc Hamilton et jusqu'à 1 ^{o}C sur le banc Fur Island. En résumé, l'année 2003 a été à plusieurs égards une année d'extrêmes dans nombre de régions; des températures sous les normales ont été observées au début du printemps, mais elles sont passées au-dessus des normales pendant l'année. En général, les valeurs observées de la température en 2002 et 2003 ont été moindres que celles observées en 1999-2000, mais sont restées au-dessus des normales dans la plupart des régions, ce qui prolonge la tendance qui s'est établie en 1996.

Introduction

This manuscript presents an overview of physical oceanographic conditions in the Newfoundland and Labrador Region during 2003, 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 convention of the World Meteorological Organization. Most of the time series presented had good temporal coverage over the years 1971-2000. The information presented for 2003 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 cross-shelf sections during annual spring, summer and fall oceanographic surveys under the Atlantic Zone Monitoring Program (AZMP), and (3) oceanographic observations made during the spring and fall multi-species research vessel surveys (Fig. 1). 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 Center (NAFC) in St. John's Newfoundland. Since 1977 (in Division 2J), and from 1981 (in Divisions 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 sampling 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. These systems record temperature and salinity data during trawl deployment and recovery as well as 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^{o}C in temperature and 0.005 in salinity. The XBT measurements are accurate to within 0.1^{o}C.

Time series of temperature and salinity anomalies were constructed at standard depths from Hamilton Bank, Station 27 and the Flemish Cap. For Station 27 the 1971-2000 data set was sorted by day of the year to determine the annual cycle. Following the general methods of Petrie et al. (1992) and Myers et al. (1990), the seasonal cycle at the selected depth was determined by fitting a least squares regression of the form $\mathbf{A\cos(\omega t-\phi)}$ to the data. **A** is the amplitude, ω is the annual frequency, **t** is the time in days and ϕ is the phase. The fitted values were the mean, the annual frequency ω and its first two harmonics. The seasonal cycle was then removed to determine anomalies. For the other areas the 1971-2000 data sets were sorted by month to determine monthly means. The seasonal cycle was then removed from each observation by subtracting the 1971-2000 monthly mean to determine anomalies. These anomalies are based on data collected over relatively large geographical areas and therefore may exhibit variability due to spatial differences. In addition, 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 but 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 2003. 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-dimensional Kriging) procedure. Bottom temperature anomaly maps were computed by subtracting the 2003 and the average temperature grids. 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, which starts in early to mid-October normally, finishes around mid-December but was not completed this year until the end of January 2004.

Near-bottom temperature data from the multi-species assessment surveys were used to compute 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 it's 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 $\leq 0^oC$, $0\text{-}1^oC$, $1\text{-}2^oC$, $2\text{-}3^oC$ and $\geq 3^oC$. 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)

Station 27, located in the Avalon Channel off Cape Spear (Fig. 1a), was sampled 59 times (50 CTD profiles, 9 XBT profiles) during 2003. 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

2003 are displayed in Fig. 2. The annual and monthly anomalies of temperature and salinity at selected standard depths and depth ranges are displayed in Figs. 3 to 5.

The cold near isothermal water column during the winter months has temperatures ranging from 0^o to -1.5^oC. These temperatures persisted throughout the year in the bottom layers. Surface layer temperatures ranged from about -1^o to 0^oC from January to mid-April, after which the surface warming commenced. By mid-May upper layer temperatures had warmed to 2^oC and to over 13^oC by August at the surface, after which the fall cooling commenced. These temperatures were about 0.25^o to 0.5^oC above normal during the winter months over most of the water column. Temperatures during the spring were generally below normal. During the remainder of the year, temperatures were above normal (by $>1.5^oC$ in surface layers during the summer) except for a mid-depth cold anomaly during the fall.

Surface salinities reached maximum values by late winter (>32.4 in mid-March) and decreased to minimum values by late summer (<31.3 in 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 fall months. In the depth range from 50-100-m, salinities generally ranged from 32.4 to 32.8 and near bottom, they varied throughout the year between 32.8 and 33. Except from May to July bottom salinities were near normal during most of 2003 (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 at the 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 at normal to above normal values up to 2003. 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 2003 have remained above the long-term average, however during 2002 and 2003 they decreased over the highs of 1996-2001. Monthly surface temperatures during 2003 were about normal during the first half of the year and above normal during the second half. At the bottom, they were above normal during January and February, below normal during spring and above normal during the remainder of the year (Fig. 3 right panels).

Near-surface salinity anomalies (Fig. 4) 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 (Drinkwater 1994, Colbourne et al. 1994, Drinkwater et al. 1996, Drinkwater et al. 1999). 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 2003, surface salinities were above normal for all months with data, near-bottom however, they were below normal for 8 of 12 months for 2003 (Fig 4, right panels).

Vertically averaged annual temperature and 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 2002 the vertically averaged temperature decreased over 2001 values but increased again in 2003 to above normal values over all depth ranges (Fig. 5, left panels).

The salinity time series (Fig. 5 right panels) 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 corresponding to a warming trend is an exception. The magnitude of negative salinity anomaly on the inner Newfoundland Shelf during the 1990s was 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. From 1996 to 2001 summer salinities varied considerably from about normal to below normal. During 2002 salinities were higher than 2001 values and were the highest in 12 years over some depth ranges, particularly in the upper water column. These high values continued in 2003.

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 2002. Surface temperatures during 2003 were about normal, while values at deeper levels were similar to those of 2002, generally above normal.

It should be noted that the annual estimate for 2003 was based on only three observations.

The time series of salinity anomalies on the Flemish Cap (Fig. 6, right panels) show large fresher-than-normal anomalies from 1970 to 1975 with peak amplitudes reaching near 1 unit 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 2003 continued the increase noted in 2002 over all depths reaching >0.5 above normal at the surface.

Hamilton Bank (Division 2J)

Time series of temperature and salinity anomalies from 1951 to 2003 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 were above normal during 2003 increasing sharply over 2002 values in the upper water column and remained similar to 2002 values in deeper layers. 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 1995-2003 varied about the long-term mean with near-normal values during 2003 in the upper water column and slightly below normal below 100-m depth.

Standard Monitoring 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) (Anon. 1978). Four of these sections are occupied during mid-summer on an annual oceanographic survey conducted by DFO's Newfoundland Region. They are (1) the Seal Island section on the southern Labrador coast and Hamilton Bank, (2) the White Bay section which crosses the relatively deeper portions of the northeast Newfoundland Shelf, (3) the Bonavista section off the east coast of Newfoundland and (4) the Flemish Cap section which crosses the Grand Bank at 47°N and continues eastward across the Flemish Cap. As part of an expanded AZMP, the Bonavista and Flemish Cap sections are now occupied during the spring and fall with the addition of the Southeast Grand Bank section. Also, when time permits sections on Makkovik Bank and Nain Bank (Beachy Island) on the mid-Labrador Shelf are occupied during the summer (Fig. 1a). We present the physical oceanographic results from these sections for the spring, summer and fall of 2003. The temperature and salinity anomalies referenced to the 1971-2000 data sets are also presented. The levels of confidence in these estimates are not yet assessed, but are the highest for the summer sections. The sigma-t and % dissolved oxygen ($D0_2$) saturation sectional plots are presented for information purposes.

Southeast Grand Bank

The Southeast Grand Bank section was sampled twice during 2003 (April and November). Contours of temperature, salinity, sigma-t and dissolved oxygen saturation along this section are shown in Fig. 8 and 9. During the spring temperatures were generally <0^{o}C along this section in the inshore areas and at the shelf break. Temperatures on the shallower portions of the Grand Bank ranged from 0^o-1.5^{o}C during spring and over 8^{o}C during the fall near the surface. These values were below normal in all areas during the spring (by 1^o -1.5^{o}C) and varied considerably about the mean during the fall. Bottom temperatures across the southeast Grand Bank during the fall ranged from near normal to above normal values in many areas.

Upper layer salinities along the section during the spring ranged from <32.75 near shore to >33 in the offshore region. Bottom salinities on the Grand Bank ranged from 32.75-33.0 and from 33-34 over the southeast slope of the Grand Bank. Except for the extreme southeastern regions these values were predominantly saltier-than-normal over most of the southeast Grand Bank during the spring. During the fall, salinities decreased over spring values, particularly in the inshore Labrador Current with values reaching below 32. These values were above normal in the inshore to near normal across much of the southeast Grand Bank.

Flemish Cap

The Flemish Cap section was sampled 3 times during 2003 (April, July and November) (Fig 10, 11 and 12). Near surface temperatures along this section over the Grand Bank ranged from –0.5^o-0^{o}C during the spring to 7^o-10^{o}C during the summer, and 3^o-5^{o}C during the fall. Less than 0^{o}C temperatures generally persisted throughout the year 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. During the spring temperatures on Grand Bank were below normal while temperatures in the Flemish Pass area and to the east of the Flemish Cap were above normal. Temperatures varied considerably about the mean during the summer, except in areas east of the Cap where temperatures were up to 8°C above normal. Bottom temperatures over most of the Grand Bank during the fall were mostly above normal. Temperatures over the Flemish Cap area ranged from below normal during the spring to near normal during the summer to above normal in the fall.

Salinities along this section on the Grand Bank were very similar to that observed further south along the southeast Grand Bank section. They are characterized by generally fresher conditions on the Grand Bank (<33), a strong horizontal gradient at the shelf break and generally salty (>34.25) water offshore in the Flemish Pass. Salinity anomalies during 2003 were generally above normal throughout the section.

Bonavista

The Bonavista section was also sampled 3 times during 2003 (April, July and November) (Fig. 13, 14 and 15). The dominant feature along this section is the cold intermediate layer of <0°C water (CIL) which develops during early spring after intense winter cooling. Temperatures along the Bonavista section shoreward of the shelf break in the upper water column ranged from <0°C during spring, reached a maximum of 7-8°C during the summer and decreased to 2°-4°C by late fall. These values were generally below normal (up to 2°C) in the inshore areas during spring and summer and above normal in the offshore areas. During the fall the CIL area had almost disappeared and temperatures were above normal by 1° -2°C in all areas along the section. Near bottom temperatures across the eastern Newfoundland Shelf along this section were above normal from spring to fall.

Bonavista section salinities near the surface generally range from <32.5 in the inshore region to >34 in the offshore region. Bottom salinities ranged from 32.75 in the inshore regions, to 34.75 at about 325-m depth near the shelf edge. Similar to the Flemish Cap section, salinities were generally above normal throughout the section with the magnitude of the anomalies decreasing with depth. In general, salinities during both 2002 and 2003 along the Bonavista section increased over values observed in 2001.

White Bay

The White Bay section, which crosses the deeper portions of the northeast Newfoundland Shelf, was sampled in July of 2003 (Fig. 16). The CIL water during the summer is usually quite extensive along this section, with a large area of water with <0^{o}C temperatures extending from the coast to near 400 km offshore. At about mid-shelf temperatures below 200 m increased from 0^{o}C to >3^{o}C at the outer edge of the shelf. Temperatures along this section were generally below average over the inner shelf during 2003, while in the offshore portion of the section values were generally above normal. Surface salinities ranged from <31.5 in White Bay to near 34.75 in the offshore region. Bottom salinities ranged from 33 near shore to 34.75 at the edge of the shelf. These values were saltier-than-normal in the surface layer and in the offshore regions and generally about normal over the inner shelf at mid-depth.

Seal Island

The Seal Island section, which crosses Hamilton Bank on the southern Labrador Shelf, was also sampled in July of 2003 (Fig. 17). Upper layer temperatures across the shelf in this region ranged from –1^{o}C at mid-depth within the CIL to between 6^o-8^{o}C at the surface. Temperatures below the CIL and near bottom ranged from 0^o-2^{o}C. Near the shelf break bottom temperatures increase to 2^o-4^{o}C. Temperature anomalies in the surface layer and offshore of the shelf break were generally above normal. In water generally associated with the CIL, temperatures were about normal. Surface salinities along this section ranged from <31.5 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. These values were saltier-than-normal in the surface layers over the shelf, below normal at the shelf break and above normal in the offshore areas.

Makkovik Bank and Beachy Island (Nain Bank)

The Makkovik Bank and Beachy Island sections on the mid-Labrador Shelf were occupied in August of 2003 for the 5th consecutive year (Fig. 18 and 19). Along the Makkovik Bank section upper layer temperatures over the shelf ranged from 0^{o}C at approximately 50-m depth to between 3^o-5^{o}C at the surface. Temperatures below 50-m depth were generally <0^{o}C and as low as -1.5^{o}C over the shelf, but increased to >0^{o}C near the outer edge of the Bank and to >3^{o}C on the shelf slope below approximately 350-m depth. Except near bottom, temperature anomalies over most of the shelf were above normal by up to 2^{o}C near the surface. Surface salinities along this section ranged from <31.75 over the shelf 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. Except for the near surface layer and in the extreme offshore regions salinities were fresher-than-normal.

Along the Beachy Island section, which crosses Nain Bank, surface temperatures ranged from 0^o-5^{o}C. The area of water with temperatures below –1^{o}C was much less than that on Makkovik Bank. Offshore temperatures were very similar along both sections. Temperature anomalies in this area were generally above average, except in the inshore regions below 50 m depth where they were about normal. Surface salinities along this section ranged from <31.5 inshore and

>34 in the offshore region. Bottom salinities ranged from 33.5 on Nain Bank to 34.75 at the edge of the Labrador Shelf. These values were generally fresher-than-normal over the shelf and saltier-than-normal offshore of the shelf break.

Cold Intermediate Layer (CIL) Time Series

As shown in the previous section in 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^{o}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 White Bay section (Fig. 16) the CIL extends approximately 400 km offshore, with a maximum vertical extent of approximately 200 m in the White Bay area. This corresponds to a cross-sectional area of around 40-50 km^2 in most years. Figure 20 shows time series of the CIL cross-sectional area anomalies defined by the 0^{o}C contour for the Flemish Cap, Bonavista, White Bay and Seal Island sections.

Along the Flemish Cap section the CIL area was below the 1971-2000 normal in 2003, similar to conditions observed during the past 5-years but a slight increase over 2002. Off Bonavista the CIL area was also below normal for the ninth consecutive year. Along the White Bay and Seal Island sections the area of <0^{o}C water increased slightly over 2002 values continuing the below normal trend establish during the mid-1990s. In general, all sections showed a slight increase over 2002 but continued the trend of below normal values observed since 1994. 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 sections during the summer are also shown in Fig. 20 (right panels). The overall minimum temperature observed along the Flemish Cap, Bonavista, White Bay and Seal Island sections during 2003 were -1.55^{o}, -1.62^{o}, –1.58^{o}, and -1.40^{o}C, respectively. These were all near the long-term mean except for the Seal Island section where it was above normal.

The total volume of CIL water on the Newfoundland and southern Labrador Shelves shoreward of the 1000-m isobath and within NAFO divisions 2J3KL is shown in Fig 21. The calculation of the volume of CIL water overlying the continental shelf has been described by Colbourne and Mertz (1995). The CIL volume is principally determined by the thickness of the layer of water <0^{o}C on the shelf. The isolines of CIL thickness show large variations from summer to fall of the same year and from cold years to warm years (Colbourne, 1995). The average thickness of the CIL is maximum (>150 m) along the east coast of Newfoundland within 100 km of the shore and decreases to zero near the edge of the shelf, on the southern Grand Bank and on Hamilton Bank during warm years in the fall. The time series of total volume of CIL water over the 2J 3KL area shows maximum values during the cold periods of the mid-1980s and early 1990s. The total volume of CIL water on the shelf increased from approximately 3.3 x 10^4 km^3 during the summer of 1989 to 5.6 x 10^4 km^3 in 1990, a 70% increase. Since 1993 the volume of CIL water on the Newfoundland Shelf during the fall has been slowly decreasing reaching a minimum during 1999. The CIL volume during the fall of 2003 was very similar to 2002 continuing the trend of below average values experienced since the mid-1990s. The fall time series show similar trends as in the summer, however the total volume is only about 60% of the summer values. Due to data limitations, the volume estimates were not calculated prior to 1980 and during the summers of 2000 to 2003.

Geostrophic Circulation and Transport

The temperature and salinity data from the summer 2003 survey were used to calculate geostrophic currents relative to 300 m along the Flemish Cap, Bonavista, White Bay, Seal Island, Makkovik Bank and the Beachy Island (Nain Bank) sections (Fig. 22). The geostrophic component of the Labrador Current along these sections shows distinct inshore and offshore branches. The inshore branch is generally much weaker than the shelf-slope offshore branch and is usually restricted to the inshore troughs within approximately 50-100 km of the coast. Typical geostrophic current speeds in these regions range from 0.05-0.10 ms^{-1}, although some estimates were up to 0.15 ms^{-1} along the Seal Island section during 2003. The much stronger offshore branch is normally located at the shelf break in water depths generally greater than 400 m. The offshore distance and the width of the current vary according to the underlying topography. Along the Seal Island section, for example, the core of the offshore branch is about 100 km wide, centred at about 215 km offshore over the 400-m isobath, while off Makkovik Bank the width of the current is approximately 50 km centred at about 125 km offshore. In the offshore branch, typical speeds range from 0.05 ms^{-1} at 175-m depth to >0.2 ms^{-1} in the upper water column. At mid-shelf the currents sometimes reverse direction, with clockwise circulation on Hamilton Bank and Flemish Cap, for example. These currents are weak however with speeds generally less that 0.05 ms^{-1}. In general, geostrophic currents along the Labrador Shelf (Seal Island, Makkovik Bank and Nain Bank) are stronger than observed along the eastern Newfoundland Shelf with speeds over 0.50 ms^{-1} along the shelf-slope off Makkovik Bank for example (Fig. 22).

The historical (1951-2003) summer (July-August) temperature and salinity data along the Seal Island, Bonavista and Flemish Cap sections were used to compute a time series of geostrophic transports. The volume transport was calculated by integrating the speed both vertically through the water column and horizontally through the offshore branch of the current. A common reference level of 135-m was chosen for these calculations since this was the deepest level common to all three transects that did not intersect the bottom, thus eliminating potential problems associated with a bottom reference level. Also, the main interest was to examine variations in volume transport during recent ocean climate changes on the continental shelf. Short-term climate changes generally result in variations in upper layer shelf stratification due mainly to salinity changes resulting from increased ice formation and melt. This determines in part, the magnitude of the shelf-slope density front and hence the strength of the geostrophic component of the Labrador Current. The time series of volume transport of the offshore branch of the Labrador Current for the three sections (Fig. 23) show large inter-annual variations with an average transport of between 0.4-0.5 Sv (1 Sv = 10^6 m^3/s) to the south, relative to 135 m. In general, the time series indicate higher than average transport during the late 1950s and into the 1960s, lower than average values during the cold period of the early 1970s and to a lesser extent during the cold period of the mid-1980s. During the late 1980s the transport increased to above average values, which for the most part continued into the mid-to-late 1990s. During 2003 the transport through the Flemish Pass increased over 2002 to the highest in the time series. Along the Seal Island and Bonavista sections, the transport in the offshore branch of the Labrador Current during 2003 was very similar to 2002.

Multi-Species Survey Results

Canada has been conducting stratified random bottom trawl surveys in NAFO Sub-areas 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 were 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 2003, in water depths down to 366 m until 1979 and to 548 m since then; 3L in spring from 1971-2003, except 1983 and 1984; 3NO in spring from 1971-2003, 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 1977-2003; 3K in fall from 1978-2003; 3L in fall from 1981-2003, 3NO in fall from 1990-2003. 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 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 any temperature dependent near-bottom habitat for various species of marine organisms. An analysis of the 3P data set is presented in a separate document to meet the mid-fall regional stock assessment (RAP) requirements (Colbourne and Murphy 2003).

3LNO Spring

Bottom temperatures and their anomalies for NAFO Divs. 3LNO during the spring of 2002 and 2003 are shown in Fig. 24. 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°C to 5°C along the slopes of the Grand Bank in Div. 3O. During the spring of 2002 and 2003, <0°C water was mostly restricted to Div. 3L, although there was an increase in the amount of <0C water in the northern portions of 3NO. In general, bottom temperatures were mostly above normal in northern areas and below normal in southern regions.

The areal extent of the bottom covered by water in various temperature ranges during spring for the 3LNO region is displayed in Fig. 25. In this region from 1975 to 1983 most of the bottom area was covered by water above 0°C with only approximately 20% covered by <0°C water. From 1984 to 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 percentage 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 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°C water on the Grand Bank decreased to about 10%, the lowest since 1978. During 2000 to 2003 this area has increased to about 25-40%.

The average bottom temperature for the 3LNO region (Fig. 25, bottom panel) 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 2003 the average bottom temperature decreased over the 2000 value to about 1°C. The corresponding series for water depths <100 m show similar trends but temperatures in the shallow area of the region are generally colder.

3LNO Fall

Bottom temperatures and their anomalies for NAFO Divs. 3LNO during the fall of 2002 and 2003 are shown in Fig. 26. 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 fall bottom temperatures ranged from 1°C to 3°C during both years on the Southeast Shoal and to >3°C along the southwest edge of the Grand Bank. These values were above normal on the northern Grand Bank and along the edge of the Grand Bank by up to 0.5^{o} to 1^{o}C. Bottom temperature anomalies in 3NO were quite variable except for the southeast shoal where they ranged from 0.5^{o}C to 2^{o}C below normal.

The areal extent of the bottom covered by water in various temperature ranges during the fall for the 3LNO region is displayed in Fig. 27. 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 $\geq$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 2003 the area of <0^{o}C water increased slightly over 2002 to about 30%. The average bottom temperature for all strata in Divs. 3LNO during the fall decreased from approximately 1.5^{o}C during 1990 to 1^{o}C during 1993 and 1994, then increased to approximately 1.8^{o}C during 1995. These remained relatively constant up to 1998 but then increased to over 2.5^{o}C during 1999, the highest in the 10 year record (Fig. 27 bottom panel). During the fall of 2000 to 2003 the mean bottom temperature decreased by nearly 1^{o}C over the 1999 value, but was still above the cold condition of the early 1990s.

3K Fall

Bottom temperatures and their anomalies for NAFO Div. 3K during the fall of 2002 and 2003 are shown in Fig. 28. Most of the 3K region 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 2002 and 2003 ranged between 2^{o} to 3^{o}C, which were about 0.5^{o} to 1^{o}C above their long-term means. Near the edge of the continental shelf in water depths below 500-m temperatures are generally around 3.5^{o}C, which was about normal.

The areal extent of the bottom covered by water in various temperature ranges and the mean bottom temperature during the fall for Div. 3K is displayed in Fig. 29. The percent 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 early 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 2003. The average bottom temperature in Div. 3K (Fig. 29, bottom panel) during the fall ranged from 1^{o}C in 1982, to 2.3^{o}C in 1986, with an overall average of about 2^{o}C. From 1995 to 1999 they increased to above-average values reaching about 2.7^{o}C during 1999. During the fall of 2000 to 2003 bottom temperatures were lower than in 1999, but remained relatively warm between 2.2^{o} to 2.5^{o}C.

2J Fall

Bottom temperatures and their anomalies for NAFO Div. 2J during the fall of 2002 and 2003 are shown in Fig. 30 and 31. Temperatures generally 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° to 2°C above normal on Hamilton Bank and about normal along the edge of the shelf. The negative anomalies apparent near the coast may be an artifact of the sampling in the extreme inshore regions.

The areal extent of the bottom covered by water in various temperature ranges and the mean bottom temperature during the fall for Div. 2J is displayed in Fig. 32. The percent area of the bottom covered by <0°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%. 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 2001 and 2003. Since 1996 the area of the bottom covered with <0°C water decreased to <10%. 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. From 1996 to 2003 mean bottom temperatures remained relatively constant slightly >2.5°C.

Summary

The annual water-column averaged temperature at Station 27 for 2003 remained above the long-term mean and increased over 2002 values at all depth ranges. The annual surface temperature at Station 27 was 0.7°C above normal, while the annual bottom temperature remained similar to 2002 at 0.2°C above normal. . Bottom temperatures were above normal during January and February, below normal during spring and above normal during the remainder of the year Water-column averaged annual salinities at Station 27 remained above normal, similar to 2002 values, the highest in over a decade. Surface salinities at Station 27 were above normal for 11 of 12 months, while bottom salinities were generally below normal, particularly during the period April to July.

The cross-sectional area of <0°C (CIL) water on the Newfoundland and Labrador Shelf during the summer of 2003 increased slightly over 2002 values but remained below the long-term mean. The CIL areas were below normal along all sections from the Flemish Cap section on the Grand Bank, to the Seal Island section off southern Labrador. Off Bonavista for example, the CIL area was below normal for the ninth consecutive year. The total volume of <0°C (CIL) water on the Newfoundland and southern Labrador Shelf during the fall decreased very slightly compared to 2002, continuing the trend of below normal values observed since the mid-1990s. In general, the cold temperatures observed along the standard sections during the spring moderated by summer and were generally above normal by fall.

Bottom temperature anomalies on the Grand Bank during the spring of 2003 were highly variable with amplitudes of ±0.5^{o}C in many areas. Temperature anomalies were mostly positive in the northern areas of 3LNO during both spring and fall. However, fall bottom temperatures for the shallow waters of the southeast Grand Bank were similar to 2002, up to 2^{o}C below normal. Fall bottom temperatures in Divs. 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 2003 in all NAFO divisions remained very similar to 2002 values. 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 continued 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. During 2000 to 2002 ocean temperatures were cooler than 1999 values, but remained above normal over most areas continuing the trend established in 1996. The past year was one of extremes in many areas with below normal temperatures in early spring but which increased to above normal values by fall. 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. Annual salinity measurements at Station 27 during 2003 continued to show above normal values.

Acknowledgements

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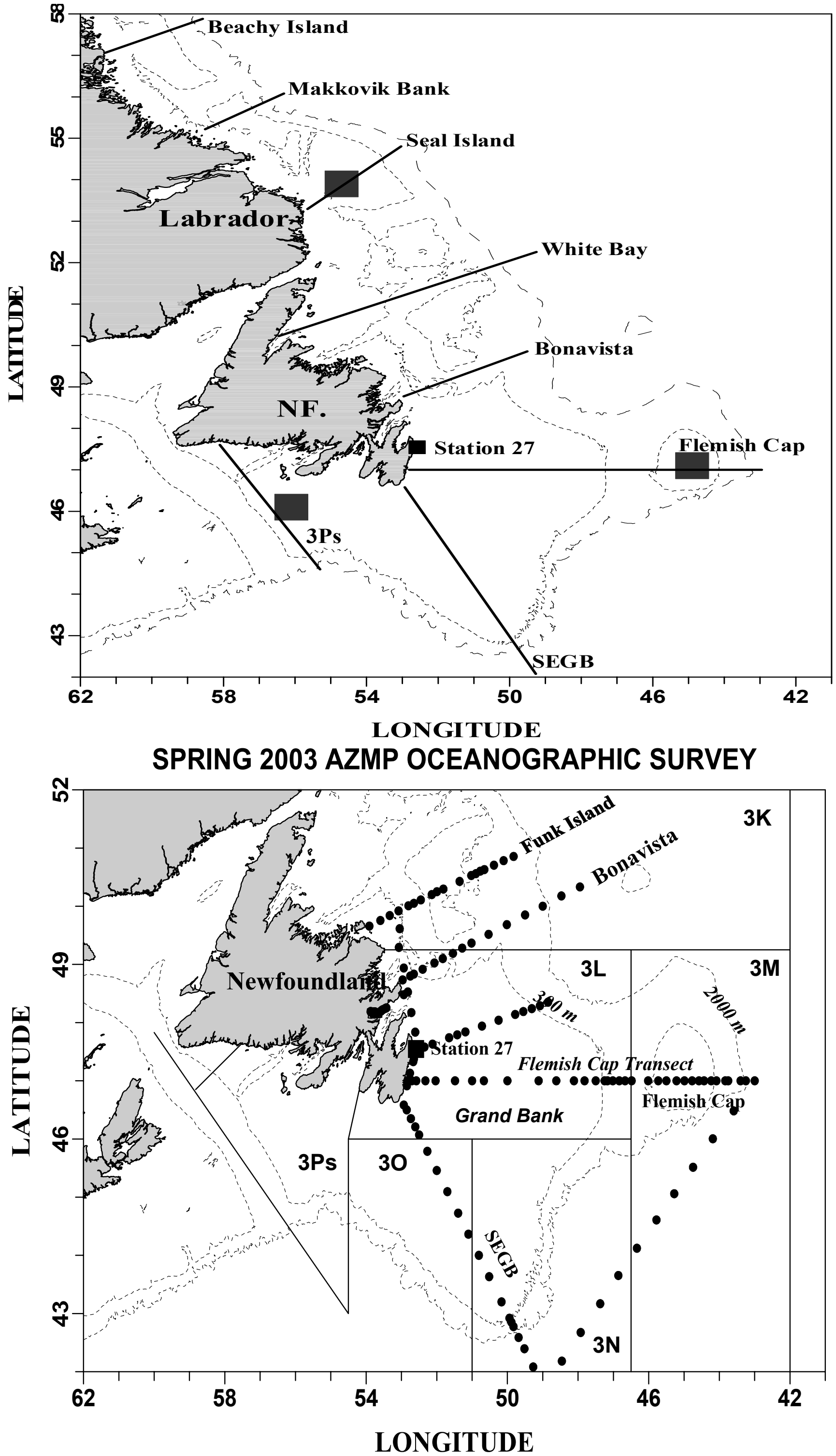


Fig. 1a. Location maps showing the position of standard sections, time series boxes, Station 27 and the position of all stations occupied during the spring AZMP 2003 survey. Bathymetry contours are 300 and 2000 m.

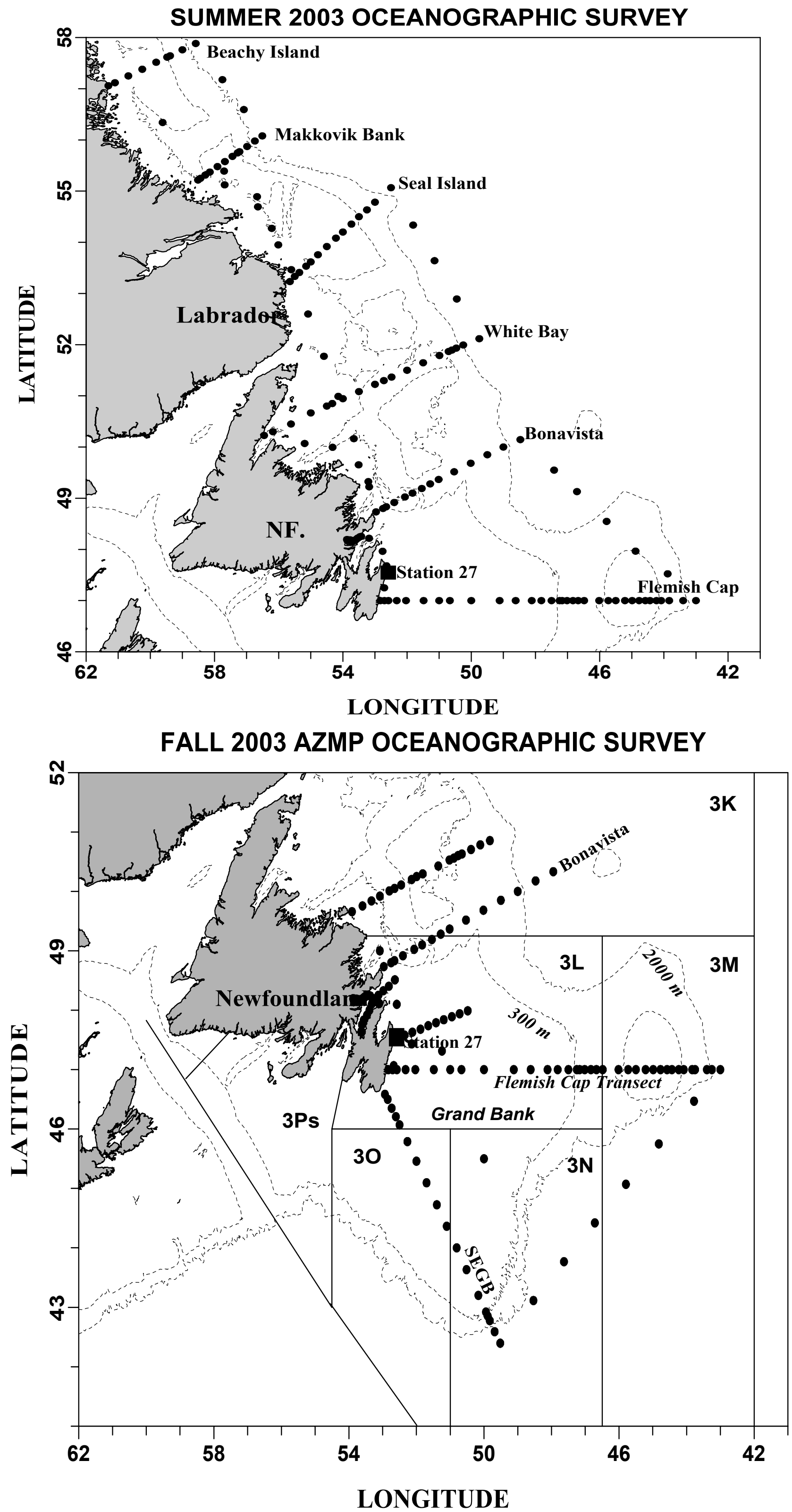
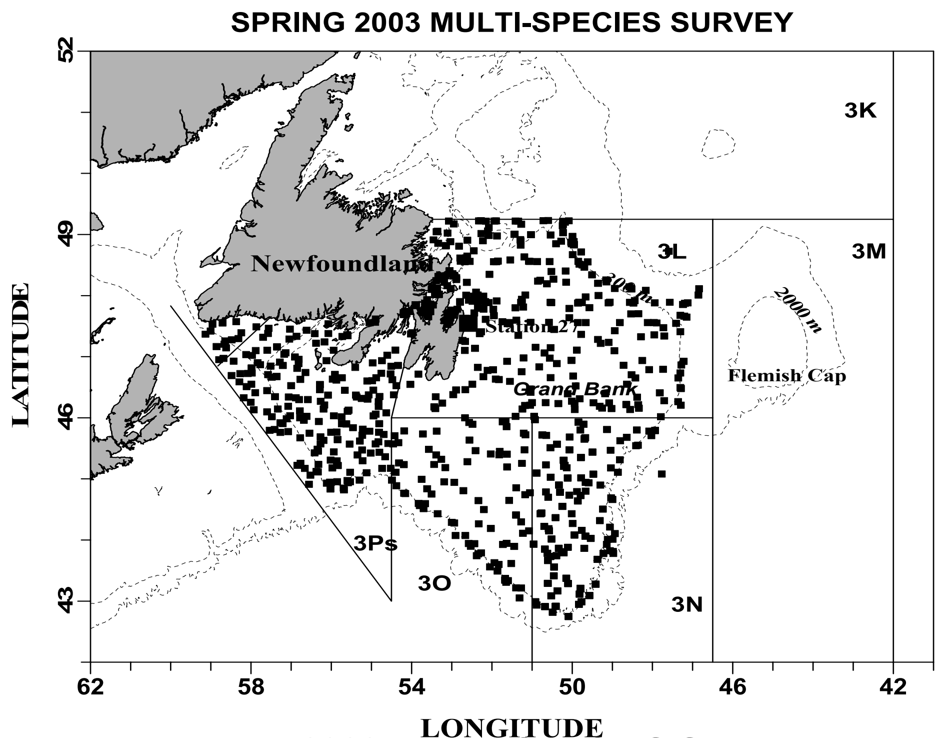


Fig. 1b. Location maps showing the position of all stations occupied during the summer and fall oceanographic surveys during 2003. Bathymetry contours are 300 and 2000 m.



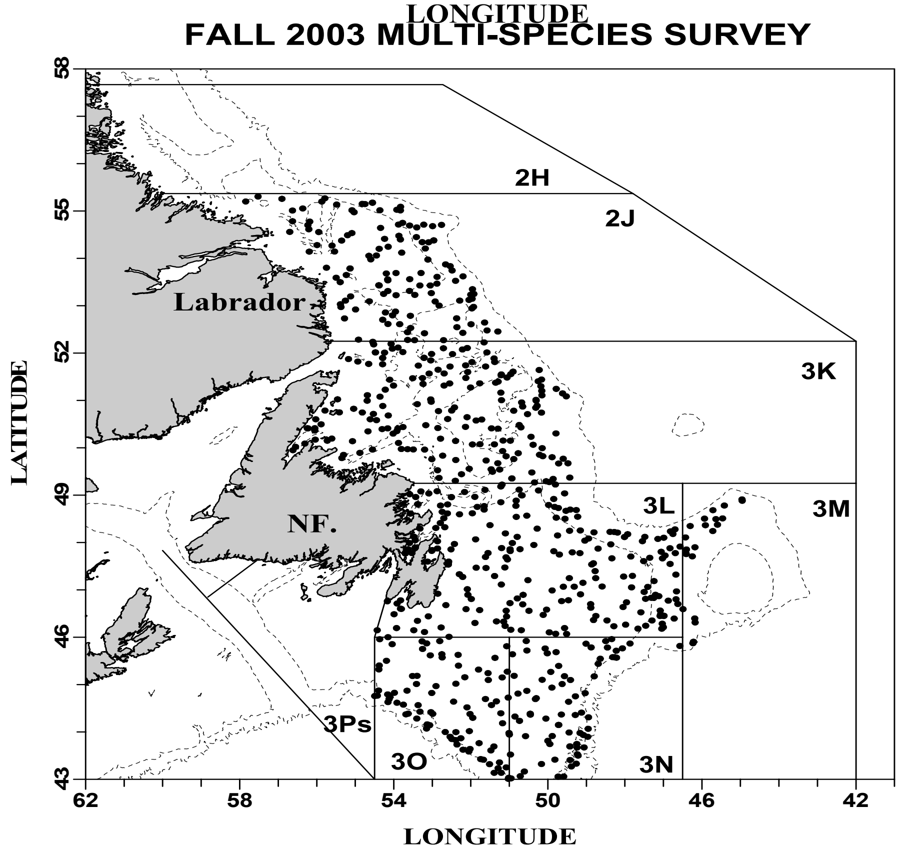


Fig. 1c. Location maps showing the positions of sets with oceanographic data from the multi-species surveys during the spring and fall of 2003. Bathymetry contours are 300 and 3000 m.

STATION 27 ANNUAL T/S CYCLE AND ANOMAILES

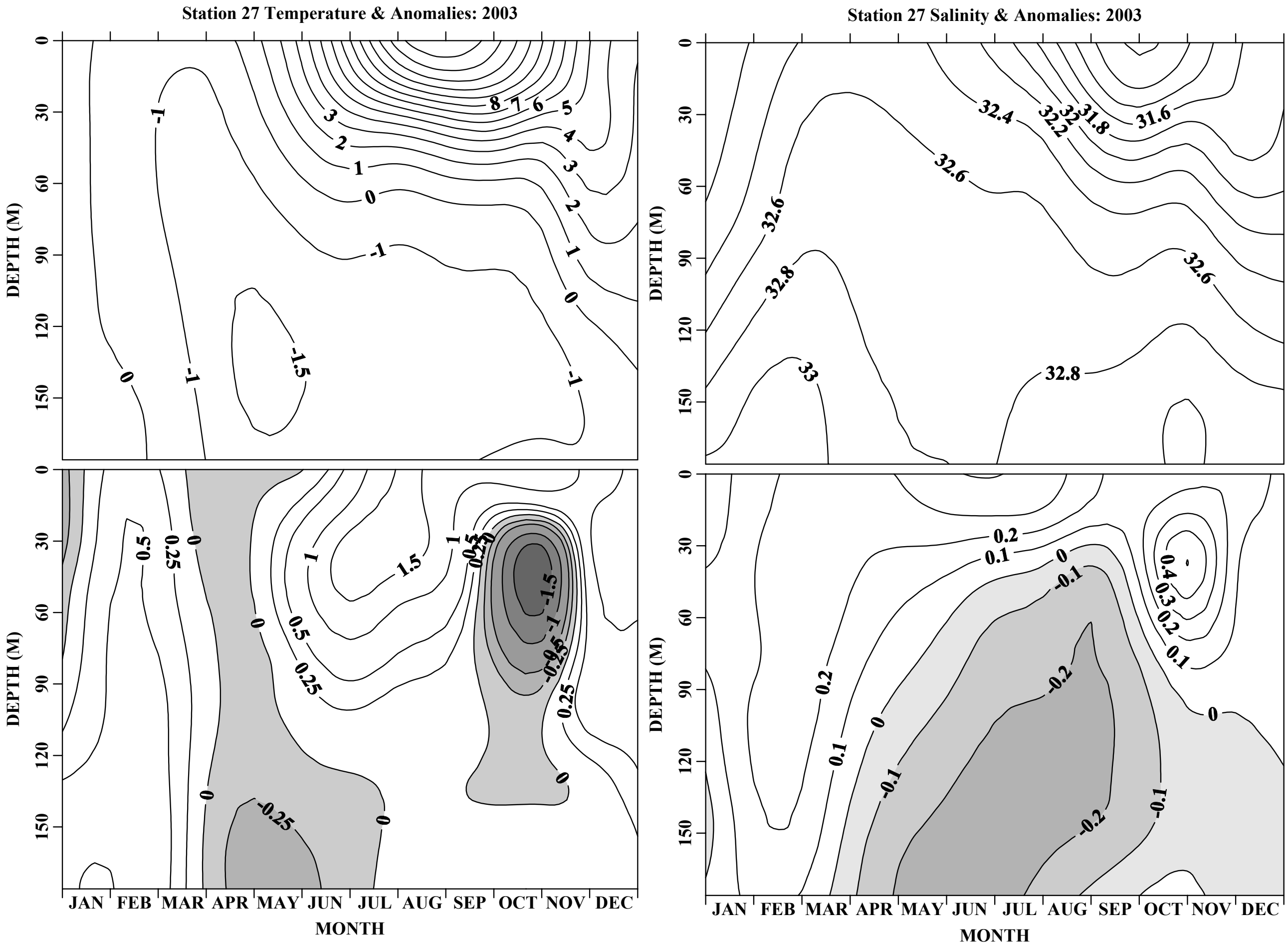


Fig. 2. Contours of monthly temperature (left panels) and salinity (right panels) and their anomalies (in °C) at Station 27 as a function of depth for 2003.

STATION 27 TEMPERATURE ANOMALIES

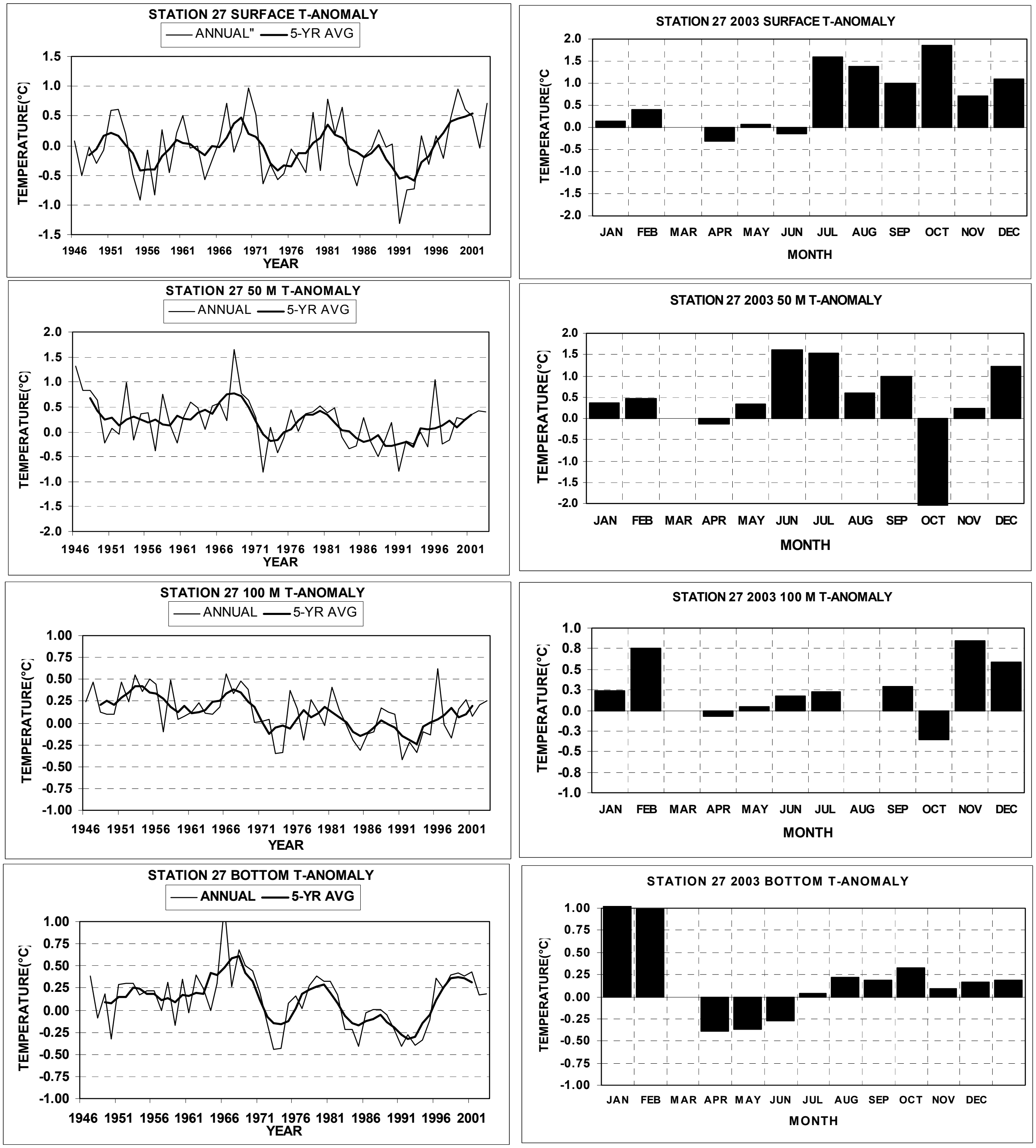


Fig. 3. Station 27 annual temperature anomalies and their 5-year running means at selected depths (left panels) and monthly temperature anomalies (right panels) for 2003.

STATION 27 SALINITY ANOMALIES

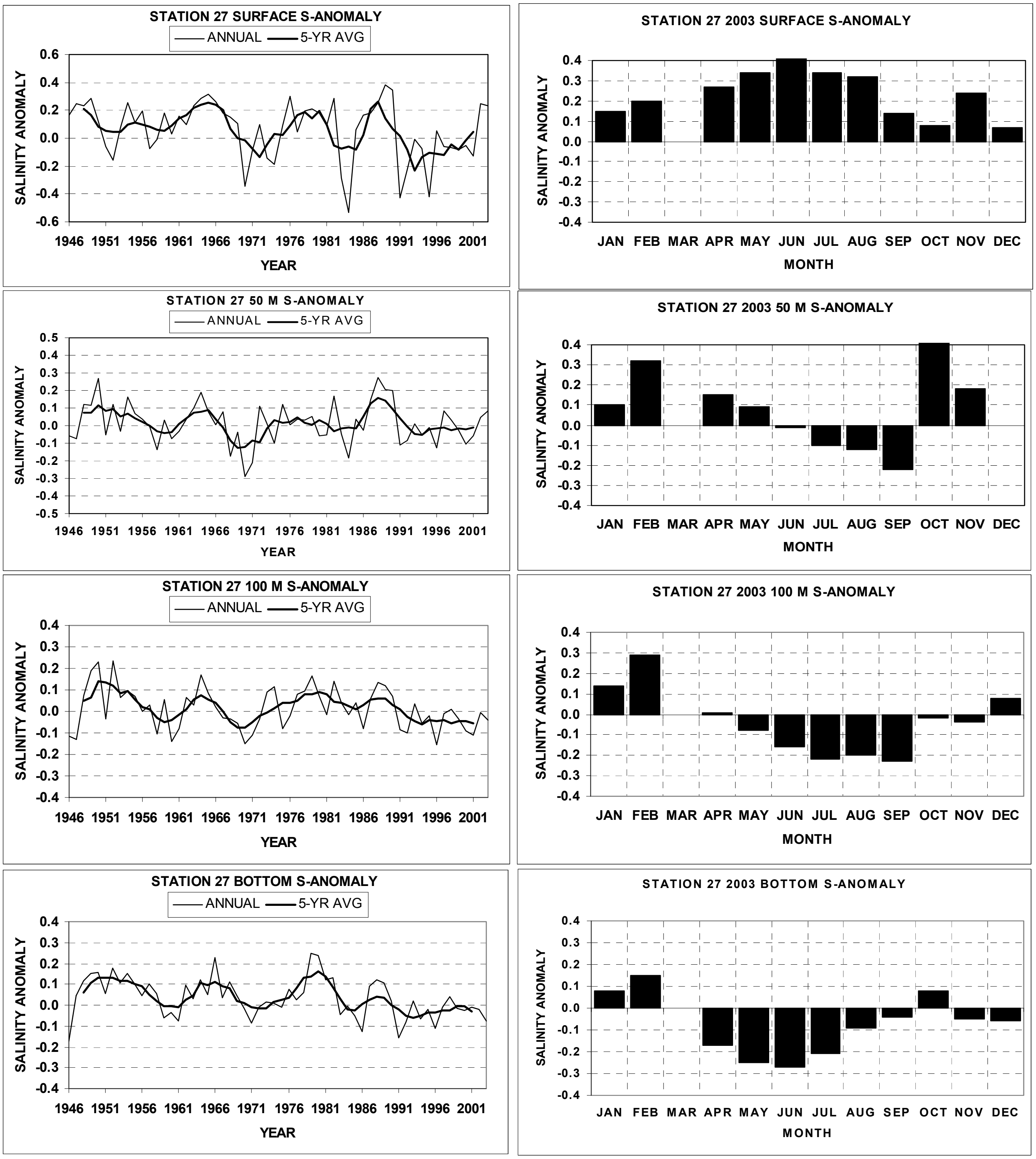


Fig. 4. Station 27 annual salinity anomalies and their 5-year running means at selected depths (left panels) and monthly salinity anomalies (right panels) for 2003.

STATION 27 WATER COLUMN AVERAGES

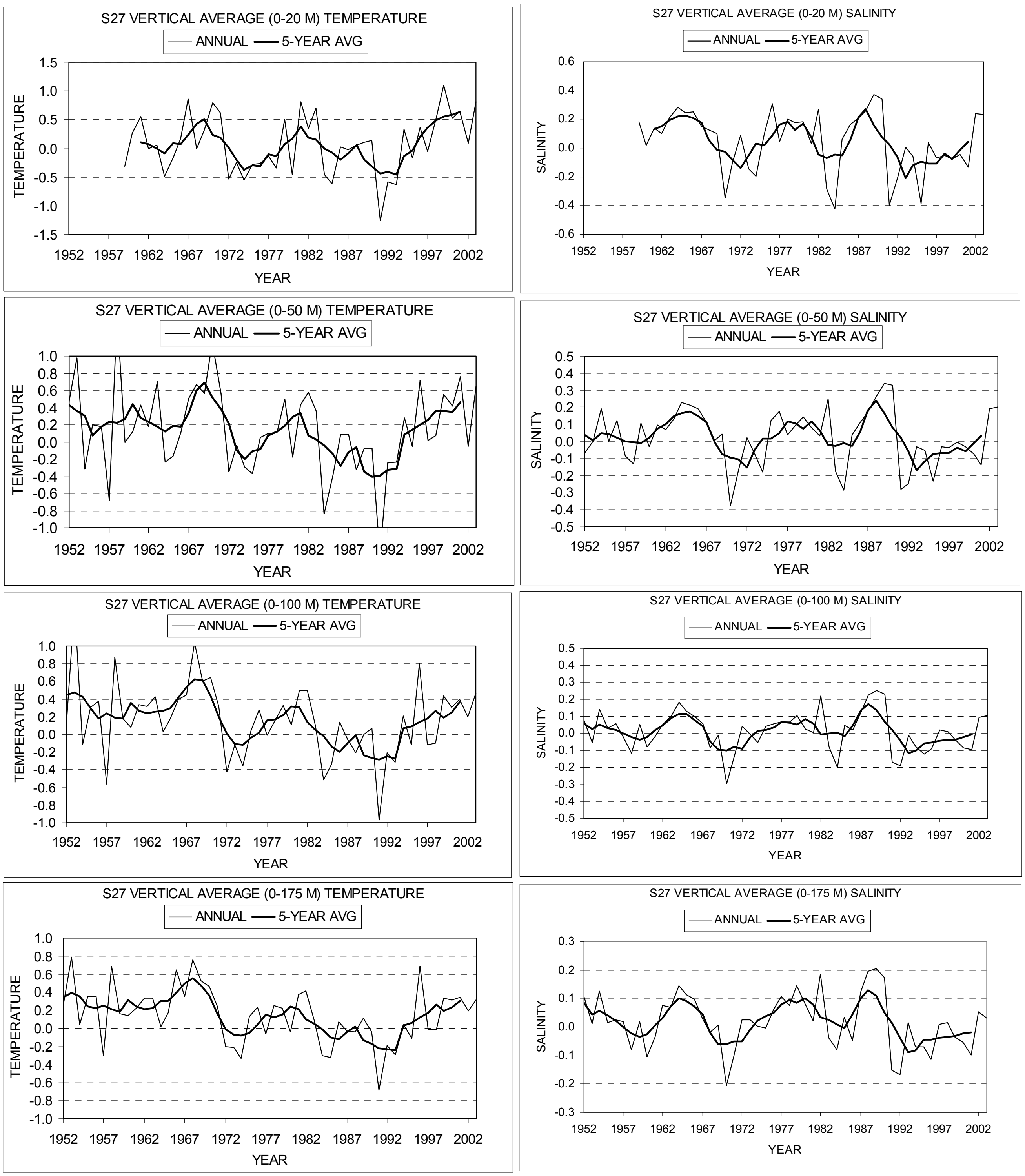


Fig. 5. Depth averaged Station 27 temperature (in °C) anomalies (left panels) and annual salinity anomalies (right panels) over selected depth ranges. The heavy lines are the 5-year running means.

FLEMISH CAP TEMPERATURE AND SALINITY ANOMALIES

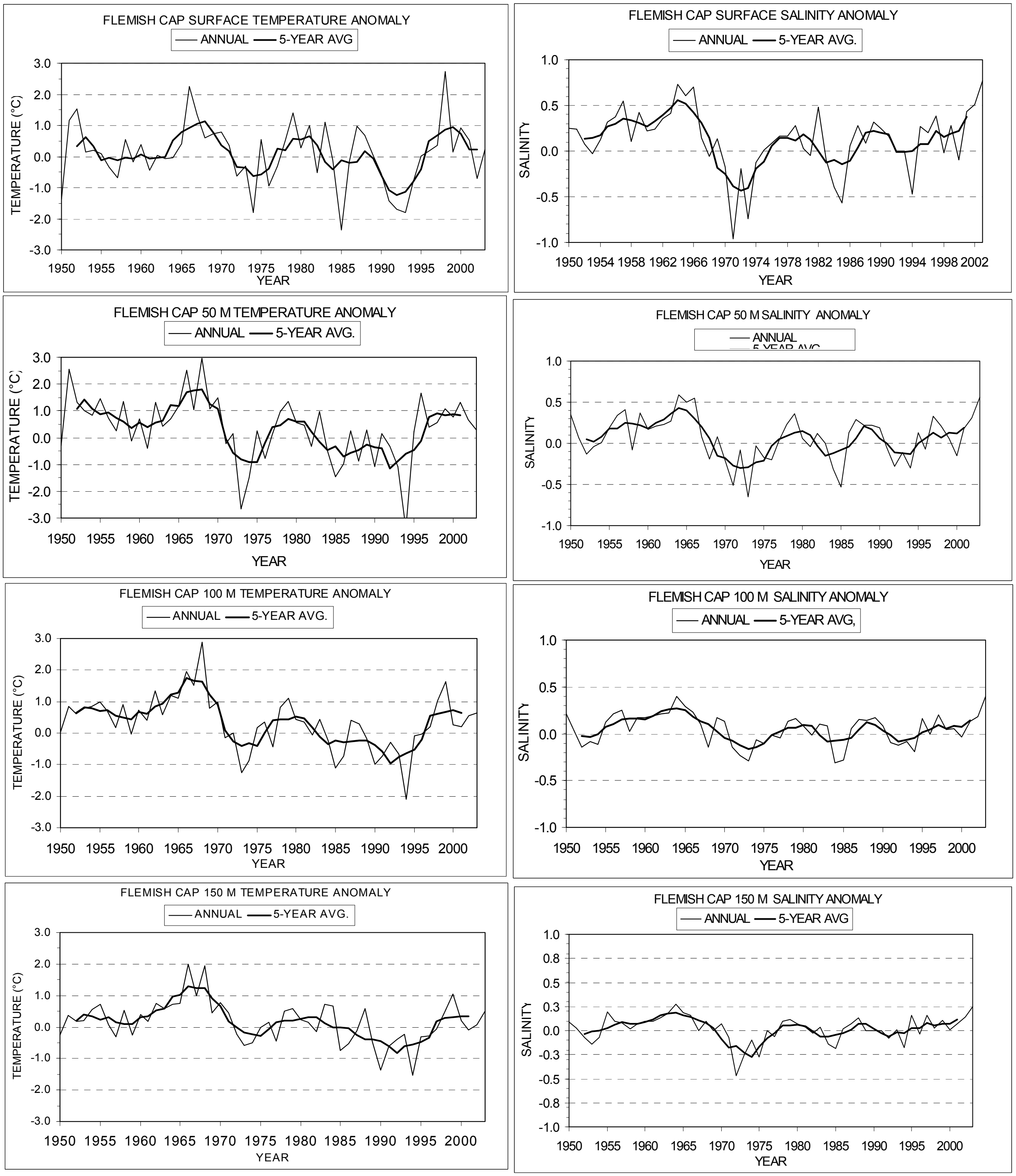


Fig. 6. Annual temperature (left panels) and salinity anomalies (right panels) on the Flemish Cap in NAFO Division 3M at selected water depths. The heavy lines are the 5-year running means.

HAMILTON BANK TEMPERATURE AND SALINITY ANOMALIES

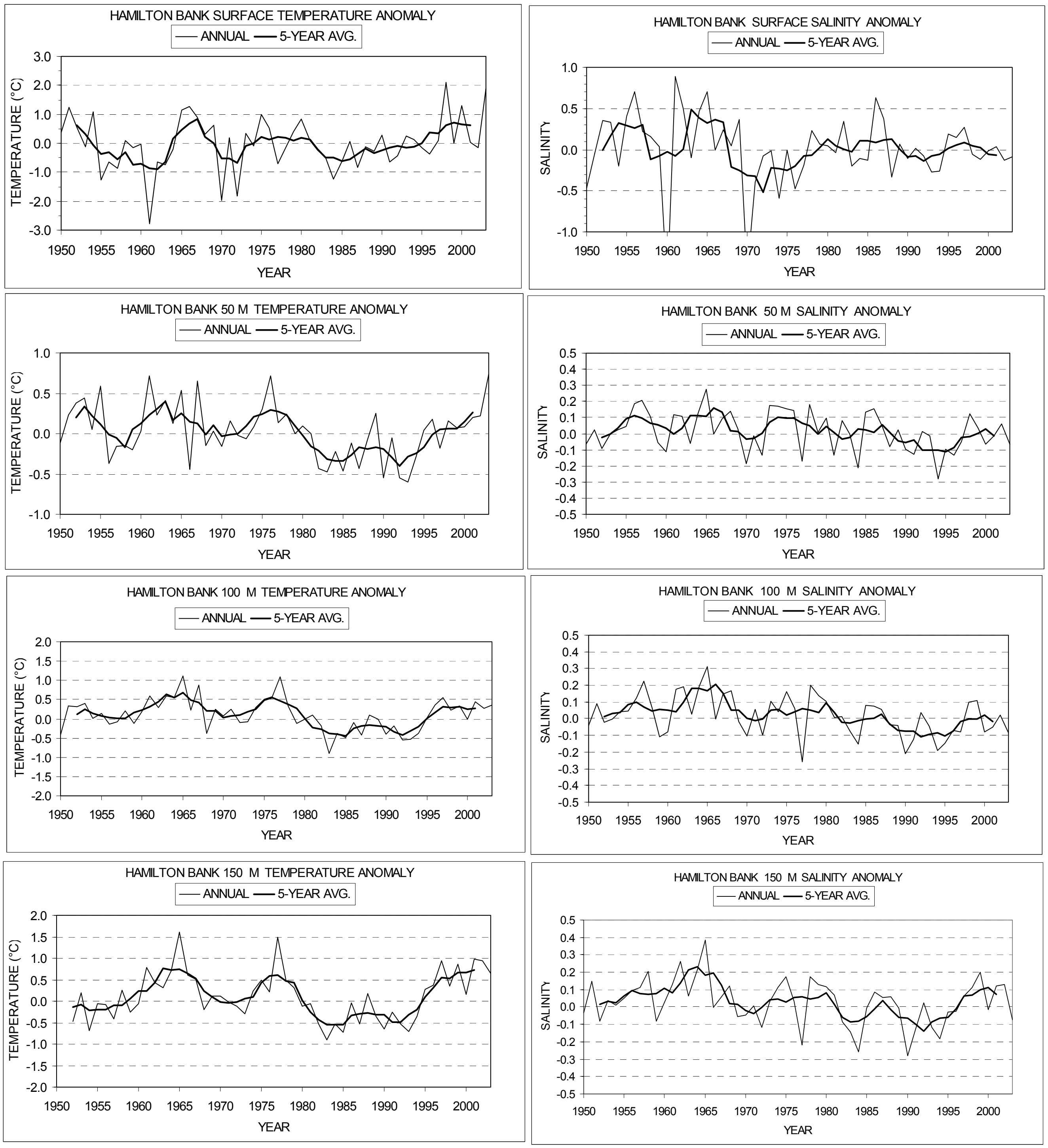


Fig. 7. Annual temperature (left panels) and salinity anomalies (right panels) on Hamilton Bank in NAFO Division 2J at selected water depths. The heavy lines are the 5-year running means.

SOUTHEAST GRAND BANK SECTION (SPRING 2003)

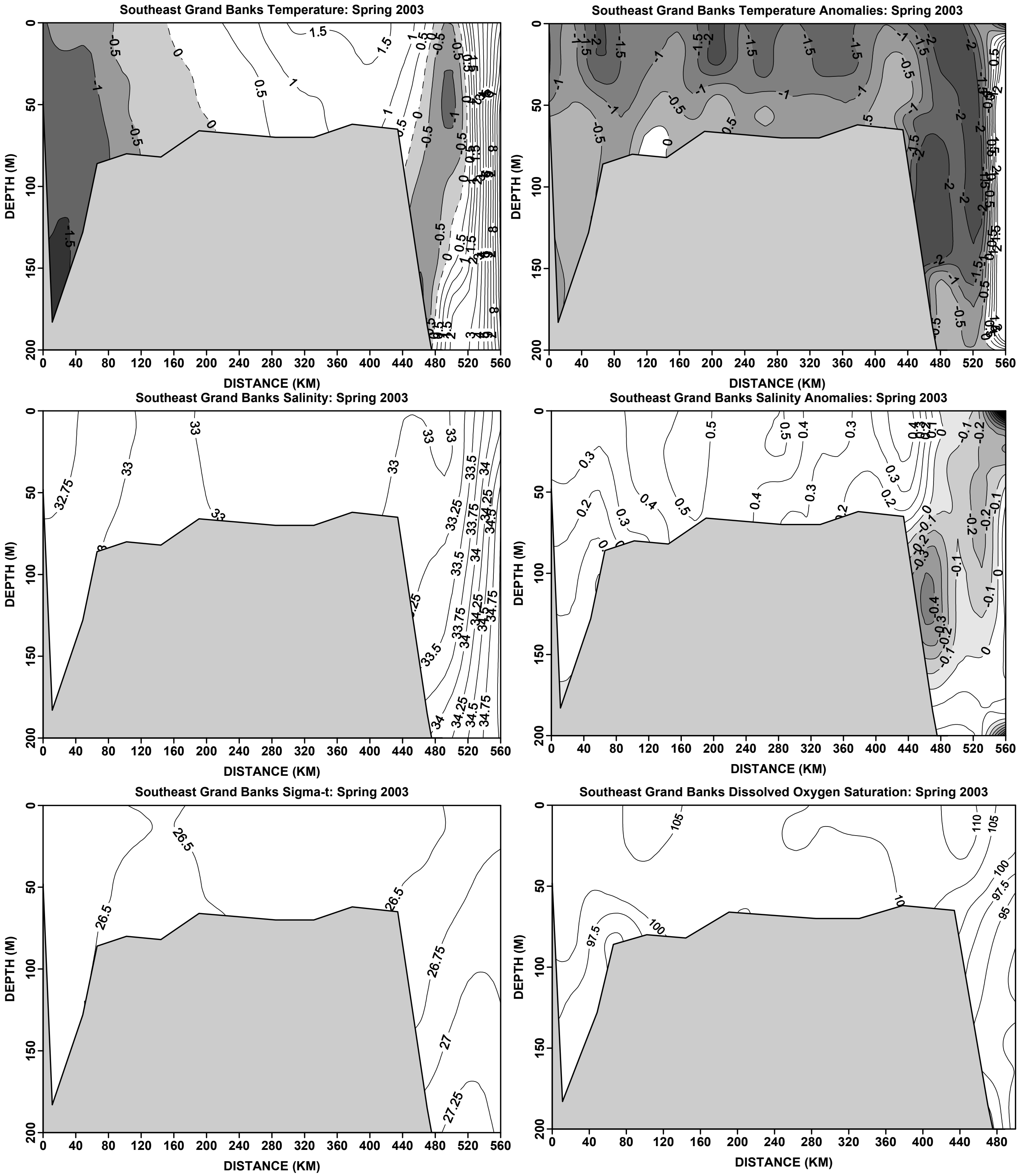


Fig. 8. Contours of temperature and salinity and their anomalies, sigma-t and dissolved oxygen saturation along the Southeast Grand Bank section during the spring of 2003.

SOUTHEAST GRAND BANK SECTION (FALL 2003)

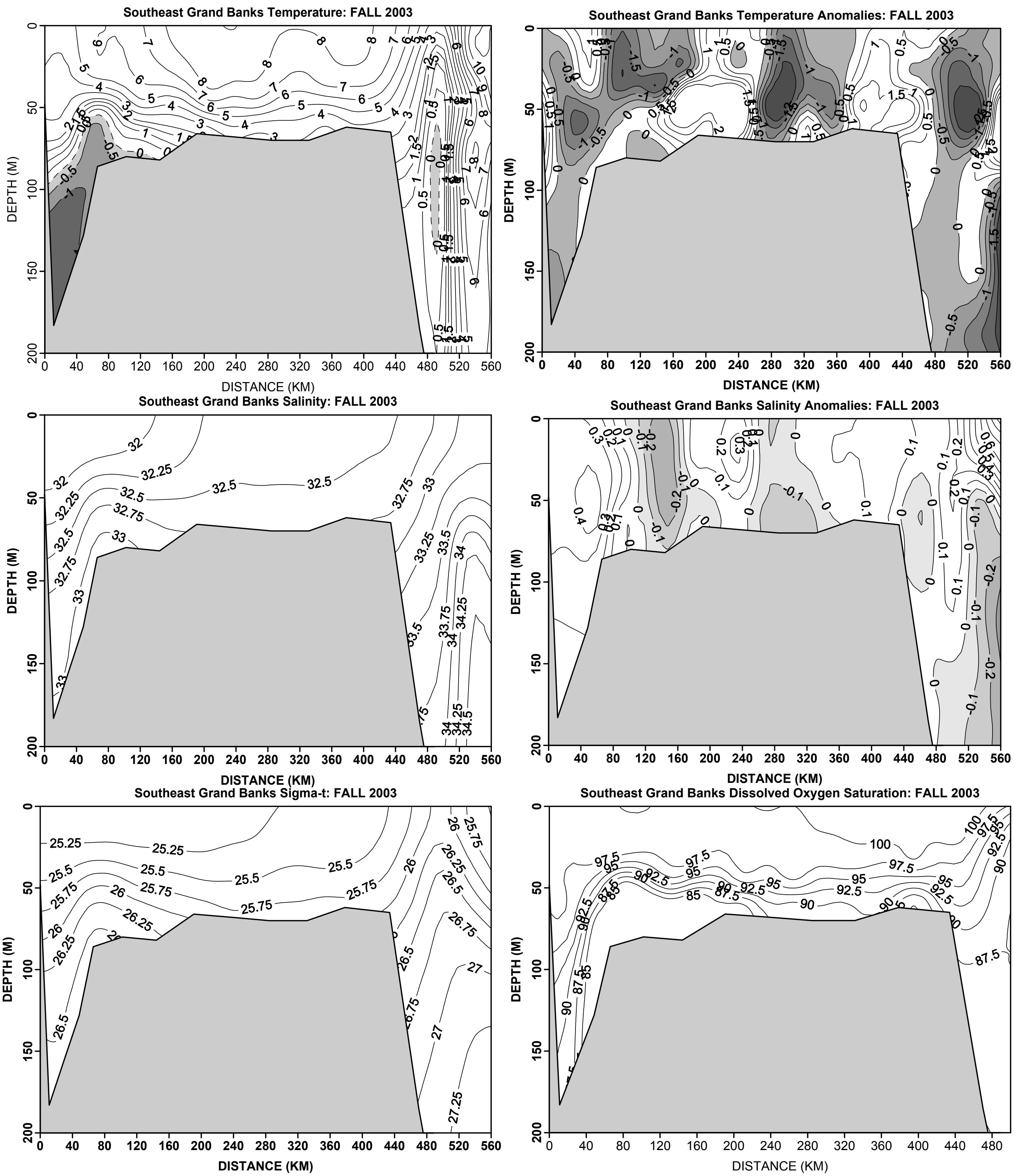


Fig. 9. Contours of temperature and salinity and their anomalies, sigma-t and dissolved oxygen saturation along the Southeast Grand Bank section during the fall of 2003.

FLEMISH CAP SECTION (SPRING 2003)

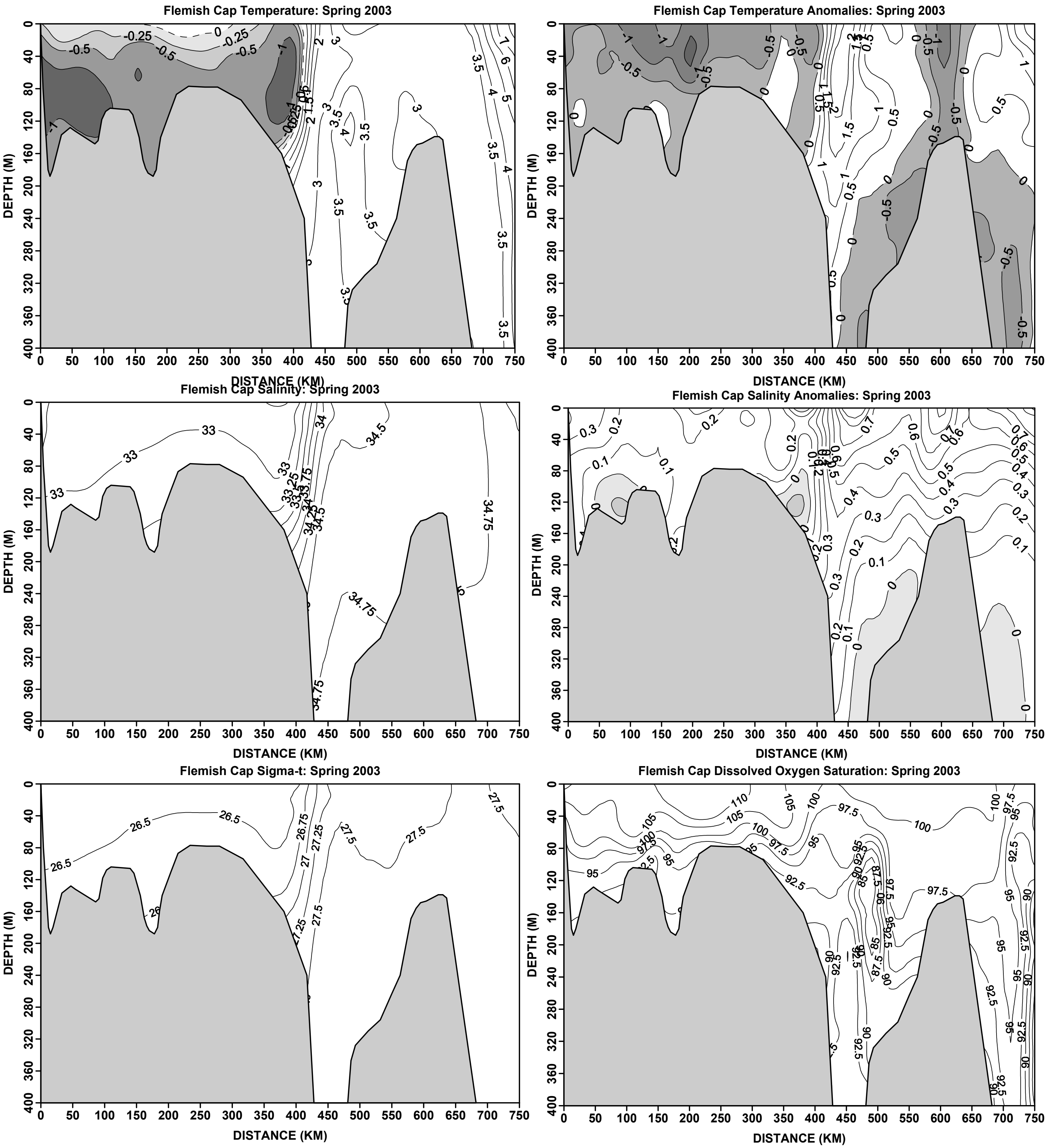


Fig. 10. Contours of temperature and salinity and their anomalies, sigma-t and dissolved oxygen saturation along the standard Flemish Cap section during the spring of 2003.

FLEMISH CAP SECTION (SUMMER 2003)

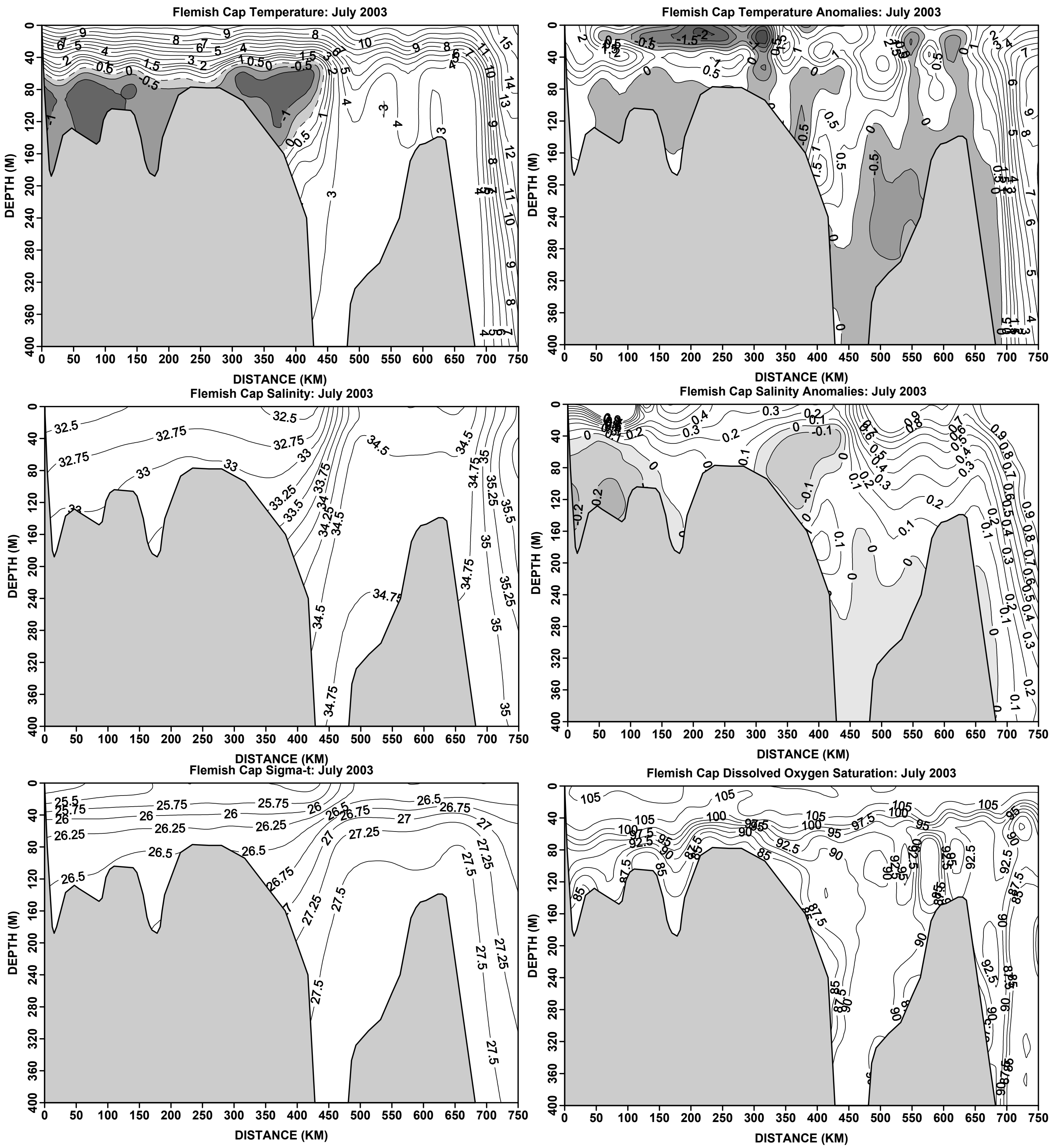


Fig. 11. Contours of temperature and salinity and their anomalies, sigma-t and dissolved oxygen saturation along the standard Flemish Cap section during the summer of 2003.

FLEMISH CAP SECTION (FALL 2003)

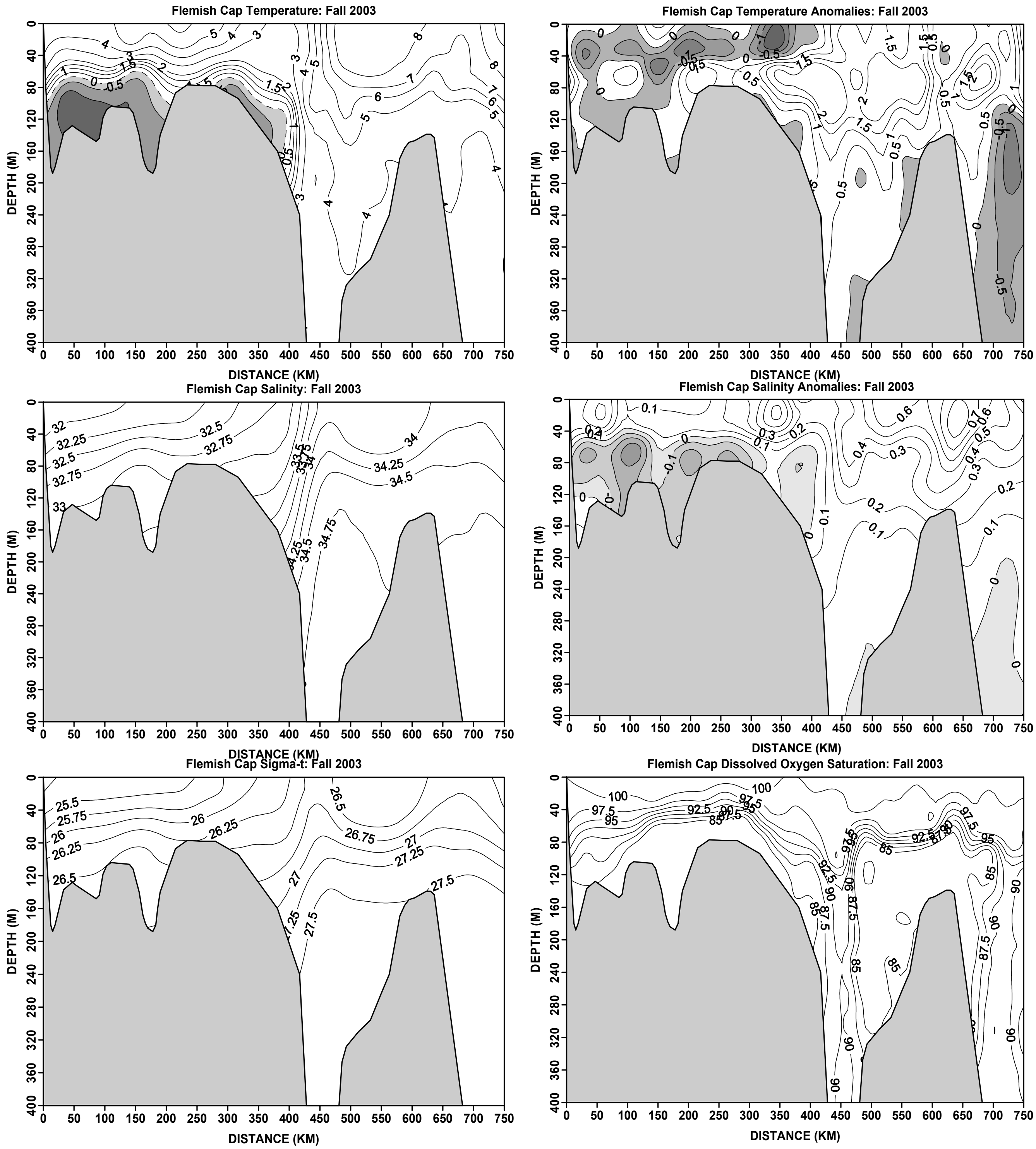


Fig. 12. Contours of temperature and salinity and their anomalies, sigma-t and dissolved oxygen saturation along the standard Flemish Cap section during the fall of 2003.

BONAVISTA SECTION (SPRING 2003)

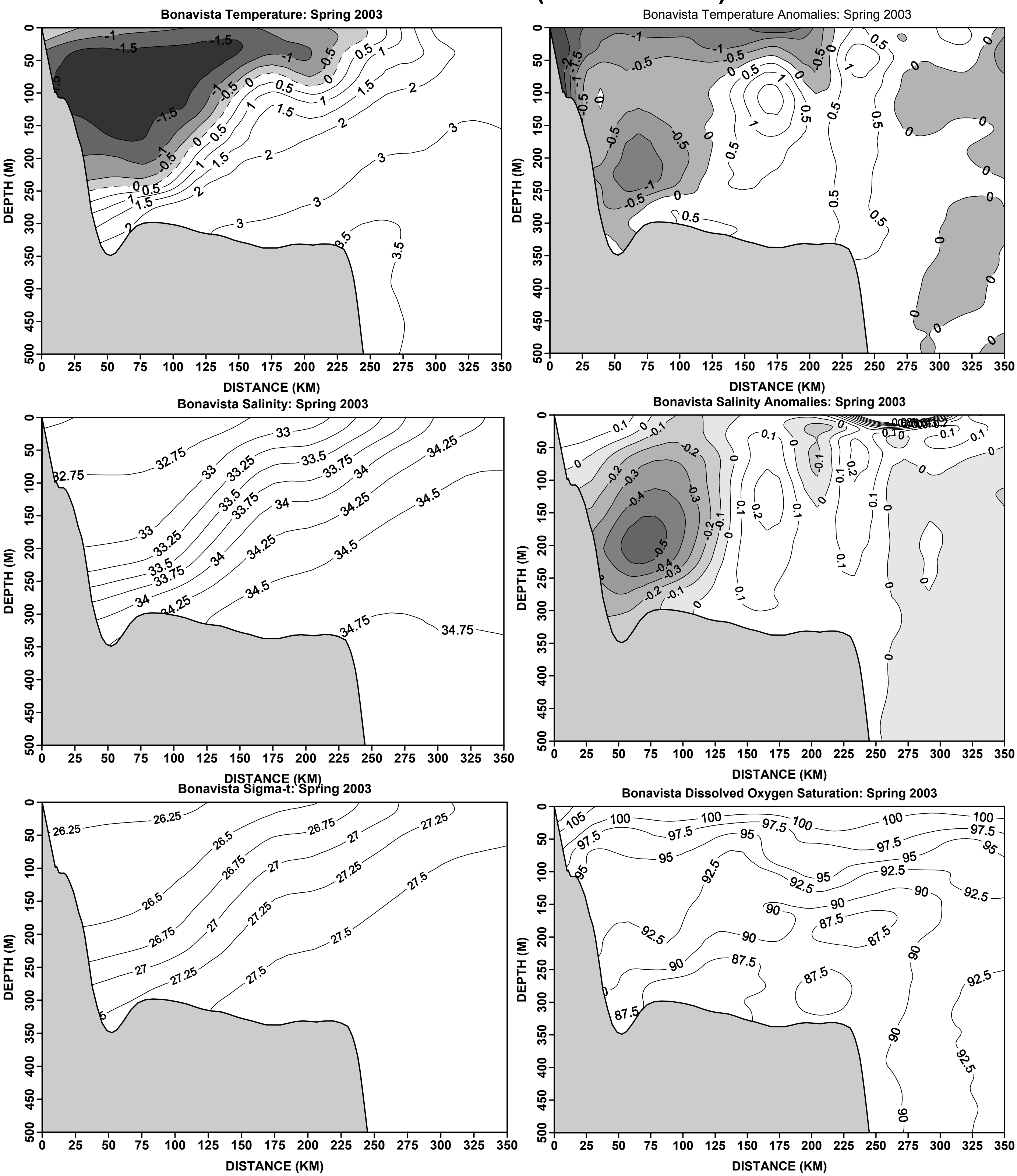


Fig. 13. Contours of temperature and salinity and their anomalies, sigma-t and dissolved oxygen saturation along the standard Bonavista section during the spring of 2003

BONAVISTA SECTION (SUMMER 2003)

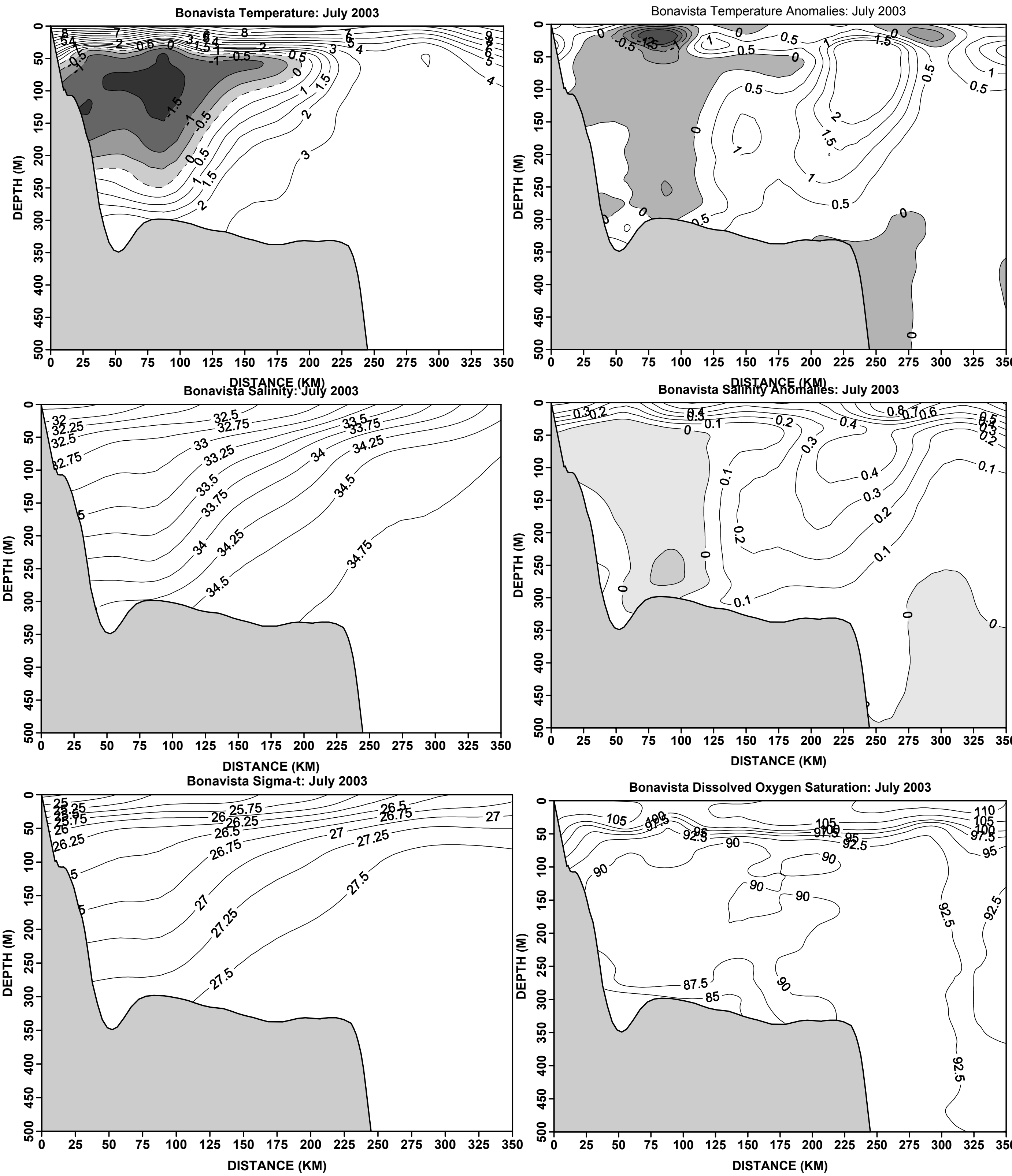


Fig. 14. Contours of temperature and temperature anomalies, salinity, sigma-t and dissolved oxygen saturation along the standard Bonavista section during the summer of 2003.

BONAVISTA SECTION (FALL 2003)

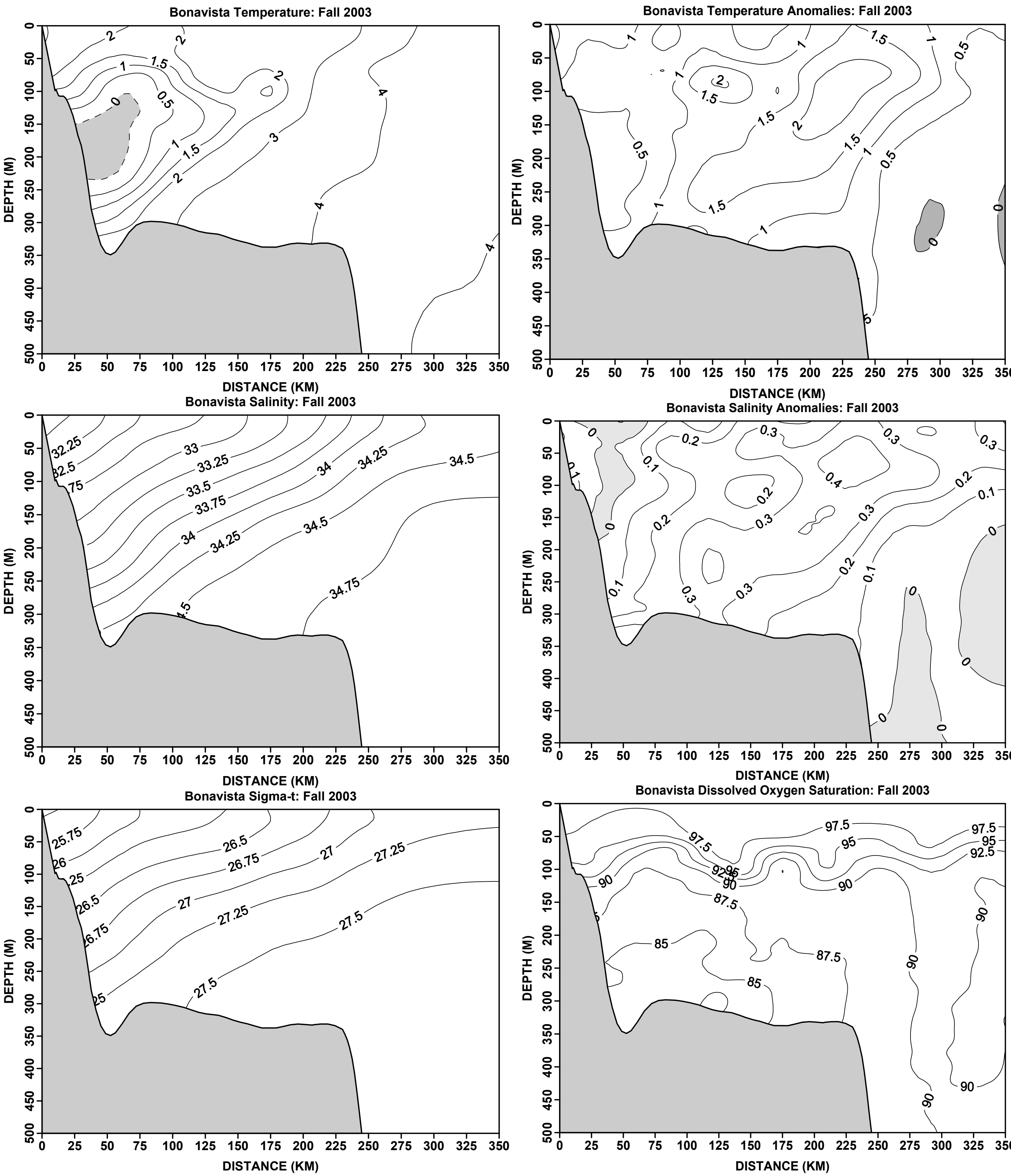


Fig. 15. Contours of temperature and salinity and their anomalies, sigma-t and dissolved oxygen saturation along the standard Bonavista section during the fall of 2003.

WHITE BAY SECTION (SUMMER 2003)

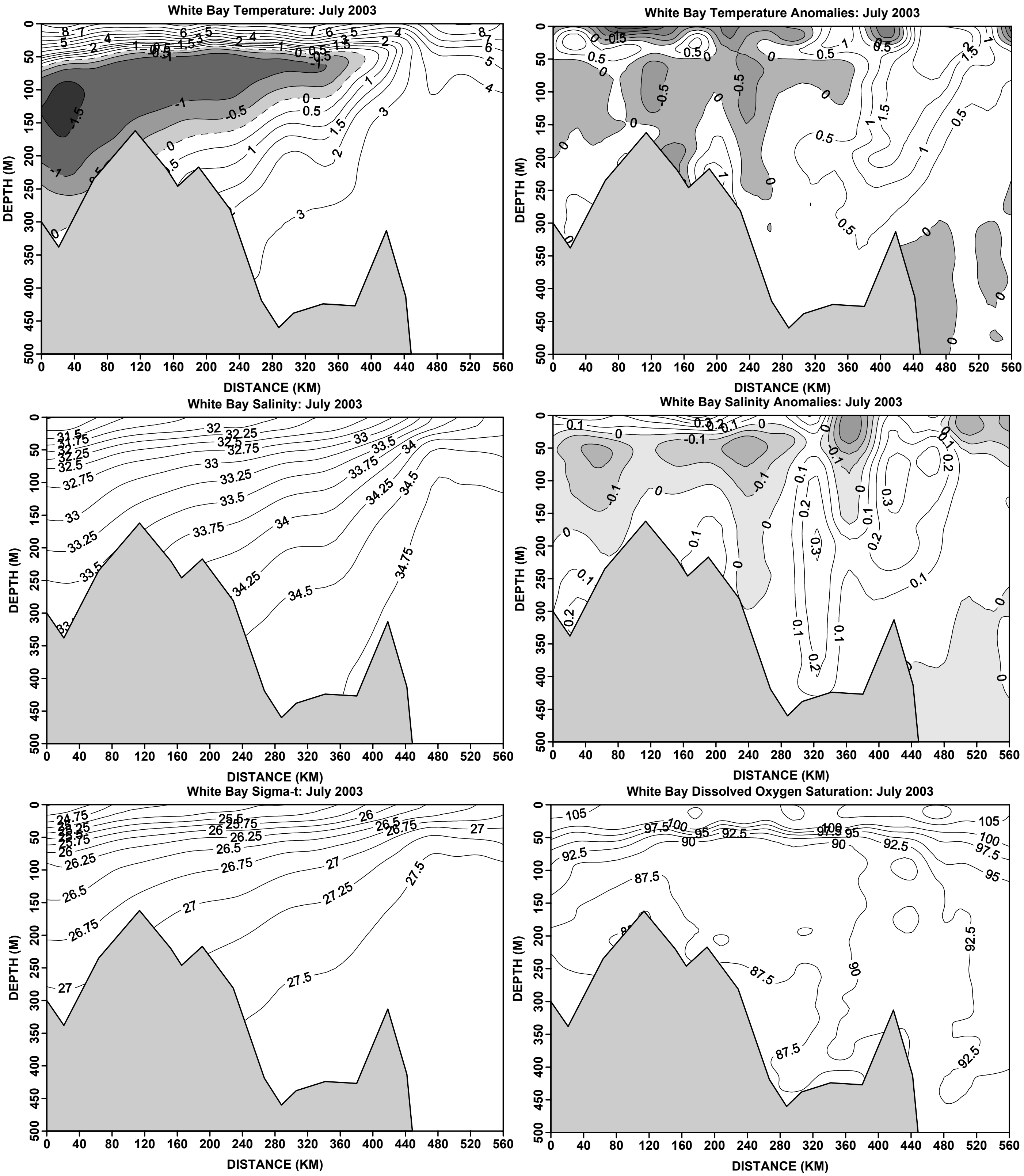


Fig. 16. Contours of temperature and salinity and their anomalies, sigma-t and dissolved oxygen saturation along the standard White Bay section during the summer of 2003.

SEAL ISLAND SECTION (SUMMER 2003)

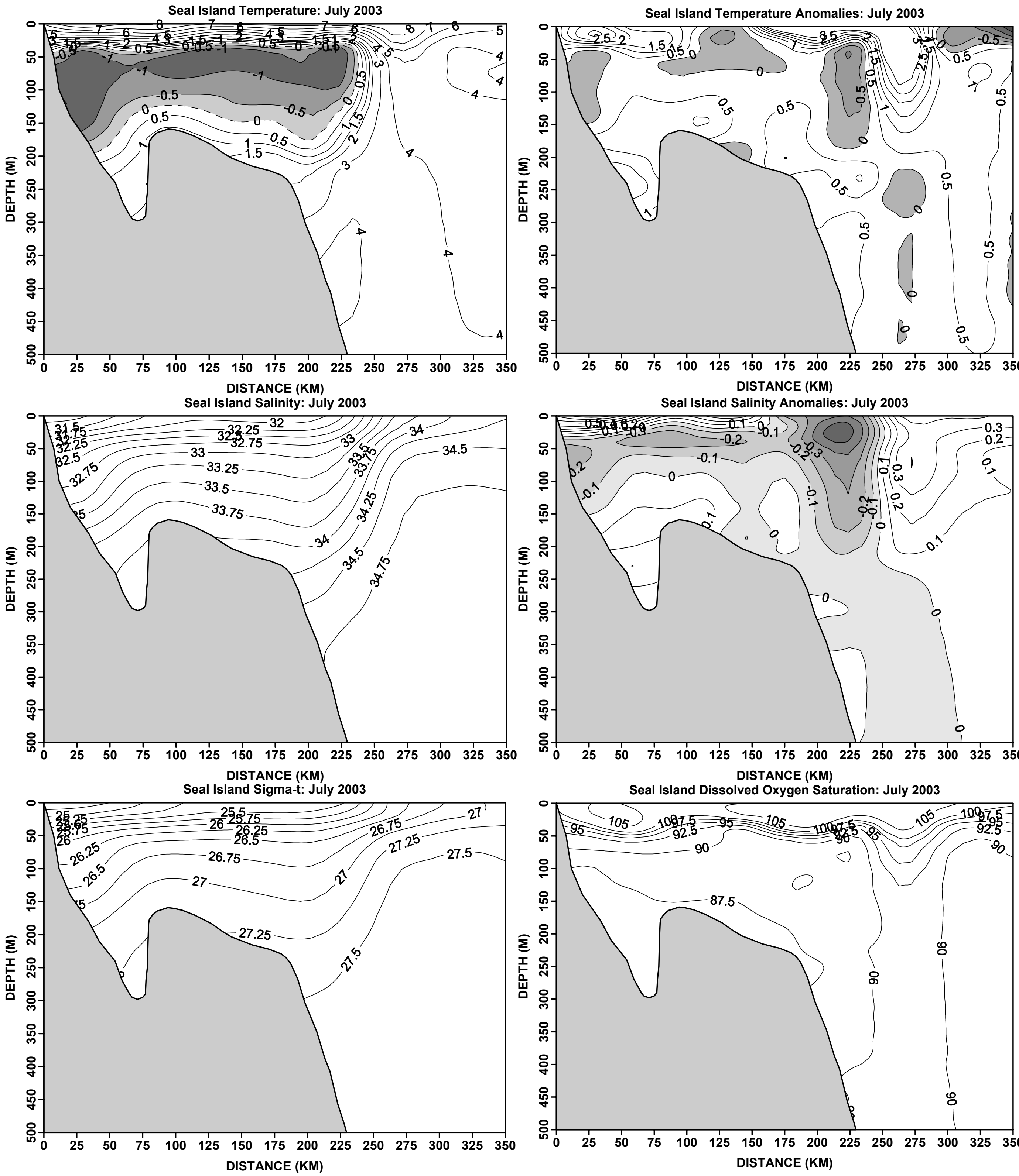


Fig. 17. Contours of temperature and salinity and their anomalies, sigma-t and dissolved oxygen saturation along the standard Seal Island transect during the summer of 2003.

MAKKOVIK BANK SECTION (SUMMER 2003)

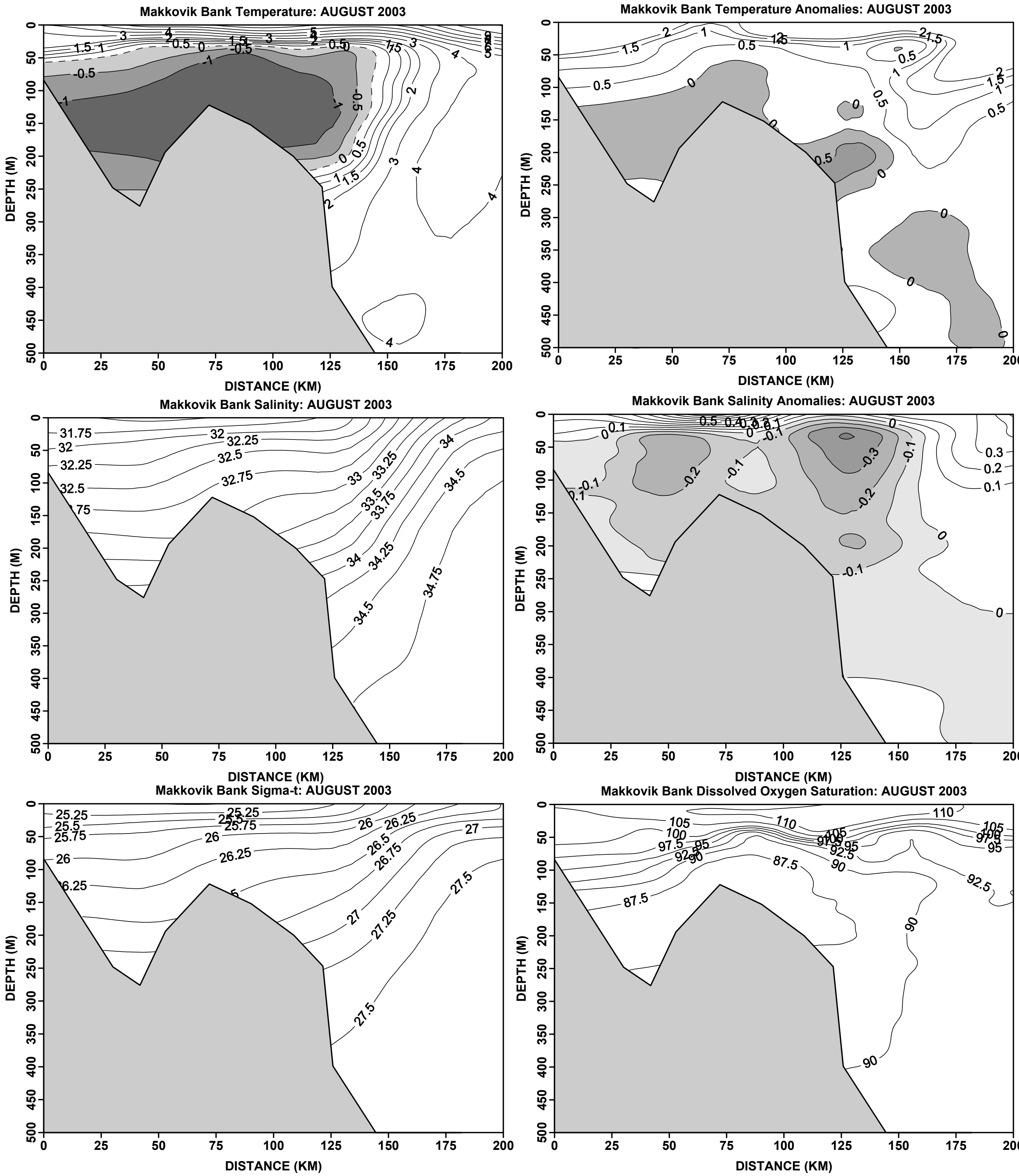


Fig. 18. Contours of temperature and salinity and their anomalies, sigma-t and dissolved oxygen saturation along the Makkovik Bank section during the summer of 2003.

NAIN BANK (BEACHY ISLAND) SECTION (SUMMER 2003)

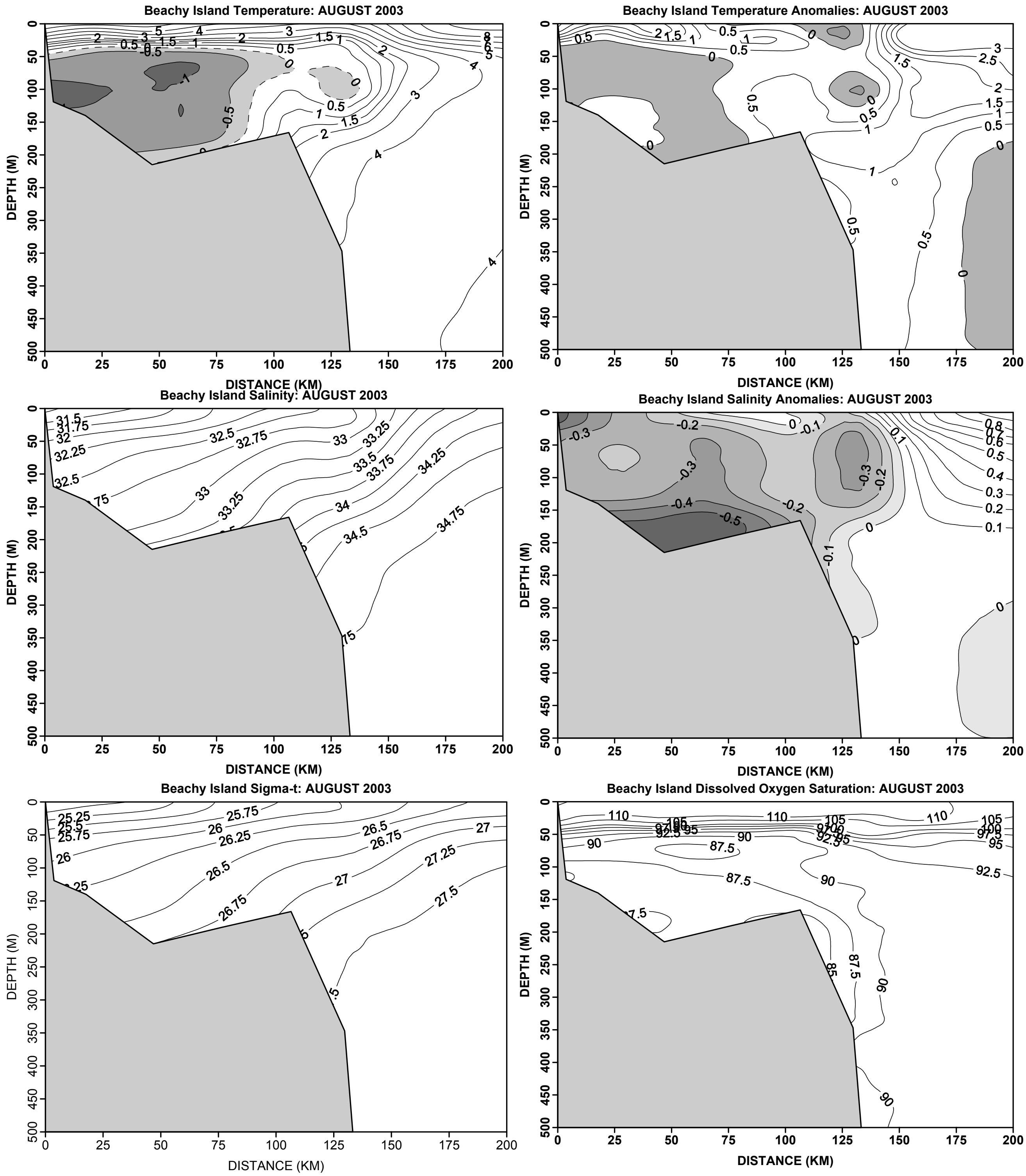


Fig. 19. Contours of temperature, salinity, sigma-t and dissolved oxygen saturation along the Standard Beachy Island section during the summer of 2003.

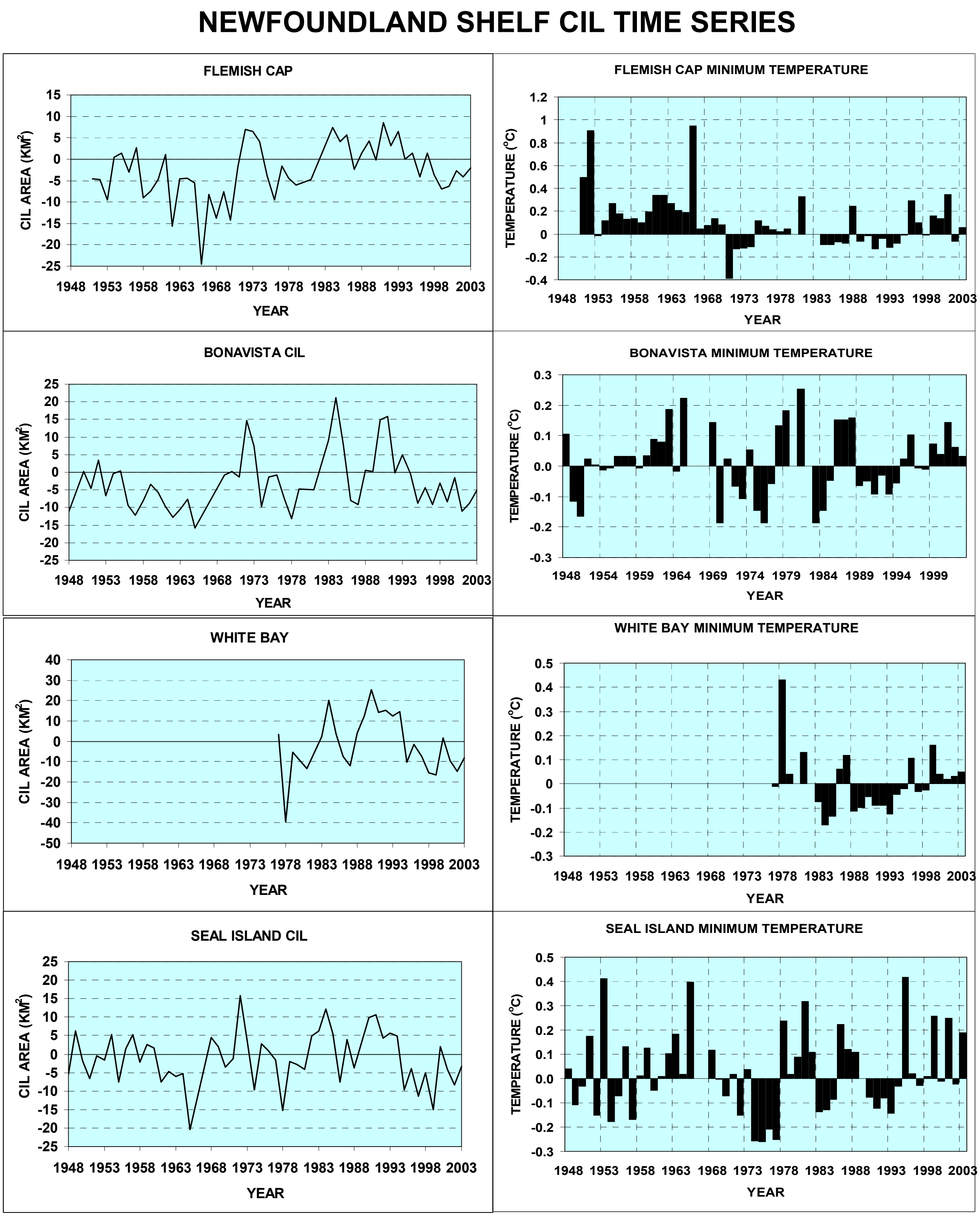


Fig. 20. Annual summer CIL cross-sectional area (left panels) and minimum temperature (right panels) anomalies along the Flemish Cap, Bonavista, White Bay and Seal Island sections. The anomalies are referenced to the 1971-2000 mean.

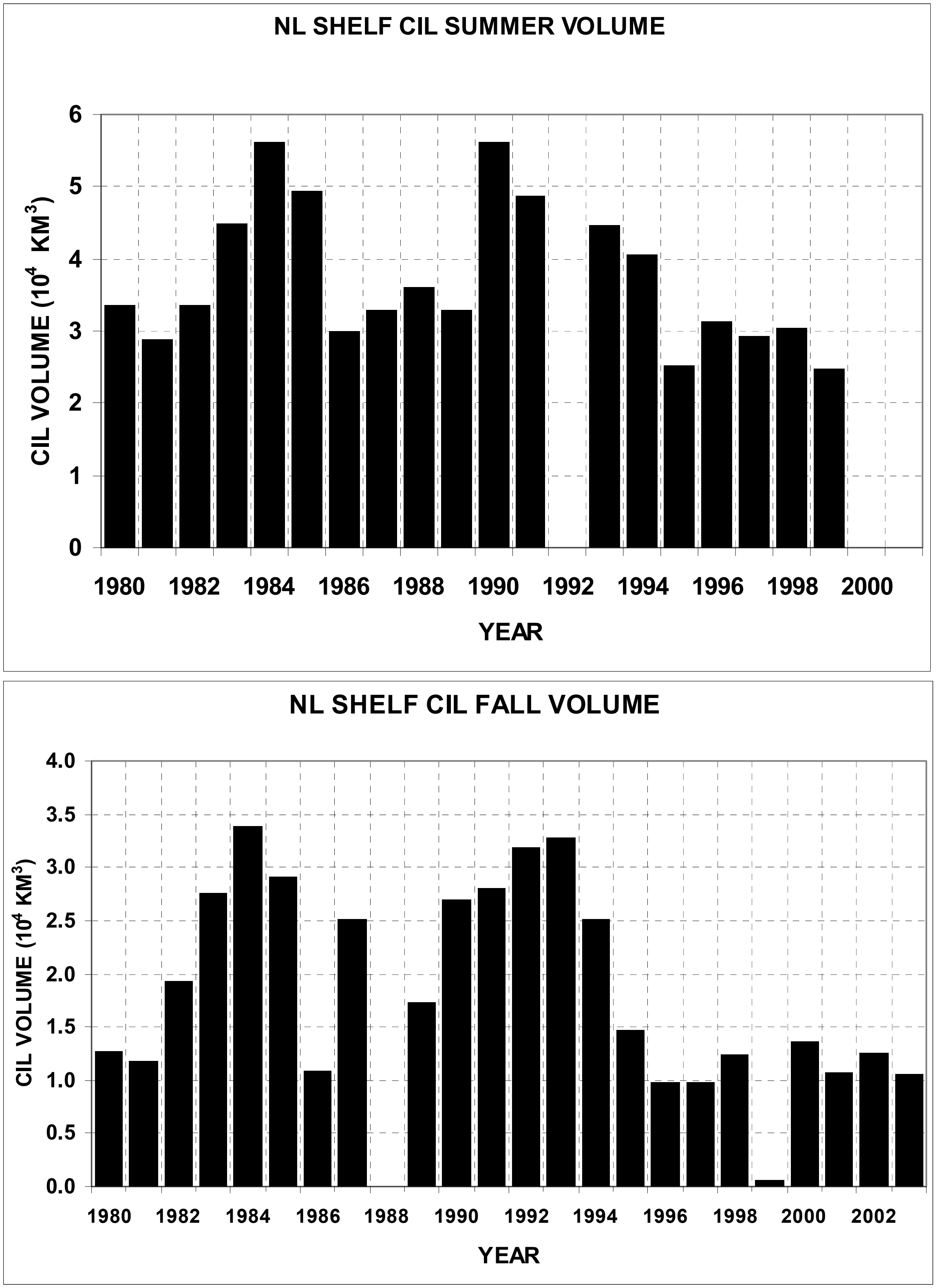


Fig. 21. Summer and fall cold-intermediate-layer (CIL) volumes with temperatures <0°C over the 2J3KL areas. There were insufficient data to calculate the summer 2000 to 2003 values.

GEOSTROPHIC CURRENTS (SUMMER 2003)

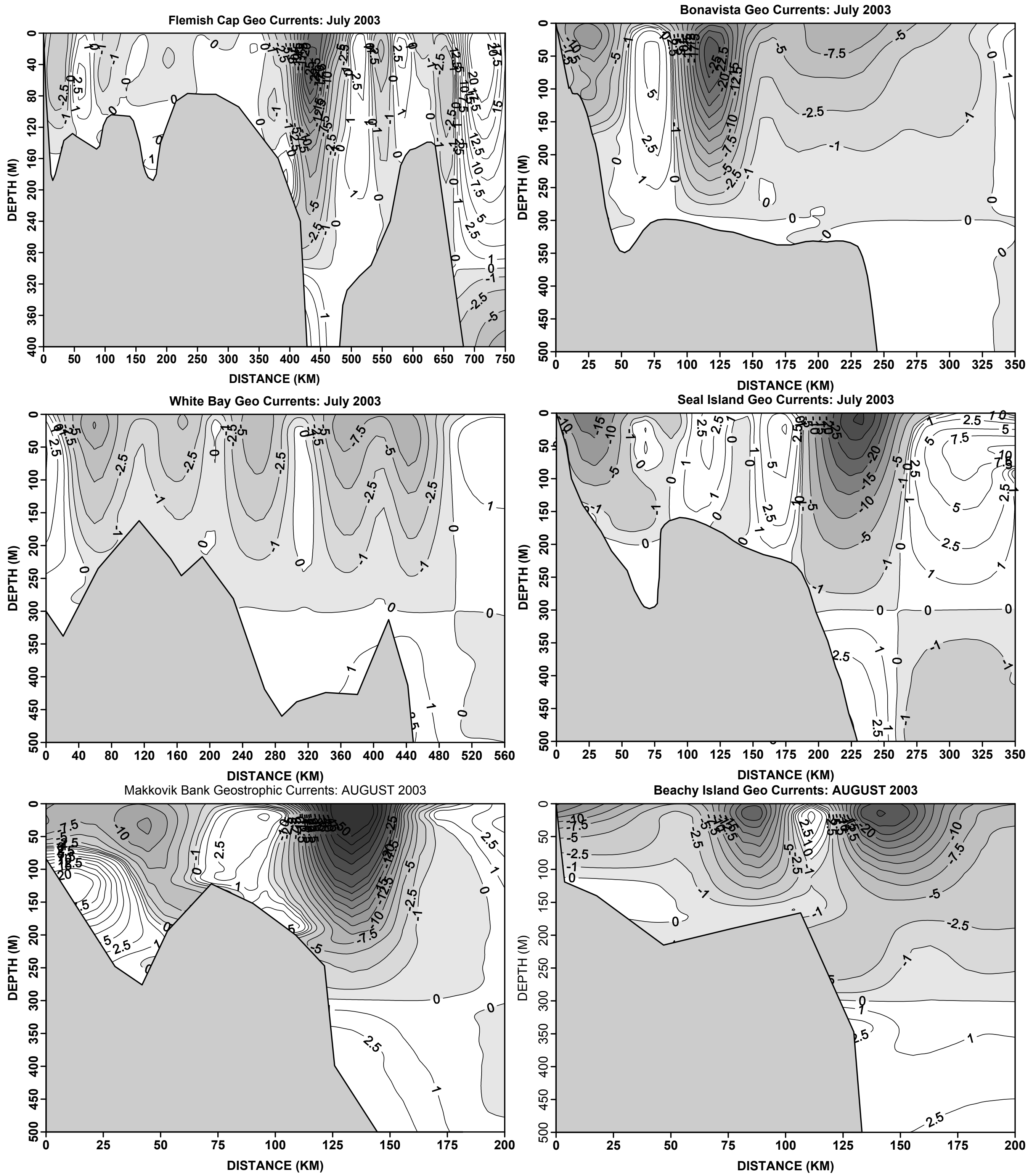


Fig. 22. Contours of geostrophic currents (in cm/s) along the Flemish Cap, Bonavista, White Bay, Seal Island, Makkovik Bank and Beachy Island sections during the summer of 2003. Negative shaded values are southward.

GEOSTROPHIC TRANSPORT

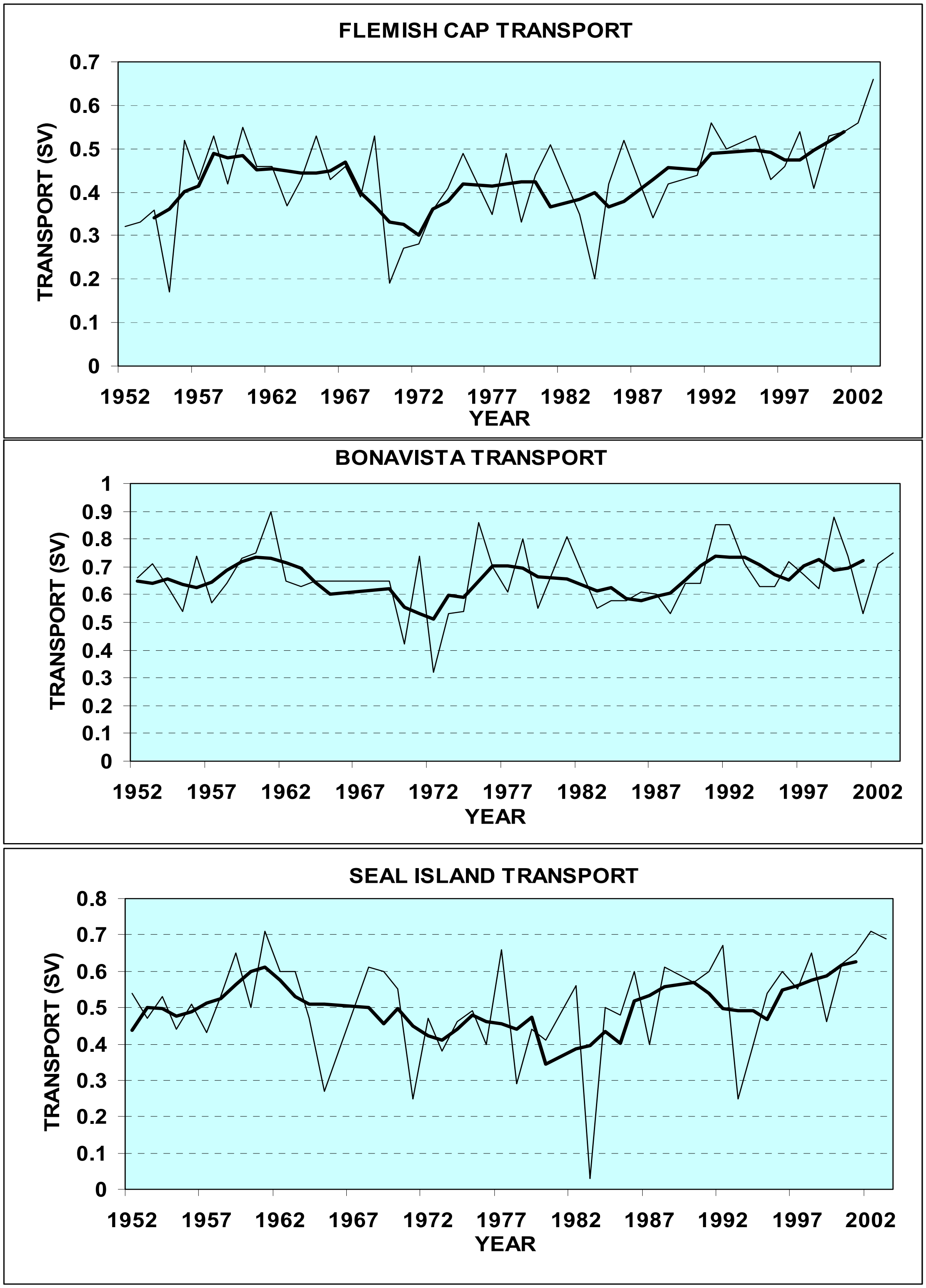


Fig. 23. Time series of geostrophic transport (10^6 m^3/s) relative to 135-m depth of the offshore branch of the Labrador Current through the Seal Island, Bonavista and Flemish Cap sections. The heavy line is the 5-year running mean.

MULTI-SPECIES SURVEY (SPRING 2002 and 2003)

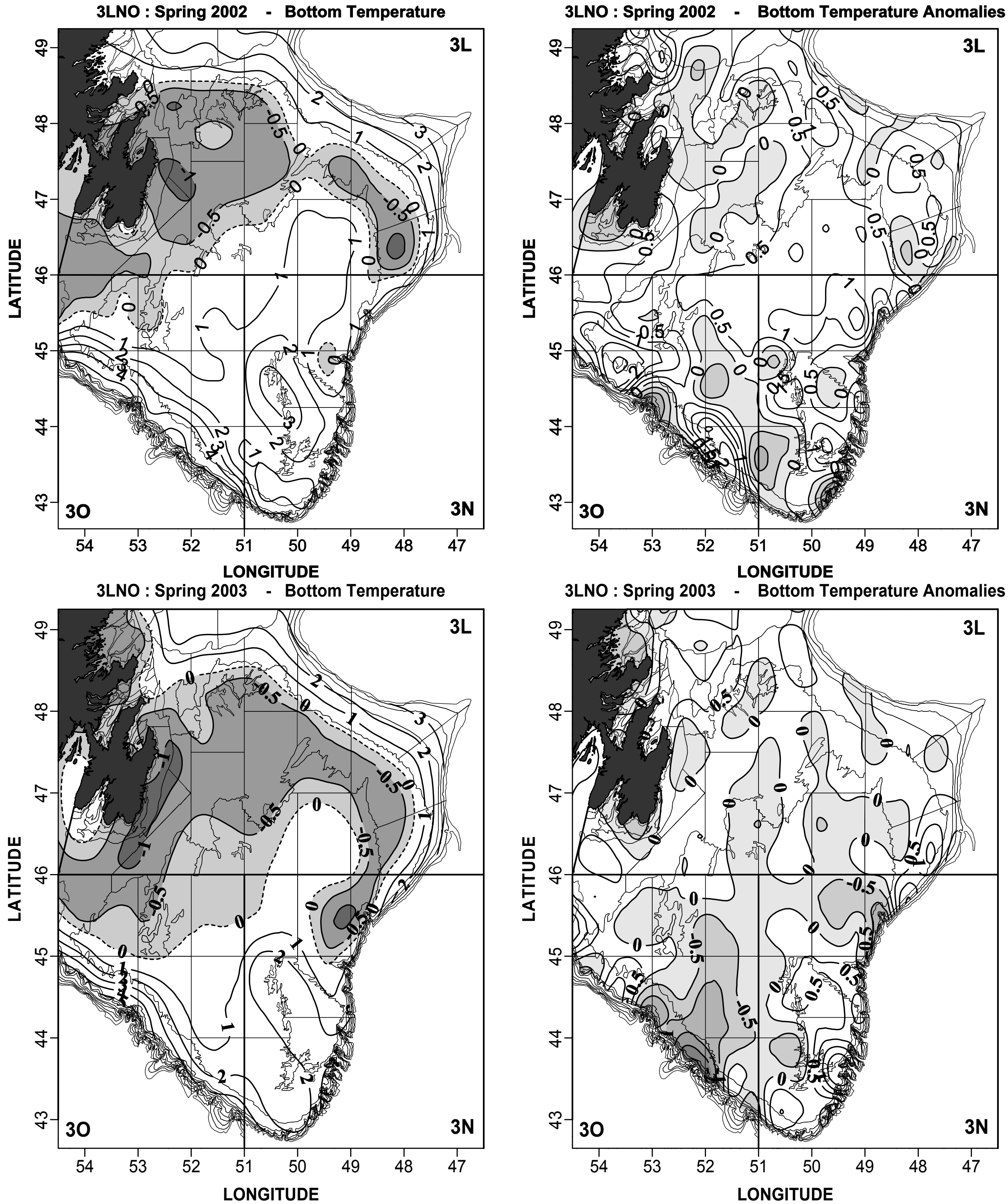


Fig. 24. Contours of bottom temperature and their anomalies (in °C) for the spring of 2002 and 2003 from the multi-species survey of NAFO Divs. 3LNO.

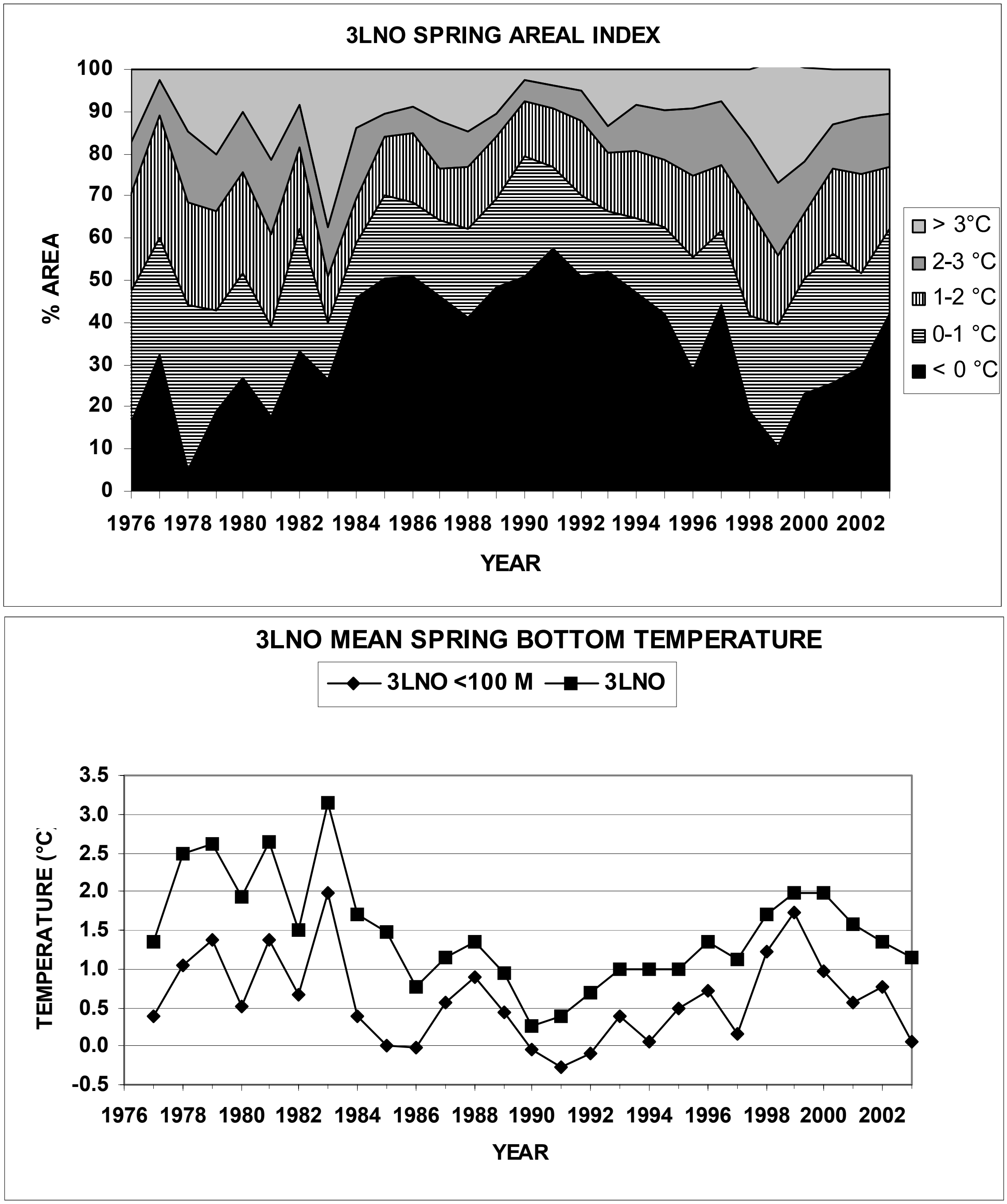


Fig. 25. Time series of the percentage area of the bottom in NAFO Divs. 3LNO covered by water with temperatures ≤ 0°C, 0-1°C, 1-2°C, 2-3°C and ≥3°C during spring (upper panel) and the mean bottom temperature in °C (bottom panel).

MULTI-SPECIES SURVEY (FALL 2002 AND 2003)

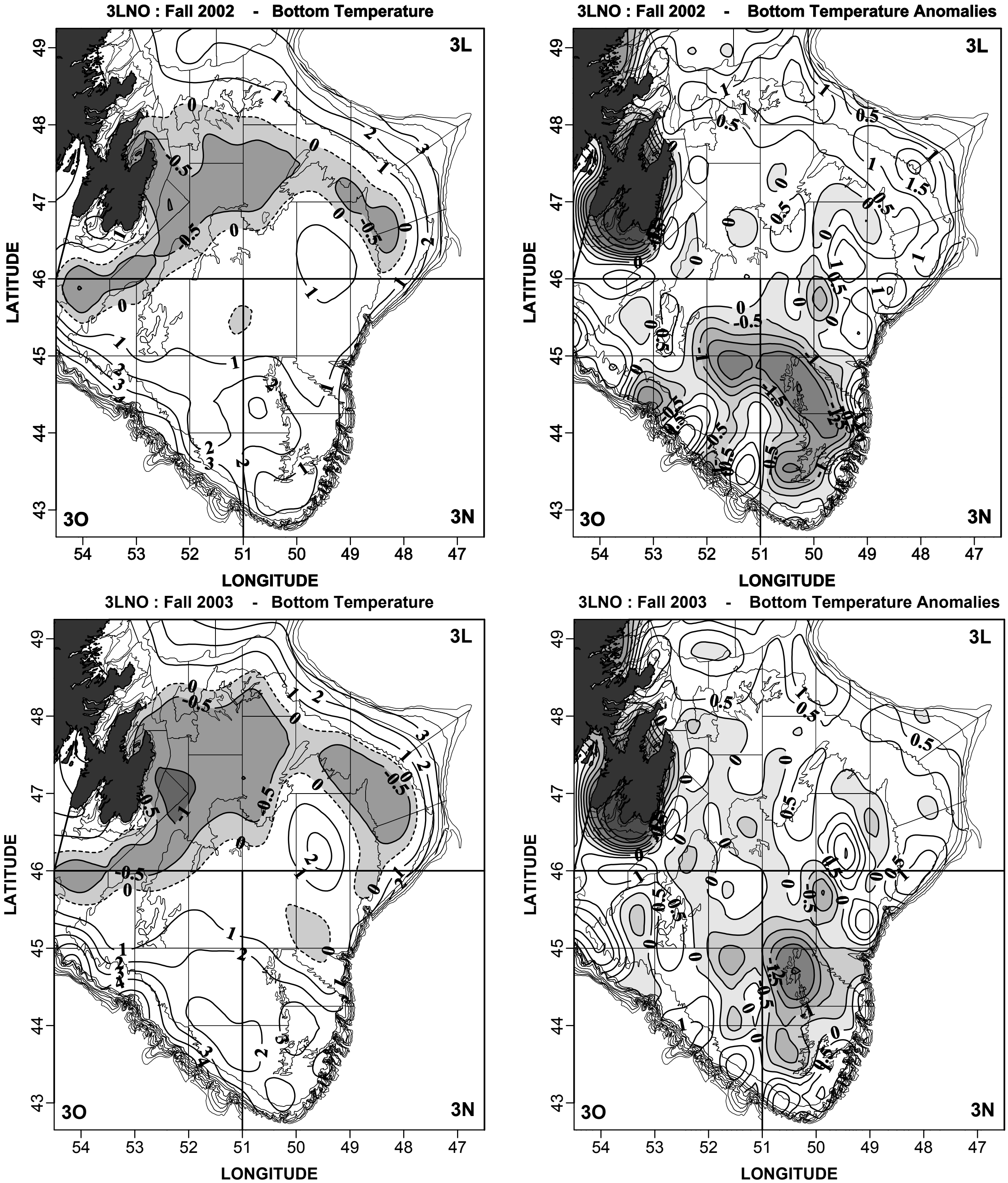


Fig. 26. Contours of bottom temperature and their anomalies (in °C) for the fall of 2002 and 2003 from the multi-species survey of NAFO Divs. 3LNO.

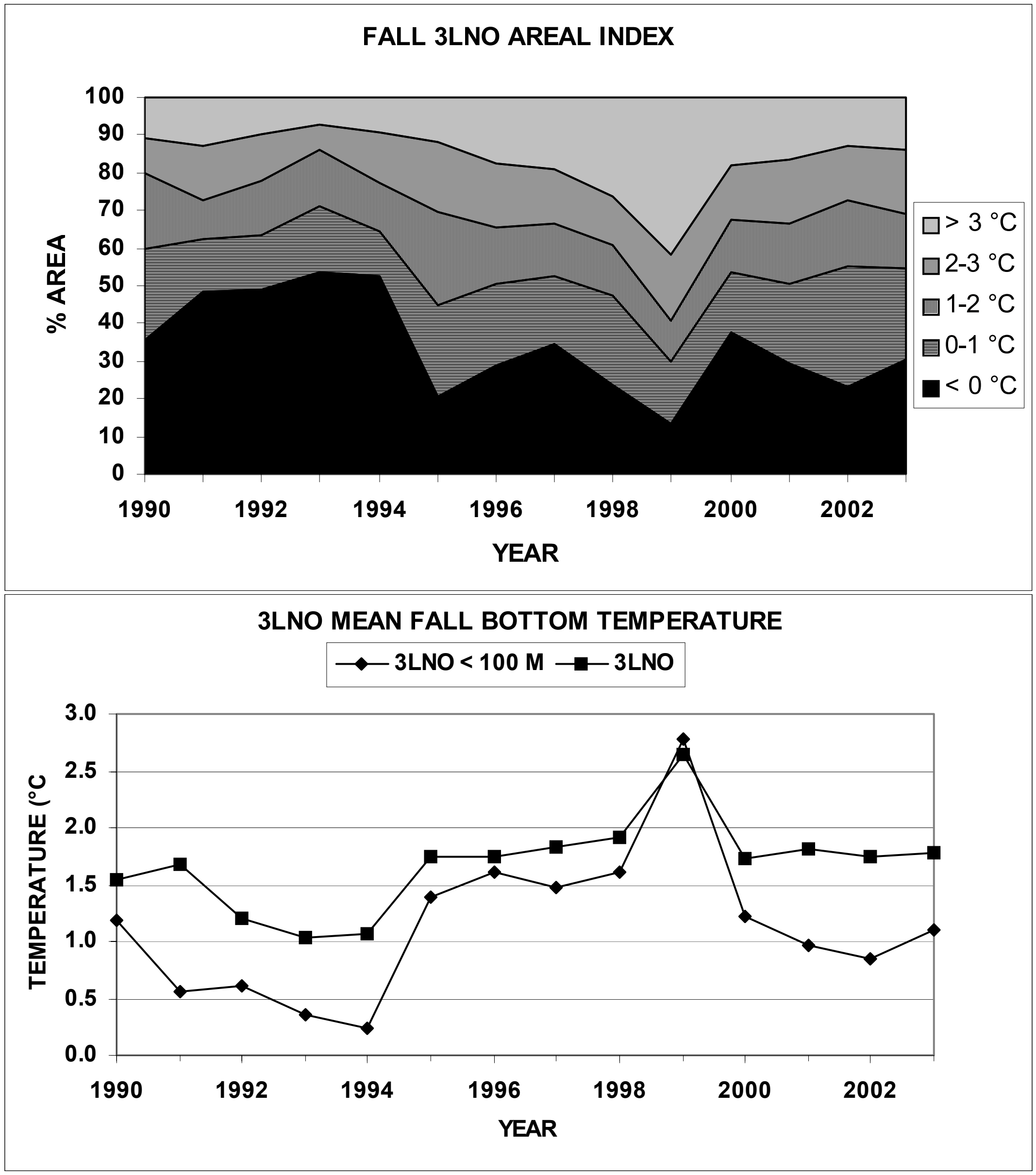


Fig. 27. Time series of the percentage area of the bottom in NAFO Divs. 3LNO covered by water with temperatures ≤ 0°C, 0-1°C, 1-2°C, 2-3°C and ≥3°C during the fall (upper panel) and the mean bottom temperature in °C (bottom panel).

MULTI-SPECIES SURVEY (FALL 2002 AND 2003)

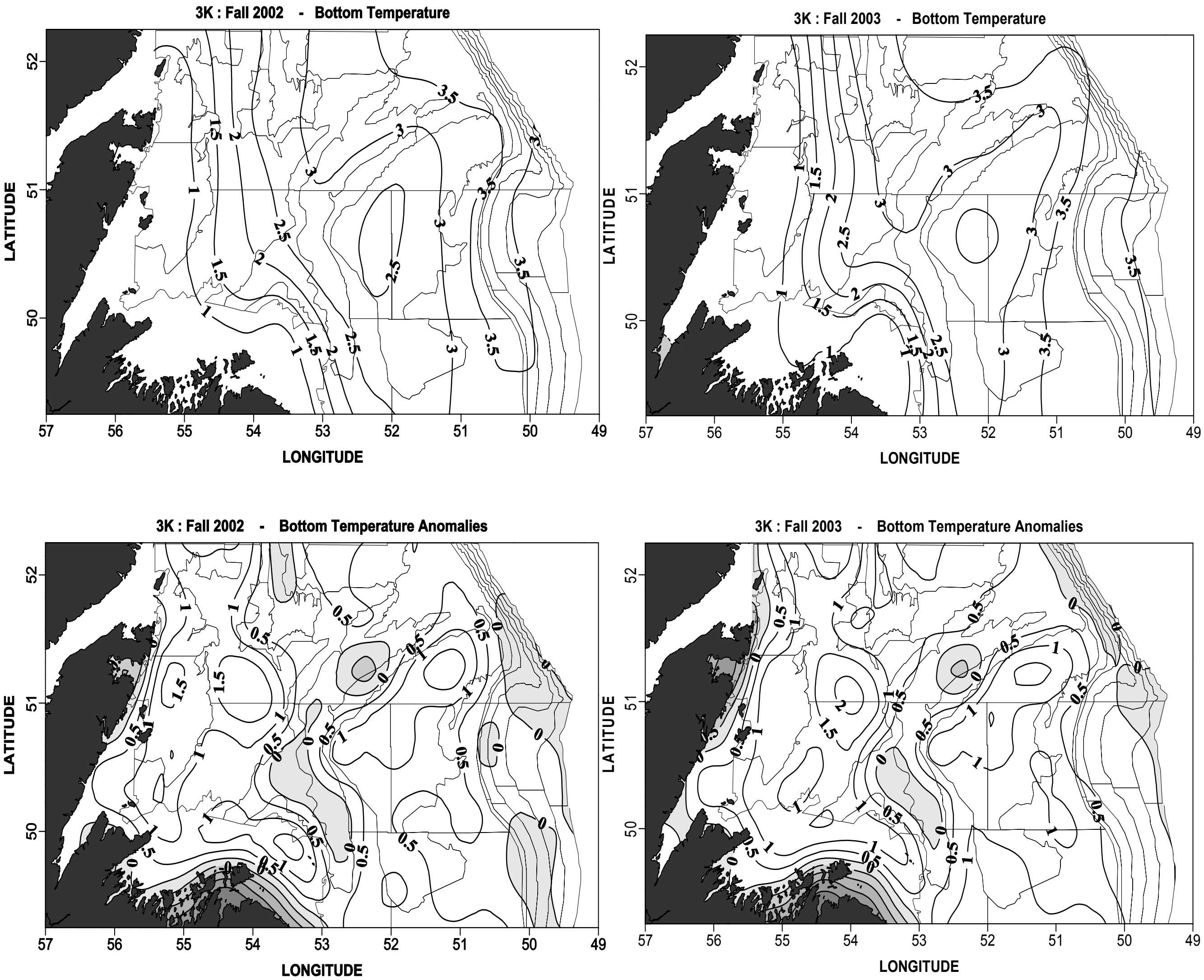


Fig. 28. Contours of bottom temperature and anomalies (in °C) for the fall of 2002 and 2003, from the multi-species survey of NAFO Div. 3K.

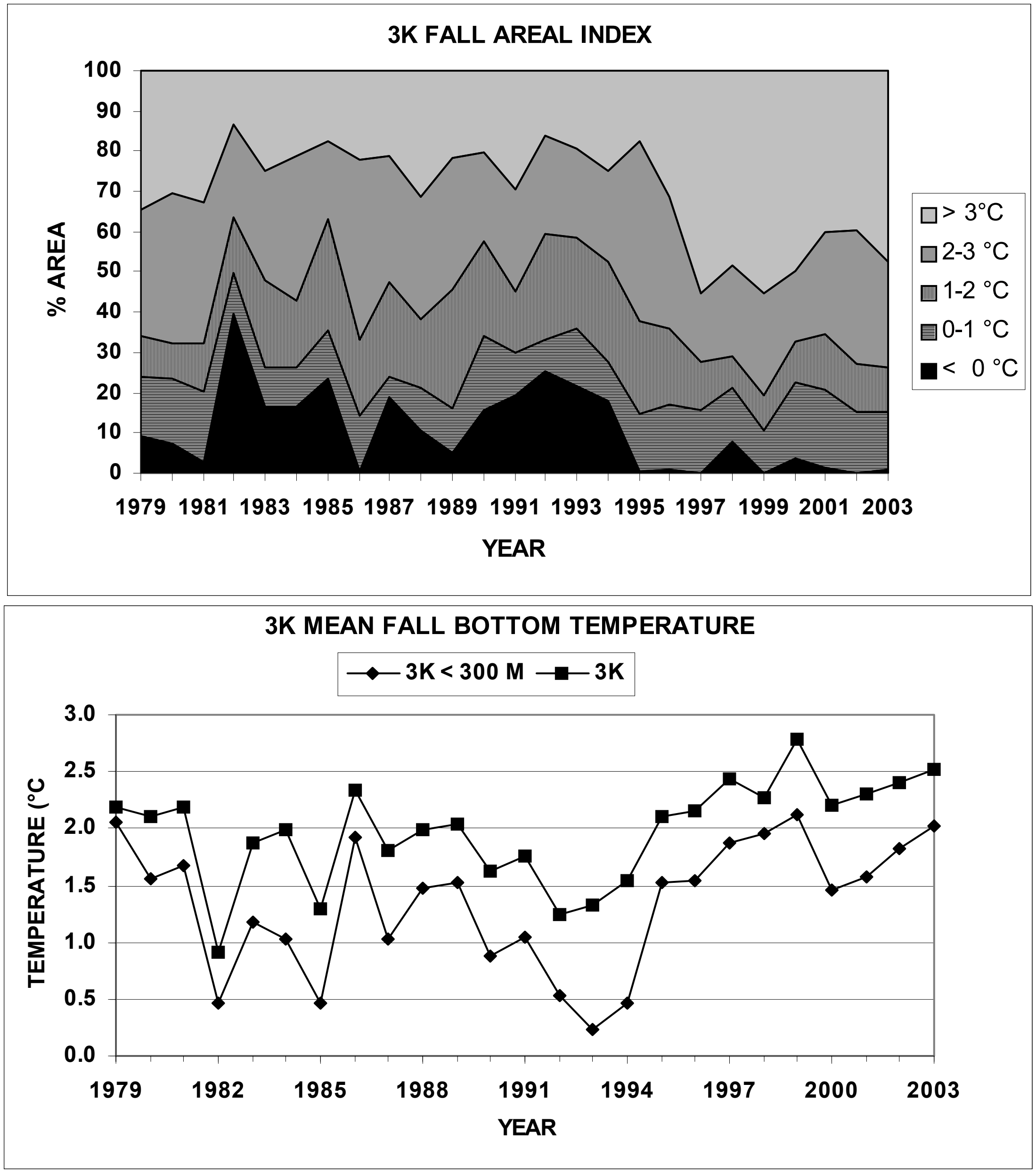
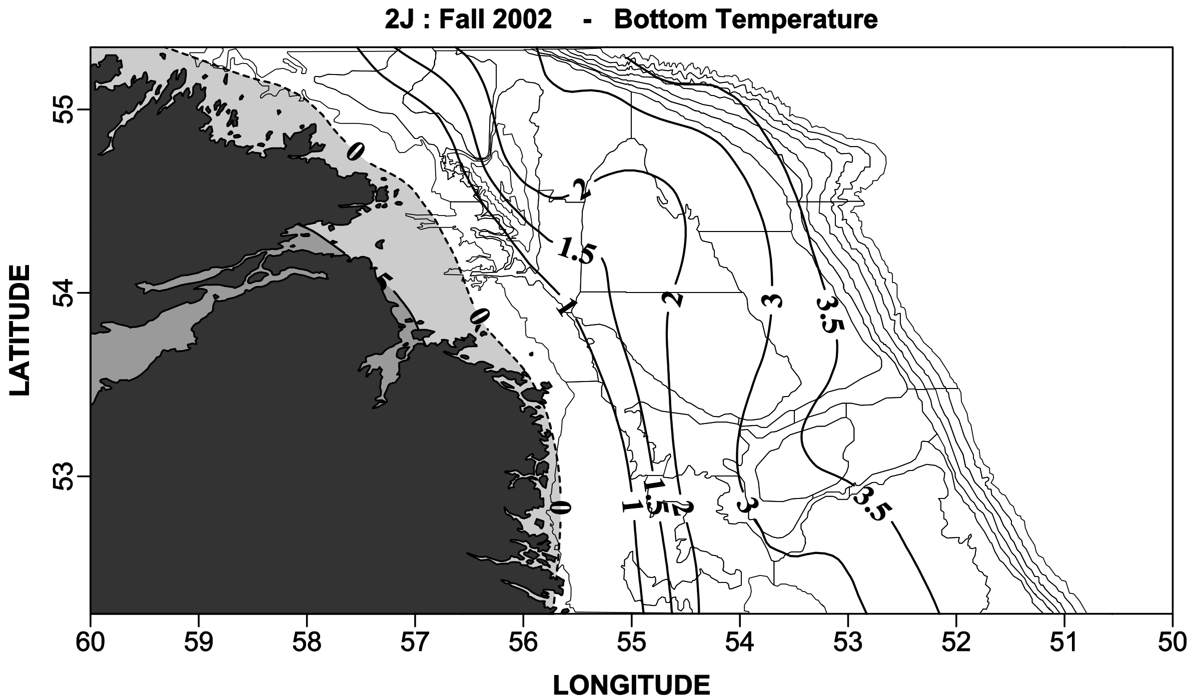


Fig. 29. Time series of the percentage area of the bottom in NAFO Div 3K covered by water with temperatures ≤ 0°C, 0-1°C, 1-2°C, 2-3°C and ≥3°C during the fall (upper panel) and the mean bottom temperature in °C (bottom panel).

MULTI-SPECIES SURVEY (FALL 2002)



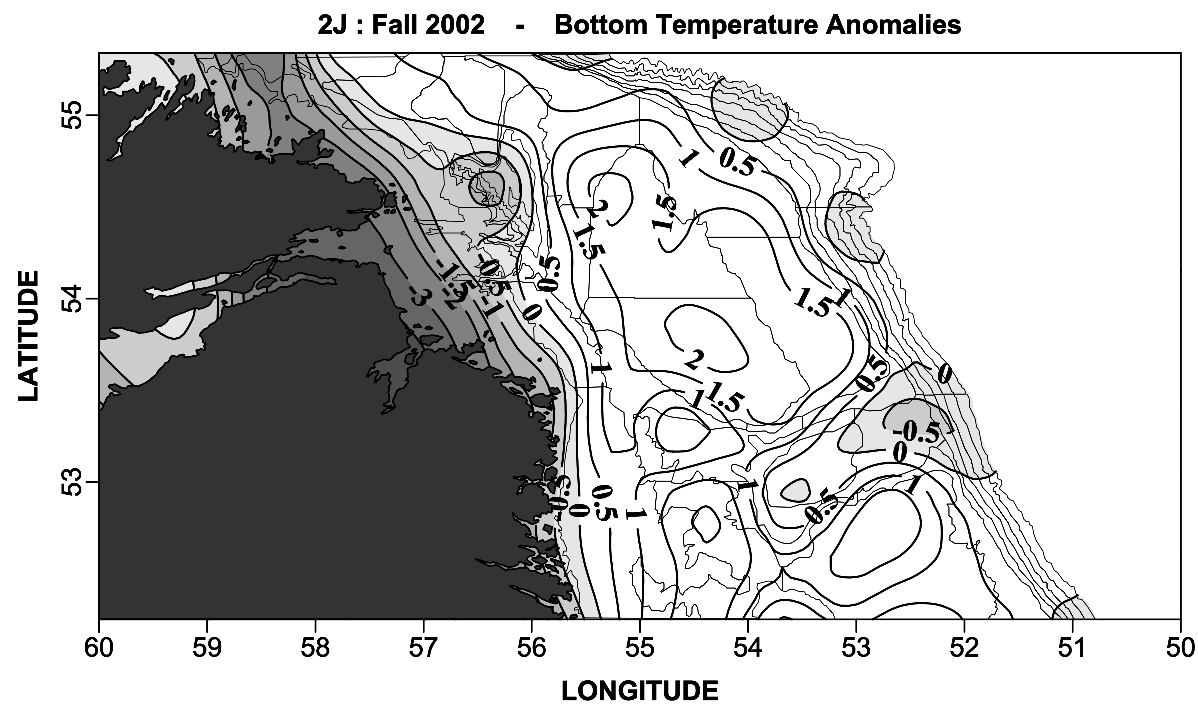


Fig. 30. Contours of bottom temperature and anomalies (in °C) for the fall of 2002, from the multi-species survey of NAFO Div. 2J.

MULTI-SPECIES SURVEY (FALL 2003)

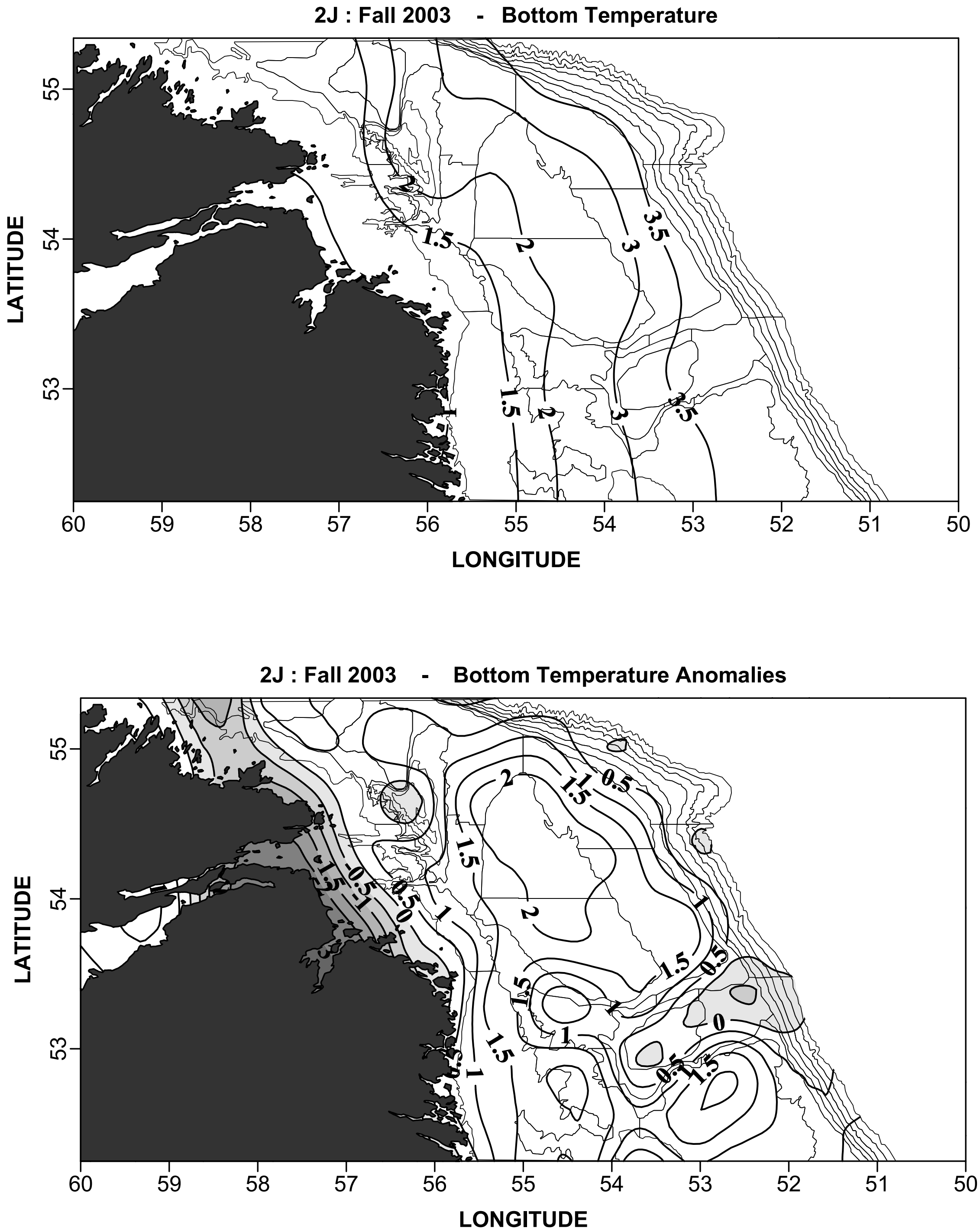


Fig. 31. Contours of bottom temperature and anomalies (in °C) for the fall of 2003, from the multi-species survey of NAFO Div. 2J.

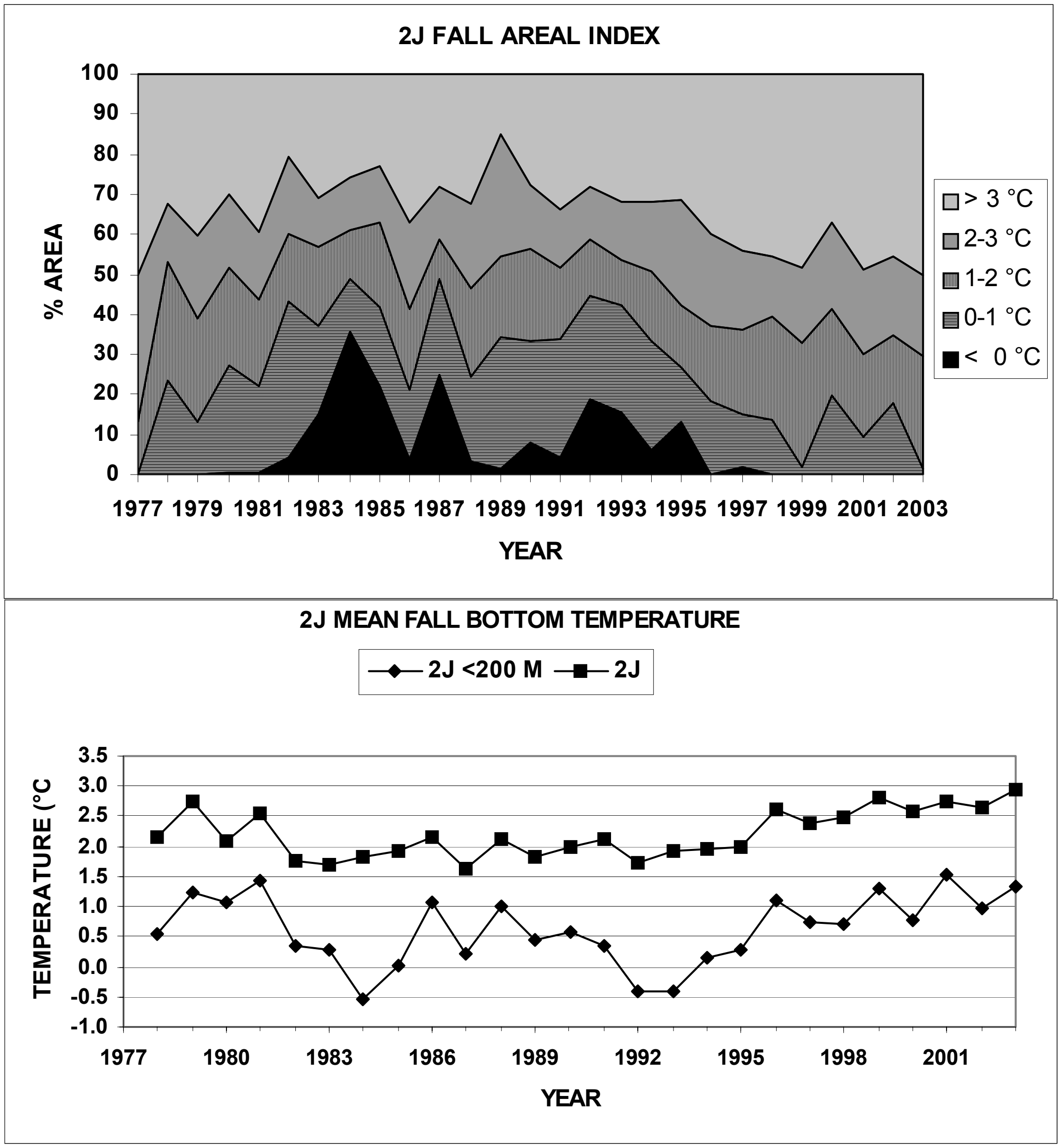


Fig. 32. Time series of the percentage area of the bottom in NAFO Div 2J covered by water with temperatures ≤ 0°C, 0-1°C, 1-2°C, 2-3°C and ≥3°C during the fall (upper panel) and the mean bottom temperature in °C (bottom panel).