NOT TO BE CITED WITHOUT PRIOR
REFERENCE TO THE AUTHOR (S)

Northwest Atlantic Fisheries Organization

Serial No. N4846 **NAFO SCR Doc. 03/31**

SCIENTIFIC COUNCIL MEETING – JUNE 2003

Physical Oceanographic Conditions on the Scotian Shelf and in the Gulf of Maine during 2002

by

K. F. Drinkwater, B. Petrie, R. G. Pettipas, W. M. Petrie and V. Soukhotsev

Department of Fisheries and Oceans, Maritimes Region
Ocean Sciences Division, Bedford Institute of Oceanography
P.O. Box 1006, Dartmouth, N.S. B2Y 4A2

ABSTRACT

A review of physical oceanographic conditions on the Scotian Shelf and in the Gulf of Maine and adjacent offshore areas during 2002 is presented. Warm and salty conditions tended to dominate most of the Scotian Shelf and Gulf of Maine areas in 2002. Mean annual sea-surface temperature at Boothbay Harbor was the 3rd warmest in 97 years and at St. Andrews the 9th warmest in 81 years. Particularly warm waters were observed in the Gulf of Maine at all depths in the Bay of Fundy at Prince 5, in Georges Basin, on Georges Bank and on Lurcher Shoals. Where salinity data were available, such as at Prince 5, waters tended to be saltier-than-normal. At Halifax Station 2 (H2) the surface and near bottom layers were warmer-than-usual but at mid-depths they varied through the year between colder and warmer than average. Waters at all depths at H2 tended to exhibit above normal salinities. Similarly warm waters were found in the deepest reaches of Emerald Basin and in the upper 50 to 100 m over Misaine Bank and in Sydney Bight. In these latter two areas, the lower layer waters tended to be on the cold side. Cabot Strait deep-water (200-300 m) temperatures measured on the high side of normal. Exceptions to the warm conditions included the SSTs at both Halifax and over most of the Scotian Shelf during the groundfish survey in July. Subsurface temperatures and salinities on the Shelf varied spatially but tended to be dominated by positive anomalies. There was a noticeable increase in bottom temperatures compared to 2001, however. The vertical stratification in the upper water column (between surface and 50 m) over the Scotian Shelf continued to weaken in 2002 relative to the last few years, and was below normal for the second consecutive year. The annual mean positions of the Shelf/Slope front and the Gulf Stream were similar to those observed in 2001. The Shelf/Slope front was seaward of its normal position while the Gulf Stream was shoreward of its normal position.

Introduction

This paper describes temperature and salinity characteristics during 2002 of the waters on the Scotian Shelf and in the Gulf of Maine (see Fig. 1 for the study area). The results are derived from data obtained at coastal sea surface stations and long-term monitoring stations, along standard transects, on annual groundfish surveys, and from ships-of-opportunity and research cruises. Most of the data are available in the BIO historical temperature and salinity (AFAP) database (http://www.mar.dfo-mpo.gc.ca/ science/ocean/database/data-query.html), which is updated monthly from the data archive at the Marine Environmental Data Service (MEDS) in Ottawa. The analyses in this paper use data up to and including the 8 January 2003 update. Additional hydrographic data were obtained directly from DFO fisheries personnel. In addition, we provide information on the position of the Gulf Stream and the boundary between the shelf waters and the offshore slope waters. New this year we are including information on sea level data from Halifax. This represents the fourth year that the environmental reviews for the Fisheries Oceanography Committee (FOC) are being presented as part of the Atlantic Zonal Monitoring Program (AZMP).

In order to detect long-term trends, we have removed the potentially large seasonal cycle by expressing oceanographic conditions as monthly deviations from their long-term means (called anomalies). Where possible, long-term monthly and annual means have been standardized to a 30-yr average, using the base period 1971-2000 in accordance with the convention of the recommendations of the Northwest Atlantic Fisheries Organization (NAFO, 1983) and DFO's Fisheries Oceanography Committee (FOC). Meteorological, sea ice and satellite-derived sea-surface temperature information for eastern Canada during 2002 are described in Drinkwater *et al.* (2003a). Of particular relevance for the Scotian Shelf and the Gulf of Maine was that air temperatures and sea surface temperatures over most of the northwest Atlantic during 2002 were warmer-than-normal and for the Scotian Shelf there was less ice.

Coastal Sea Surface Temperatures

Monthly averages of coastal sea surface temperature (SST) for 2002 were available at Boothbay Harbor in Maine and Halifax in Nova Scotia. Data from St. Andrews in New Brunswick were available for 10 months of 2002, with no data for January and February and most of 2001 due to instrument failure. The monthly mean temperature anomalies relative to the 1971-2000 long-term averages at each site for 2001 and 2002 are shown in Fig. 2.

At Boothbay Harbor in 2002, all twelve months experienced positive temperature anomalies, thus continuing the warm conditions of the past several years. The anomalies equalled or exceeded 2 standard deviations (based upon the years 1971-2000) in 6 months (March, April, July-October) and one standard deviation in 5 other months (January, February, May, June and November). At St. Andrews, 9 of the 10 months of data had positive anomalies and in 5 months the anomalies exceeded 1 standard deviation (March, April, August-October). In contrast to the warm conditions at Boothbay Harbor and St. Andrews, Halifax temperatures were mostly below normal (8 out of the 12 months). The first four months of 2002 were above normal but the remainder of the year was below normal. Temperature anomalies in June 2002 at Halifax exceeded 2 standard deviations and in another two months (January and August) they exceeded one standard deviation. The maximum monthly anomalies were 3.6^{o}C at Boothbay in August, 1.3^{o}C at St. Andrews in both September and October and -2.3^{o}C at Halifax in June.

Time series of annual anomalies show that the surface temperature at Boothbay Harbor and St. Andrews have been above their long-term means in recent years and generally increasing since the minimum in the late-1980s (Fig. 2). The annual mean temperature in 2002 at Boothbay was 10.6^{o}C, which is 1.8^{o}C above the 1971-2000 mean. This temperature is the warmest observed since the mid-1950s and the 3rd warmest year in the 97-year record. At St. Andrews, because of the missing data in the first two months, a true mean temperature for the year can not be determined. However, the average of the anomalies for the remaining ten months suggests an annual anomaly of 0.6^{o}C, which would make it the 9th warmest year there in its 81-year record. At Halifax the annual average for 2001 was 7.4^{o}C and 0.4^{o}C below its long-term mean. This is similar to conditions in 2001 and those experienced in the late-1980s and 1990s.

Fixed Stations

Prince 5

Temperature and salinity measurements have been taken since 1924 at Prince 5, a station near St. Andrews, New Brunswick, adjacent to the entrance to the Bay of Fundy (Fig. 1). It is the longest continuously operating hydrographic monitoring site in eastern Canada. Prior to the 1990s, data were obtained using reversing thermometers and water bottles. Since then data have been collected with a CTD (Conductivity, Temperature, Depth) profiler. Up to and including 1997, there was only one observation per month but since 1998, multiple occupations per month have been taken. For months with multiple measurements, an arithmetic average was used to estimate the monthly mean temperature and salinity. A single observation, or even three per month (especially in the surface layers in the spring or summer when some stratification can develop) may not necessarily produce results that are representative of the true monthly "average" conditions. While this is less of a problem in such a well-mixed area as the Bay of Fundy, still the interpretation of the anomalies must be viewed with some caution. No significance should be placed on any individual monthly anomaly, but persistent anomaly features are likely to be real. The general vertical similarity in temperatures over the 90 m water column is due to the strong tidal mixing within the Bay of Fundy.

In 2002, monthly mean temperatures ranged from a minimum in March of 3.3^{o}C at the surface to a maximum in September of 12.8^{o}C, again near the surface (Fig. 3, 4). Monthly temperature anomalies were dominated by positive values throughout the year with the only negative anomalies appearing in the top 50 m in May (Fig. 3). The highest positive anomaly (1.8°C) occurred in January near the surface and anomalies were >1°C throughout most of the water column from January to April and in October. The annual mean temperatures exhibit high year-to-year variability with evidence of strong long-term trends (Fig. 4). The temperature patterns at both the surface and 90 m are similar. These include colder-than-normal temperatures prior to 1945, throughout the 1960s, and again in the mid-1980s to mid-1990s. The later years of the 1990s exhibited positive anomalies. In 2002, the annual temperature anomalies throughout the water column were positive and increased relative to 2001. These positive anomalies continue the long-term warming trend that began in the early-1990s. The maximum annual temperatures at this site occurred in the early-1950s and the minimum in the mid-1960s.

The salinity at Prince 5 showed a typical annual cycle with lowest values in the spring (May) at the surface (31) and the highest values (>33) near bottom in the autumn (Fig. 3, 5). The salinity anomalies were positive throughout the year except below 50 m in April (Fig. 3). Maximum anomalies (>0.5) occurred at the surface in May, June and November (Fig. 5). Annual salinity anomalies in 2002 were well above their long-term means at all depths with the highest value at the surface (0.45). There have been large interannual fluctuations in salinity, but the longer-term trends show that salinities generally freshened from the late-1970s to at least the late-1990s. The lowest salinities on record at Prince 5 occurred in 1996. These salinity changes paralleled events in the deep waters of Jordan and Georges Basin and appear to have been related to advection from areas further to the north (Smith *et al*., 2001; Drinkwater *et al*., 2003b). Salinities rose above normal by 1999 and have remained there with the highest values in the last 3 years recorded in 2002.

Halifax Line Station 2

As part of the AZMP, a standard monitoring site was established in 1998 on the Scotian Shelf. Based on representativeness and logistic considerations, the selected site was Station 2 on the Halifax Line (Fig. 1). This station, hereafter referred to as H2, is situated approximately 30 km off the entrance to Halifax Harbour in about 150 m of water at the inner edge of Emerald Basin. It was felt that it was far enough offshore to avoid extensive contamination by high frequency upwelling and downwelling but close enough to shore to be able to be monitored on a monthly basis using small vessels if necessary. Hydrographic measurements are taken using a CTD. In addition, nutrient and biological sampling are conducted. In this paper we only report on the hydrographic information. The long-term monthly means of temperature, salinity and density (sigma-t) were discussed in Drinkwater *et al*. (2000).

Surface temperatures at H2 ranged from <2°C to >18°C in 2002 (Fig. 6). Near-bottom temperatures typically rose to their highest level (>8°C) in the summer. Relative to the long-term means, surface and near bottom waters were both predominantly above normal throughout the year. At mid-depth in the region of the cold intermediate layer, they varied almost equally between positive and negative anomalies. Maximum positive temperature anomalies were on the order of 4°C in both the surface layers in July and the bottom waters in February and October, whereas the minimum anomalies were below -2°C in the vicinity of the thermocline during June and again in August-September. The temperature anomaly patterns suggest that there was more Cold Intermediate Layer (CIL) water than usual at this site in 2002, the stratification was stronger, and the mixed layer depth was shallower. The high positive anomalies at depth suggest the deep Emerald Basin waters were warmer-than-usual or that their shoreward penetration extended into shallower depths, perhaps due to upwelling.

Sea-surface salinities were highest during the spring and generally lowest (<31) in the winter, as is typical. At subsurface depths, salinities rose during the summer, reaching maximum values (>34) near bottom. This also is typical of the seasonal pattern and is believed to be associated with coastal upwelling. Relative to the long-term means, salinities were primarily saltier-than normal, with fresher conditions occurring in March, June and October.

In the surface layers, stratification began around April-May increasing in intensity through to August-September. During autumn, the surface layer heat and low salinity waters were gradually mixed down to 30 m and deeper, resulting in a decrease in the depth of the isopycnals (lines of constant density or sigma-t). Sigma-t anomalies indicated large variability but generally near normal stratification below the pycnocline. Within the pycnocline, the densities anomalies varied with a stronger tendency for above normal densities.

Deep Emerald Basin Temperatures

Emerald Basin is located in the central Scotian Shelf. The waters in the deep layers of the Basin underwent rapid cooling in 1998 in response to the appearance of cold Labrador Slope Water at the shelf edge in the autumn of 1997 and its subsequent transport onto the shelf (Drinkwater *et al*., 2000). In 1999, warm temperatures reappeared in the Basin as the Labrador Slope Water retracted northward and was replaced by Warm Slope Water. The time series of temperature anomalies at 250 m shows this cooling and subsequent warming (Fig. 7). Dominant in the time series are the cool period of the 1960s and the relatively warm periods of the 1970s to the 1990s. In 2002, the water was warmer-than-normal by approximately 0.2°C. This is similar to 2000 and 2001 but well below the values recorded through the early-1990s. While the 250 m temperature anomalies are usually representative of the lower layers from 100 m to the bottom, this was not the case in 2002. The annual anomalies at the standard depths in Emerald Basin and their error of the means were estimated from the available monthly values. They show that the slightly above normal temperatures were confined to the bottom 50 m, where as the 75 m to 175 m layer tended to be colder-than-normal, although not significantly so (Fig. 7). The upper 50 m was predominantly warm but only the top 10 m are considered significantly above the long-term mean.

Other Scotian Shelf and Gulf of Maine Temperatures

Drinkwater and Trites (1987) tabulated monthly mean temperatures and salinities from available bottle data for irregularly shaped areas on the Scotian Shelf and in the eastern Gulf of Maine that generally corresponded to topographic features such as banks and basins (Fig. 8). Petrie *et al*. (1996) updated the information using these same areas but containing all available hydrographic data. In this report we produce monthly mean conditions for 2002 at standard depths for selected areas (averaging any data within the month anywhere within these areas) and compare them to the long-term averages (1971-2000). Unfortunately, data are not available for each month at each area and in some areas the monthly means are based upon only one profile. As a result, the series are characterized by short period fluctuations or spikes superimposed upon long-period trends with amplitudes of 1-2°C. The spikes represent noise and most often show little similarity between regions. Thus care again must be taken in interpreting these data and little weight given to any individual mean. The long period trends often show similarity over several areas. To better show such trends we have estimated the annual mean anomaly based on all available means within the year and then calculated the 5-year running mean of the annual values. This is similar to our treatment of the Emerald Basin data.

Drinkwater and Pettipas (1994) examined long-term temperature time series for most of the areas on the Scotian Shelf and in the Gulf of Maine. They showed that the temperatures in the upper 30 m vary greatly from month to month, due to atmospheric heating and cooling. Also, at intermediate depths of 50 m to approximately 150 m, temperatures had declined steadily from approximately the mid-1980s into the 1990s. On Lurcher Shoals off Yarmouth, on the offshore banks and in the northeastern Scotian Shelf, the temperature minimum in this period approached or matched the minimum observed during the very cold period of the 1960s. This cold water was traced through the Gulf of Maine from southern Nova Scotia, along the coast of Maine and into the western Gulf. Cooling occurred at approximately the same time at Station 27 off St. John's, Newfoundland, on St. Pierre Bank off southern Newfoundland (Colbourne, 1995), and in the cold intermediate layer (CIL) waters in the Gulf of St. Lawrence (Gilbert and Pettigrew, 1997). From the mid-1990s, temperatures at these depths have been warming, eventually reaching above normal values throughout the region by 2000 (Drinkwater *et al*., 2001). Below, we describe temperature conditions in several representative areas of the Scotian Shelf and Gulf of Maine.

In Sydney Bight (area 1 in Fig. 8) off eastern Cape Breton, mean profiles were available for 5 months of 2002 (Fig. 9). In the surface layer, data were only available during July and September, and these show strong positive temperature anomalies in the top 50 m. The maximum anomaly (>7°C) was at 30 m in September. Below 50 m, however, there were predominantly weak negative monthly temperature anomalies. The annual anomalies were not considered significantly different than zero in this depth range. The time series at 100 m shows high temperature anomalies in the 1950s that fell to a minimum around 1960 and then rose steadily through the 1960s (Fig. 9). Temperatures remained relatively high during the 1970s. By the 1980s temperatures began to decline and by the mid-1980s dropped to below normal with a minimum anomaly around -1°C in the early-1990s. Temperatures remained below normal through 1998, but were slowly rising from the early-1990s. Above normal temperatures were reached in 1999, fell in 2001 and remained low until late in 2002 when they rose above the long-term mean.

Monthly mean temperature profiles for Misaine Bank on the northeastern Scotian Shelf (area 5 in Fig. 8) were collected in 7 months of 2002. They show primarily warmer-than-normal temperatures in the top 100 m but a tendency to be below normal at depths of 150 m and greater (Fig. 10). This pattern is reflected in the annual anomaly profile, which indicates that while the surface anomalies are considered significantly different than zero, those in the lower half of the water column generally are not. The time series of the 100 m temperature anomalies shows an increase in 2002 from negative values in 2001 (Fig. 11). This is a return towards the anomalies observed in 1999 and 2000. These positive anomalies contrast with the predominantly negative anomalies from the mid-1980s to the late-1990s. As in Emerald Basin, the long-term temperature trend indicates relatively high temperatures in the 1950s. They then declined and at Misaine Bank reached a minimum around 1960, several years earlier than areas further to the southwest. Temperatures were near normal from the late-1960s to the mid-1970s before rising to a maximum in the late-1970s. By the late-1980s, temperatures fell below normal and reached a record sustained minimum of around -1^{o}C in the first half of the 1990s. From the early-1990s to 2000, as in Sydney Bight, temperatures slowly but steadily increased.

Lurcher Shoals is located off Yarmouth, Nova Scotia (area 24 in Fig. 8). This area exhibited warmer-than-normal temperatures in the 6 months of 2002 when data were available (Fig. 12). The annual anomalies indicate values of 1°-2°C, which are considered statistically significant. The time series at 50 m clearly shows the large increase in 2002 following the decline to below normal temperatures in 2001 (Fig. 13). The increase in 2002 represents a return to anomalies observed in 1999 and 2000. Temperatures over Lurcher Shoals tended to be high in the late-1940s and early-1950s, declined to a mid-1960s minimum, rose rapidly into the 1970s and remained above normal into the mid-1980s. As in the northeastern Scotian Shelf, temperatures declined by the mid-1980s to below normal reaching a long-term minimum in the early-1990s. Although there were a few positive monthly temperature anomalies, annual mean temperatures and most monthly means remained below normal through the 1990s until 1999.

Georges Basin is located near the southeastern entrance to the Gulf of Maine (area 26 in Fig. 8) and is connected to the offshore slope water through the Northeast Channel. Data were collected in 8 months of 2002. Annual anomalies were warmer-than-normal throughout the water column, all of which are considered significantly different from zero (Fig. 14). The maximum amplitude was at 75 m and was approximately 1°C. Temperatures in the deep regions (200 m) of Georges Basin (Fig. 15) show a striking similarity to those near bottom in Emerald Basin (Fig. 7). This includes the very cold conditions in 1998 and generally warm temperatures from 1999 through 2002. Also similar in the two basins is the minimum in the mid-1960s, the sharp rise to a peak in the early-1970s, and the generally above normal values until 1998. The similarity in the two basins is not surprising given that the source of the waters for both is the offshore Slope Waters (Petrie and Drinkwater, 1993).

Temperature conditions were also examined on eastern Georges Bank (area 28 in Fig. 8). Data were available in 9 months of 2002. Although variable, temperatures tend to exhibit above normal anomalies in the upper 100 m and below normal at depths of 150 m and greater (Fig. 16). The latter depths lay along the slope of the Bank. The peak in the annual anomaly (1.5°C) occurred in the surface waters. The time series of 50 m temperature anomalies exhibit extreme variability, in part due to the shallowness and hence greater direct forcing by the atmosphere than for deeper depths (Fig. 17). The long-term trend, as revealed by the 5-year running mean, shows many similarities to those in the near bottom waters of Georges Basin and Emerald Basin. These again include the low temperatures in the 1960s and the higher-than-average conditions in the 1970s through to the 1990s. In 2002, temperatures tended to be above normal and similar to conditions observed since 1999.

Temperatures during the Summer Groundfish Surveys

The most extensive temperature coverage over the entire Scotian Shelf is obtained during the annual DFO groundfish survey, usually in July. A total of 212 CTD stations were taken during the 2002 survey and an additional 174 bottom temperature stations were obtained as part of the ITQ (Individual Transferable Quota) fleet survey. The ITQ survey fills in gaps in the DFO survey for the Bay of Fundy, off southwest Nova Scotia and on the southwestern Scotian Shelf. The temperature data from the ITQ survey were obtained from Vemco Minilogs© attached to the trawl. These data are quality controlled during processing at the Bedford Institute of Oceanography. Temperatures from both surveys were combined and interpolated onto a 0.2° by 0.2° latitude-longitude grid using an objective analysis procedure known as optimal estimation. The interpolation method uses the 15 "nearest neighbours" with a horizontal length scale of 30 km and a vertical length scale of 15 m in the upper 30 m and 25 m below that. Data near the interpolation grid point are weighted proportionately more than those further away. Temperatures were optimally estimated onto the grid for depths of 0, 50, 100 m and near bottom (Fig. 18). Maximum depths for the interpolated temperature field were limited to 1000 m off the shelf. The 2002 temperature anomalies relative to the July 1971-2000 means were also computed at the same four depth levels (Fig. 19).

The broad spatial pattern of near-surface temperatures in July 2002 was similar to past years with the warmest waters (>16°C) off eastern Cape Breton and the coldest (<11°C) in the Gulf of Maine/Bay of Fundy region (Fig. 18a). The cooler surface temperatures in the Gulf of Maine compared to the Scotian Shelf are due to the intense bottom-generated vertical mixing caused by the high tidal currents. The surface temperatures in 2002 were colder-than-normal over most of the Shelf and in the Bay of Fundy (Fig. 19a). The exceptions being the inner portion of the shelf from the Laurentian Channel south to Lunenburg Bay, and off southwest Nova Scotia in the Gulf of Maine. The lowest anomaly on the Shelf was below -2°C, observed over Emerald Basin and extending towards the offshore. Relative to 2001, the surface temperatures in 2002 decreased over the northeastern Shelf, Emerald Basin and off Yarmouth, while over the southwest Scotian Shelf and other areas of the Gulf of Maine (including the Bay of Fundy) they increased compared to 2001

The temperatures at 50 m ranged from 2°C to over 9°C with the coldest waters in the northeast and the warmest waters in the Gulf of Maine and Bay of Fundy (Fig. 18a). The higher temperatures towards the outer edge of the Shelf in the central region possibly indicate the intrusion of Slope Waters onto the shelf. The higher temperatures at 50 m in the Gulf of Maine compared to the Scotian Shelf are, in part, due to the increased importance of tidal mixing. Temperature anomalies at 50 m (Fig. 19a) varied spatially over the Shelf and were mostly between 0° to ±1°C). The largest anomalies appeared along the shelf break south of Halifax (negative) and in the vicinity of Western Bank (positive). The anomalies along the shelf break must be regarded cautiously, however, due to the limited data in this region. Compared to 2001, temperatures rose over most of the Shelf and Gulf of Maine regions with the largest increase near the shelf break.

The spatial pattern of the 100 m temperatures resembles that at 50 m, although the actual temperatures tend to be slightly higher at 100 m (Fig. 18b). The temperatures at 100 m ranged from 1-2°C in the northeast to over 10°C offshore and in Northeast Channel. Temperature anomalies at this depth were again predominantly positive, mostly ranging from 0° to 2°C over the Shelf and into the Gulf of Maine (Fig. 19b). The highest anomalies (>4°C) occurred along the outer shelf off Sable Island Bank suggesting the presence of warmer-than-normal slope waters. More of the shelf was covered by colder-than-normal anomalies than at 50 m, especially in the northeast. Relative to 2001, temperatures at 100 m rose in 2002.

Near-bottom temperatures over the Scotian Shelf ranged from <2°C in the northeastern Scotian Shelf to over 9°C in Emerald Basin, the Bay of Fundy and Gulf of Maine (Fig. 18b). The source of the high temperatures differs spatially. In Emerald Basin, the high temperatures are due to the penetration of warm offshore Slope Waters into the Basin, while in the Bay of Fundy and other parts of the Gulf of Maine they are, in part, due to the intense vertical mixing by the tides. The pattern of colder temperatures in the northeastern Shelf and warmer in the Gulf of Maine and in the deep basins of the central Shelf is typical of most years. The colder waters are largely derived from the Gulf of St. Lawrence. Relative to their long-term means (1971-2000), the near-bottom temperatures were predominantly warmer-than-normal, except in the northeast where there were approximately equal areas of positive and negative anomalies (Fig. 19b). Most were weak anomalies, being between 0 and ±1°C. The largest positive anomaly (2°C) was to the southwest of Sable Island.

We also estimated the area of the bottom covered by each one degree temperature range (i.e. 1-2^{o}C, 2-3^{o}C, 3-4^{o}C, etc.) within NAFO Subareas 4Vn, 4Vs, 4W and 4X (see Fig. 1 for Subarea boundaries). These were obtained from optimally estimated temperatures from the July groundfish and ITQ surveys. The time series for each NAFO Subarea are shown in Fig. 20a,b. Several points are noteworthy. First is the generally higher temperature as one moves southwestward from 4Vs/4Vn towards 4W and 4X. In 4Vn, most of the bottom is covered by waters <6^{o}C and almost 50% is <5^{o}C (Fig. 16a). For 4Vs, 80-90% is <6^{o}C and 75% is <5^{o}C (Fig. 20a). In 4W <50% and in 4X <20% of the bottom is covered by temperatures <6^{o}C (Fig. 20b). The time series for 4Vn and 4Vs show an increase during the late-1980s and early-1990s in the amount of 0^{o}-1^{o}C waters and especially those <3°C (Fig. 20a). Also in 4Vs there are waters <1^{o}C during this colder period. In 4W there is an increase in the area of the waters <3^{o}C, but it is of smaller amplitude than in 4V. In 4X there is an increase in waters <4^{o}C, but it is not as large an amplitude as in the other regions

(Fig. 20b). During 2002 there was a decrease in the area covered by temperatures in the coldest temperature ranges in all NAFO subareas.

Cabot Strait Deep Temperatures

Bugden (1991) investigated the long-term temperature variability in the deep waters of the Laurentian Channel in the Gulf of St. Lawrence from data collected between the late-1940s to 1988. The variability in the average temperatures within the 200-300 m layer in Cabot Strait was dominated by low-frequency (decadal) fluctuations, with no discernible seasonal cycle. A phase lag was observed along the major axis of the channel such that events propagated from the mouth towards the St. Lawrence Estuary on time scales of several years. The updated time series shows that temperatures declined steadily between 1988 and late-1991 to their lowest value since the late-1960s (near 4.5°C and an anomaly exceeding -0.9°C; Fig. 21). Then temperatures rose dramatically reaching 6°C (anomaly of 0.6°C) in late-1993. During the remainder of the 1990s, temperatures oscillated about the long-term mean with a slight tendency towards positive values. Since 1999 and including 2002, temperatures in the deep waters of Cabot Strait typically have been warmer than the long-term mean.

Standard Sections

As part of the AZMP, seasonal sampling along the historical standard sections was re-established by the Canadian Department of Fisheries and Oceans in 1998. On the Scotian Shelf, this included transects off Cape Sable, Halifax, Louisbourg and across Cabot Strait (Fig. 1). While four occupations per section was the original goal within AZMP, this has not been achieved due to budgetary and vessel constraints. Dedicated monitoring cruises have typically provided 2 sections per year (April and October) with additional sections pieced together from fisheries surveys, where possible. In 2002, the October cruise was conducted but the April cruise was canceled because of mechanical problems with the ship. However, an occupation of the Halifax section was undertaken in May and again in June. Similar to the fixed stations, the measurements usually include CTDs, nutrients, chemical and plankton sampling. Only the hydrographic data are discussed in the present paper. Anomalies relative to the 1971-2000 means were only estimated for the Halifax Line and for temperature along the Louisbourg Line in November. At the other sections, or for different times or data types, the historical data were considered of insufficient quantity to determine reliable means for this time period.

During the occupation of the Halifax Line in May the most noticeable feature is the very warm, high salinity water extending shoreward to the shelf break between the outer shelf and upper slope stations (Fig. 22). The temperature and salinity anomalies over the slope reached as high as 8°C and 2, respectively. There was a sharp front at the shelf break in both hydrographic fields and their anomalies. The extremely high salinities of over 35.5 suggest that this might be a Gulf Stream eddy or a meander of the Stream. Although examination of the surface temperatures from the satellite thermal imagery did not reveal either feature at the location of the outer Halifax Line stations at the time the CTD measurements were taken, such features were nearby. Given that the highest temperatures and salinities were observed at subsurface depths, it is our belief that these might indeed be due to an eddy or Gulf Stream extension. Turning our attention to the Shelf, in Emerald Basin the temperature and salinity anomalies were positive by as much as 3°C and nearly-1, respectively, suggestive of penetration of some of the warm, high saline waters from offshore into the Basin. The downward slope of the 25 and 26 kg m^{-3} isopycnals towards the shore on the inner half of the shelf is consistent with the southwestward transport of the Nova Scotian Current. The June Halifax Section shows greater shoreward movement of the warm offshore waters than in May but a reduction in the magnitude of the positive anomalies (Fig. 23). Large, positive anomalies penetrated onshore of the shelf break with magnitudes of up to 4°C and 1, respectively. Deep waters in Emerald Basin had anomalies of 1°C and 0.5. The downward slope towards the coast of the 26 kg m^{-3} isopycnal again indicates a southwestward flow of the Nova Scotian Current.

In October, all four sections from Cabot Strait to Browns Bank were sampled (Fig. 24a-c). The Cabot Strait section shows (Fig. 24a) the characteristic layered structure of the Laurentian Channel, with a warmer, upper layer confined mainly to the Nova Scotian side of the Strait, a cold intermediate layer centered at roughly 75 m but shoaling from west to east, and a thick deep layer of Labrador Slope Water (LSW). The upper 100 m had temperatures generally below normal by as much as 3°C; on the other hand below 100 m, the anomalies were positive and reached a maximum of just above 2°C. Salinity was 0 to 0.5 above normal for most of the Strait (Fig.

24b). The tilt of the isopycnals suggests flow out of the Gulf of St. Lawrence over most of the Strait and a deep inward flow, implied by the shoaling of 27.5 kg m^{-3} surface, towards the west (Fig. 24c).

The Louisbourg section was only partially occupied in October because of severe winds. Near-surface temperatures and salinities increased relative to the Cabot Strait section (Fig. 24a). The temperature anomalies had a layered structure of alternating positive (to 3^{o}C) and negative (to –1^{o}C) values. Salinity on the other hand was close to normal (Fig. 24b). The strong coastal flow of the Nova Scotian Current was evident in the inshore tilt of the isopycnals between the stations nearer the coast (Fig. 24c).

The Halifax section had the typical 3 layer structure for October, with a warm upper layer, a cold intermediate layer particularly evident near the coast, and a deep warmer layer (Fig. 24a). Near-surface temperatures and salinities increased from the Louisbourg line. The waters of deep upper slope and deeper parts of Emerald Basin had a dominant WSW component; the Emerald Basin water properties though were near the boundary between WSW and LSW. Over most of the line, the temperature anomalies were 0-3^{o}C above normal; the lone exception was an area of below normal values centered near the bottom of the offshore side of Emerald Bank. Salinity ranged from –0.5 to 0.5 of normal (Fig. 24b). The Nova Scotian Current was not readily apparent in the density structure (Fig. 24c).

The Brown's Bank line featured less vertical stratification than the other sections. This is typical and is due to the intense vertical mixing caused by the stronger tidal currents in this area. Temperatures and salinities were above normal over the shelf by 1-3^{o}C (Fig. 24a) and 0-0.5 (Fig. 24b), respectively. This is consistent with the generally warmer and saltier conditions observed in the coastal stations (e.g. Prince 5 and over Lurcher Shoals). There was an area of below normal temperatures (0 to –3^{o}C) at the shelf break. The slope of the isopycnals implied a flow to the west over the inner shelf; on the other hand, offshore there appeared to be eastward flow (Fig. 24c).

Density Stratification

Stratification of the upper water column is an important characteristic that influences both physical and biological processes. Stratification can affect the extent of vertical mixing, the vertical structure of the wind forcing, the timing of the spring bloom, vertical nutrient fluxes and plankton speciation to mention just a few. Under increased stratification, there is a tendency for more primary production to be recycled within the upper mixed layer and hence less available for the deeper, lower layers. We examined the variability in stratification by calculating the density (sigma-t) difference nominally between 0 and 50 m. The density difference was based on a monthly mean density profile calculated for each area in Fig. 8. The long-term monthly mean density gradients for the years 1971-2000 were estimated and these then subtracted from the monthly values to obtain monthly anomalies. Annual anomalies were estimated by averaging all available monthly means within a calendar year. A 5-yr running mean of the annual anomalies was then calculated. The monthly and annual means show high variability but the 5-yr running means show some distinctive trends. The density anomalies are presented in g/ml/m. A value of 0.01 represents a difference of 0.5 of a sigma-t unit over the 50 m. As reported in previous overviews, the dominant feature of the 5-year means is the higher stratification during the 1990s throughout the Scotian Shelf (Fig. 25a, b). They began to increase steadily around 1990 with the peak in the mid- to late-1990s. There is surprising consistency in the stratification trends from area to area, over the Scotian Shelf. The higher-than-average stratification during the 1990s did not extend into the Gulf of Maine region and tended to be absent or weak in the Laurentian Channel and Sydney Bight areas. The primary cause of the increased stratification was a decrease in surface salinities that were advected from the Newfoundland area (Drinkwater *et al*., 2003). The 2002 stratification values in most areas fell below average continuing the general decrease during the past three years. This is clearly seen in the annual values of the stratification averaged over the entire Scotian Shelf (Areas 4-23 in Fig. 8) shown in Fig. 25c. The reduced stratification in 2002 is consistent with a rise in surface salinities off Newfoundland (Colbourne, 2003).

Sea Level

Sea level is a primary variable in the Global Ocean Observing System (GOOS). On Canada's east coast, two gauges, one at Halifax and the other to be established on the Labrador coast, are part of Canada's proposed contribution to the global effort. Relative sea level at Halifax (1990-2003) is plotted as monthly means and filtered using a 12-month running-mean filter (Fig. 26). The linear trend of the monthly mean data has a positive slope of 33.1 (±12.1) cm/century, in good agreement with the value of 36.7 cm/century (1897-1980) given by Barnett (1984).

Note, however, that relative sea level generally has been falling at Halifax for the past 5 years. The trend is relative to a benchmark fixed on the land and therefore is not an absolute value of the sea level rise. The solid line in the figure is a model estimate of the sea level trend, 23 cm/century at Halifax, caused by post-glacial rebound (Tushingham and Peltier, 1991). The observed trend exceeds the model's prediction for the period 1990-2003 by only 1.3 cm; given this single record, the variability at higher frequencies and the assumptions associated with the model, we cannot conclude that absolute sea level is rising, even locally.

Frontal Analysis

Shelf/Slope Front

The waters on the Scotian Shelf and in the Gulf of Maine have distinct temperature and salinity characteristics from those found in the adjacent deeper slope waters offshore. The relatively narrow boundary between the shelf and slope waters is regularly detected in satellite thermal imagery. Positions of this front and of the northern boundary of the Gulf Stream between 50°W and 75°W for the years 1973 to 1992 were assembled through digitization of satellite derived SST charts (Drinkwater *et al*., 1994). From January 1973 until May 1978, the charts covered the region north to Georges Bank, but in June 1978 the areal coverage was extended to include east to 55°W and eventually 50°W. Monthly mean positions of the shelf/slope front in degrees latitude at each degree of longitude were estimated. NOAA updated this data set until the termination of the satellite data product in October 1995. A commercial company has continued the analysis but did not begin until April 1996. These initial charts did not contain data east of 60°W but within a year were extended east to 55°W. Data for 2002 have been digitized, estimates of monthly mean positions determined, and anomalies relative to 1973-2000, were calculated. During the past several years, the analysis only extends east to 56°W due to inconsistencies in the data at 55°W.

The overall mean position of the Shelf/Slope front together with the 2002 annual mean position is shown in Fig. 27. The average position is close to the 200 m isobath along the Middle Atlantic Bight, separates slightly from the shelf edge off Georges Bank and then runs between 100-300 km from the shelf edge off the Scotian Shelf and the southern Grand Bank. It is generally farthest offshore in winter and onshore in late summer and early autumn. During 2002, the shelf/slope front was slightly seaward of its long-term mean position. The time series of the annual mean position (averaged over 56°W-75°W) shows the front was at a maximum shoreward location in 1985 with another maxima in 1993. Since 1993, the front moved steadily seaward approximately 40 km, reaching its most southerly position in 1997. During 1998 through 2000, the position of the Shelf/Slope front moved northward with the largest increased recorded in 1999. The front moved southward in 2001 to a position that was approximately 15 km seaward of its long-term mean position. Its location in 2002 was similar to that recorded in 2001.

Gulf Stream

The position of the northern boundary or "north wall" of the Gulf Stream was also determined from satellite imagery by Drinkwater *et al*. (1994) up to 1992 and has been updated in a manner similar to that for the shelf/slope front. Thus, the time series consists of the monthly position at each degree of longitude from 56°W to 75°W. The average position of the north wall of the Stream and the 2002 annual mean is shown in Fig. 28. The Stream leaves the shelf break near Cape Hatteras (75°W) running towards the northeast. East of approximately 62°W the average position lies approximately east-west. During 2002, the average position of the Stream was near to or shoreward of its long-term mean position at all degrees of longitude. The time series of the position shows the Stream was located south of its mean position during the late-1970s and 1980, near the long term mean through most of the 1980s and north of it during the late-1980s and into the first half of the 1990s (Fig. 28). The annual anomaly of the Gulf Stream was at its most northerly position in 1995. This was followed by a rapid decline in 1996 and remained low through 1997 and 1998. By 2000 the position of the Gulf Stream was shoreward of its long-term mean and has remained so through to 2002. The displacement anomaly of the Stream was similar to that recorded in 2001. The trends in the Gulf Stream roughly match variations in the NAO index.

Summary

A review of physical oceanographic conditions on the Scotian Shelf and in the Gulf of Maine and adjacent offshore areas during 2002 is presented. Warm and salty conditions tended to dominate the Scotian Shelf and Gulf of Maine areas in 2002. Mean annual sea-surface temperature at Boothbay Harbor was the 3rd warmest in 97 years and at

St. Andrews the 9th warmest in 81 years. At Prince 5, monthly mean temperatures and salinities throughout the water column were almost exclusively above normal throughout the year. At Halifax Station 2 (H2) the surface and near bottom layers were warmer-than-usual but at mid-depths they varied through the year between colder and warmer than average. Waters at all depths at H2 tended to exhibit above normal salinities. Particularly warm waters were observed in the Gulf of Maine at all depths in Georges Basin, on Georges Bank and on Lurcher Shoals. Similarly warm waters were found in the deepest reaches of Emerald Basin and in the upper 50 to 100 m over Misaine Bank and in Sydney Bight. In these latter two areas, the lower layer waters tended to be on the cold side of normal. Cabot Strait deep-water (200-300 m) temperatures measured on the high side of normal. Exceptions to the warm conditions included the SSTs at both Halifax and over most of the Scotian Shelf during the groundfish survey in July. During this same survey waters at 50 m and 100 m were spatially variable, varying about the long-term mean but with a slight preference for warmer-than-normal temperatures. Near-bottom temperatures in July were warm except in the northeast where the water temperature anomalies varied spatially. There was a noticeable increase in bottom temperatures compared to 2001, however. In May a very warm, salty water mass was observed at the offshore end of the Halifax Line. This is believed to be a Gulf Stream eddy or meander. It appears that some of this water may have penetrated onto the Shelf and contributed to warmer and saltier conditions there in both May and June. During the monitoring cruise in October of 2002 warm conditions dominated on the Browns Bank and Halifax Lines, with near normal temperatures on the Louisbourg section. In Cabot Strait, the near-bottom waters were warmer-than-normal but the top 100 m tended to be cold. While the vertical stratification in the upper water column (between the surface and 50 m) over the Scotian Shelf was below normal for the second consecutive year after a decade of higher stratification. The Shelf/Slope front and the Gulf Stream were located, on average, at about the same locations as in 2001, which was shoreward of its normal position for the Gulf Stream, but seaward for the Shelf/Slope front.

Acknowledgements

We wish to thank the many individuals who provided data or helped in the preparation of this paper, including: the Marine Environmental Data Service in Ottawa; the Bigelow Laboratory for providing Boothbay Harbor temperature data; F. Page and R. Losier of the Biological Station in St. Andrews, for providing St. Andrews and Prince 5 data; J. McRuer for the Scotian Shelf July groundfish survey data; G. Bugden of BIO and D. Gilbert of IML for their Cabot Strait temperature data; and J. Jackson and D. Gregory for their maintenance of the BIO hydrographic database.

References

Barnett, T. 1984. The estimation of “global” sea level change: a problem of uniqueness. J. Geophys. Res. 89, 7980-7988.

Bugden, G.L. 1991. Changes in the temperature-salinity characteristics of the deeper waters of the Gulf of St. Lawrence over the past several decades. p. 139-147. In J.-C. Therriault [ed.] The Gulf of St. Lawrence: small ocean or big estuary? Can. Spec. Publ. Fish. Aquat. Sci. 113.

Colbourne, E. 1995. Oceanographic conditions and climate change in the Newfoundland region during 1994. DFO Atlan. Fish. Res. Doc. 95/3, 36 p.

Drinkwater, K.F. and R.G. Pettipas. 1994. On the physical oceanographic conditions in the Scotia-Fundy region in 1993. DFO Atlantic Fish. Res. Doc. 94/37, 31 p.

Drinkwater, K.F. and R.W. Trites. 1987. Monthly means of temperature and salinity in the Scotian Shelf region. Can. Tech. Rep. Fish. Aquat. Sci. 1539: 101 p.

Drinkwater, K.F., E. Colbourne and D. Gilbert. 2001. Overview of environmental conditions in the Northwest Atlantic in 2000. NAFO SCR Doc. 01/36, 84 p. 34 p.

Drinkwater, K.F., R.A. Myers, R.G. Pettipas and T.L. Wright. 1994. Climatic data for the Northwest Atlantic: The position of the shelf/slope front and the northern boundary of the Gulf Stream between 50°W and 75°W, 1973-1992. Can. Data Rept. Fish. Ocean. Sci. 125: 103 pp.

Drinkwater, K.F., B. Petrie and P.C. Smith. 2003b. Climate variability on the Scotian Shelf during the 1990s. ICES Mar. Sci. Symp. Ser. (in press).

Drinkwater, K.F., B. Petrie, R.G. Pettipas, and W.M. Petrie. 2003a. An overview of meteorological, sea ice and sea-surface temperature conditions off eastern Canada during 2002. Can. Sci. Advis. Sec., Res. Doc. 2003/026, 37 p.

Drinkwater, K.F., R.G. Pettipas and W.M. Petrie. 2000. Physical oceanographic conditions on the Scotian Shelf and in the Gulf of Maine during 1999. Can. Stock Assessment Secretariat Res. Doc. 2000/060, 46 p.

Gilbert, D. and B. Pettigrew. 1997. A study of the interannual variability of the CIL core temperature in the Gulf of St. Lawrence. Can. J. Fish. Aquat. Sci. Vol. 54 (Suppl. 1): 57-67.

NAFO. 1983. Scientific Council Reports. Dartmouth, N.S., 151 p.

Petrie, B. and K. Drinkwater. 1993. Temperature and salinity variability on the Scotian Shelf and in the Gulf of Maine, 1945-1990. J. Geophys. Res. 98: 20079-20089.

Petrie, B., K. Drinkwater, A. Sandström, R. Pettipas, D. Gregory, D. Gilbert and P. Sekhon. 1996. Temperature, salinity and sigma-t atlas for the Gulf of St. Lawrence. Can. Tech. Rep. Hydrogr. Ocean Sci. 178: 256 p.

Smith, P.C., R.W. Houghton, R.G. Fairbanks and D.G. Mountain. 2001. Interannual variability of boundary fluxes and water mass properties in the Gulf of Maine and on Georges Bank: 1993-1997. Deep-Sea Research II:

Tushingham, A. and R. Peltier 1991. Ice 3-G: a new global model of late Pleistocene deglaciation based on geophysical predictions of post-glacial relative sea level change. J. Geophys. Res. 96, 4497-4523.

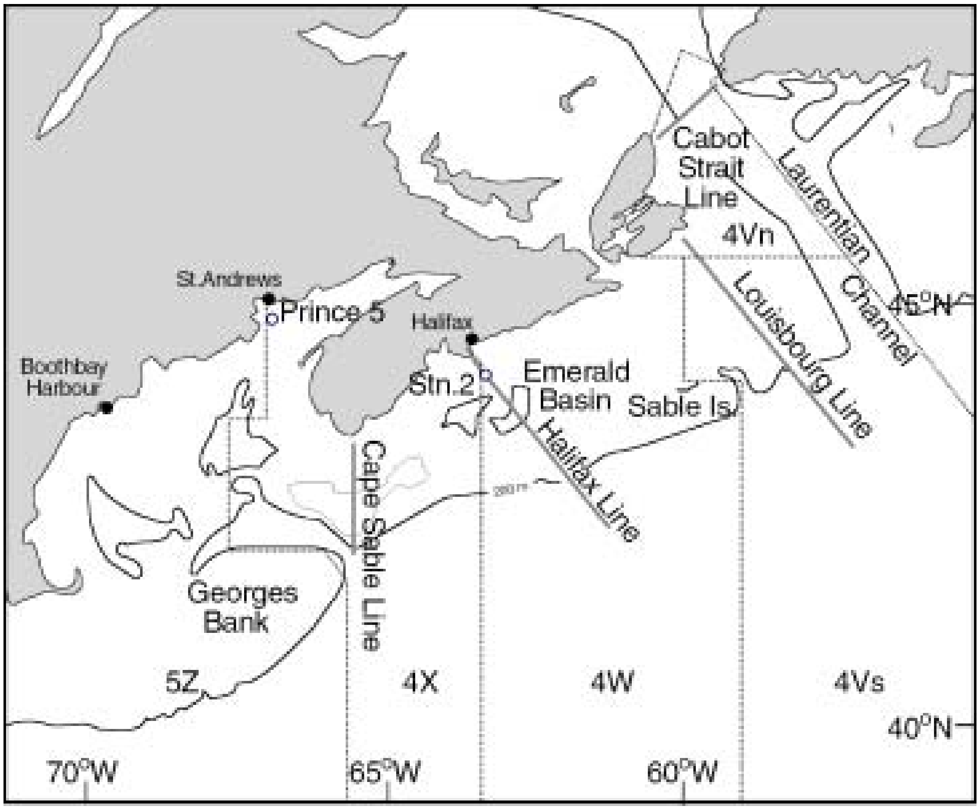


Fig. 1. The Scotian Shelf and the Gulf of Maine showing hydrographic stations, standard sections and topographic features. The dotted lines indicate the boundaries of the NAFO Subareas.

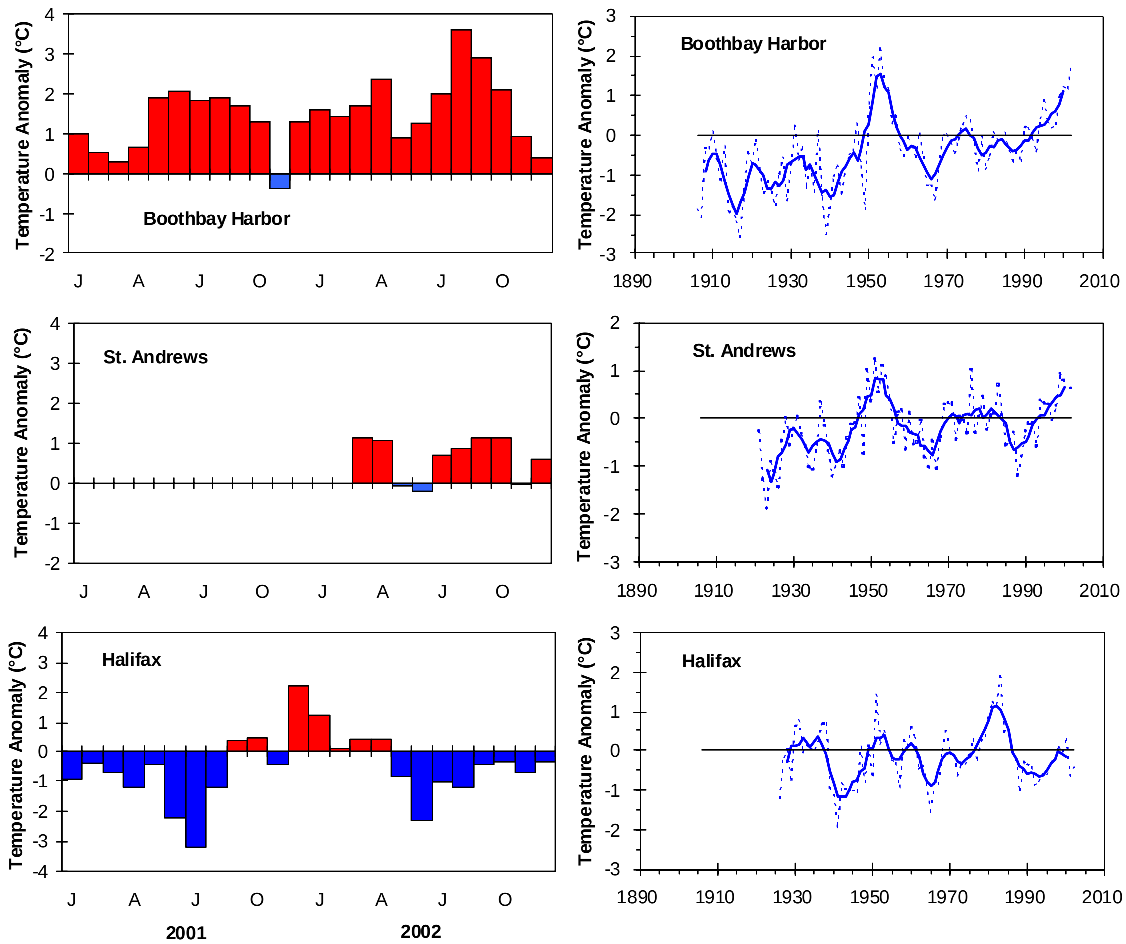


Fig. 2. The monthly sea surface temperature anomalies during 2001 and 2002 (left) and the annual temperature anomalies and their 5-year running means (right) for Boothbay Harbor, St. Andrews and Halifax Harbour. Anomalies are relative to the 1971-2000 means.

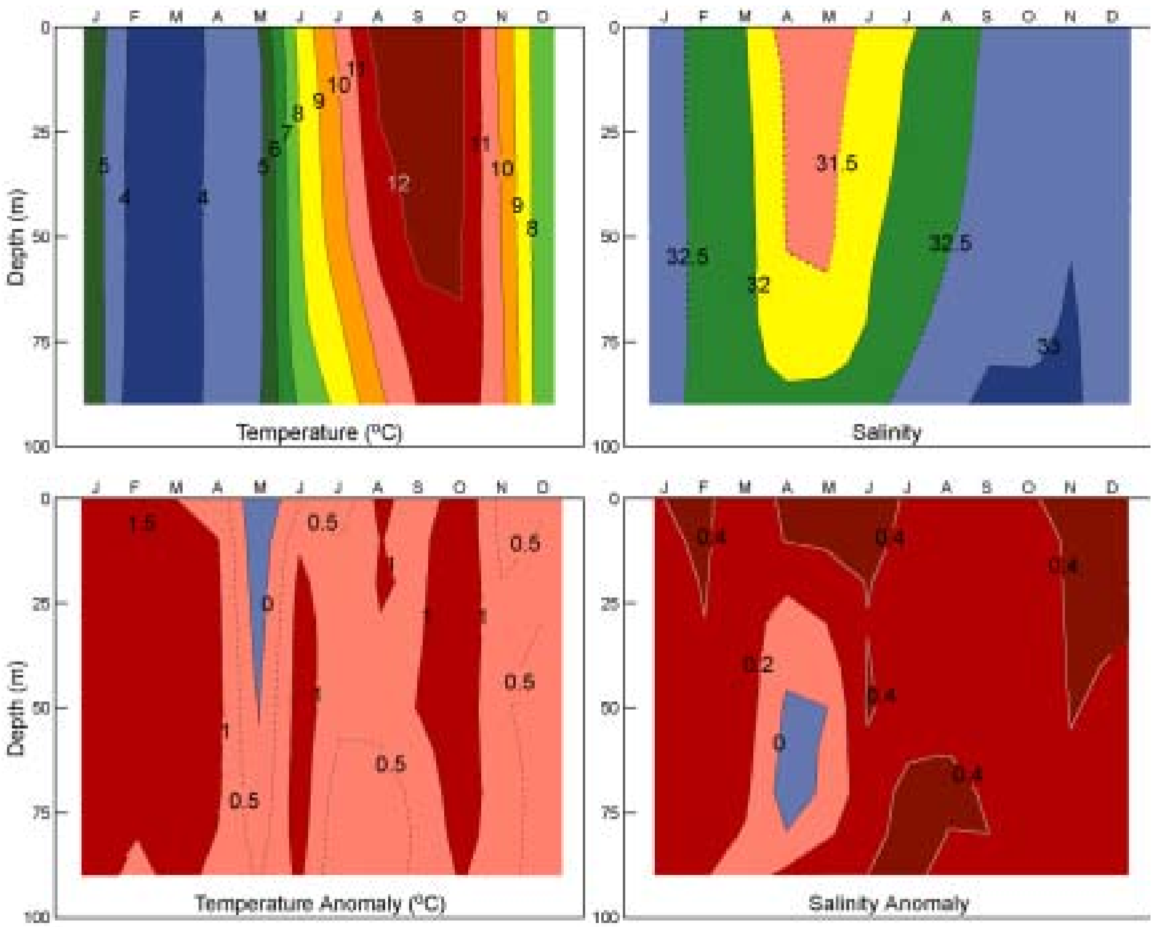


Fig. 3. Contours of monthly mean temperature (left) and salinity (right) and their anomalies (bottom panels) at Prince 5 as a function of depth during 2002 relative to the 1971-2000 means. Colder and fresher-than-normal conditions are blue.

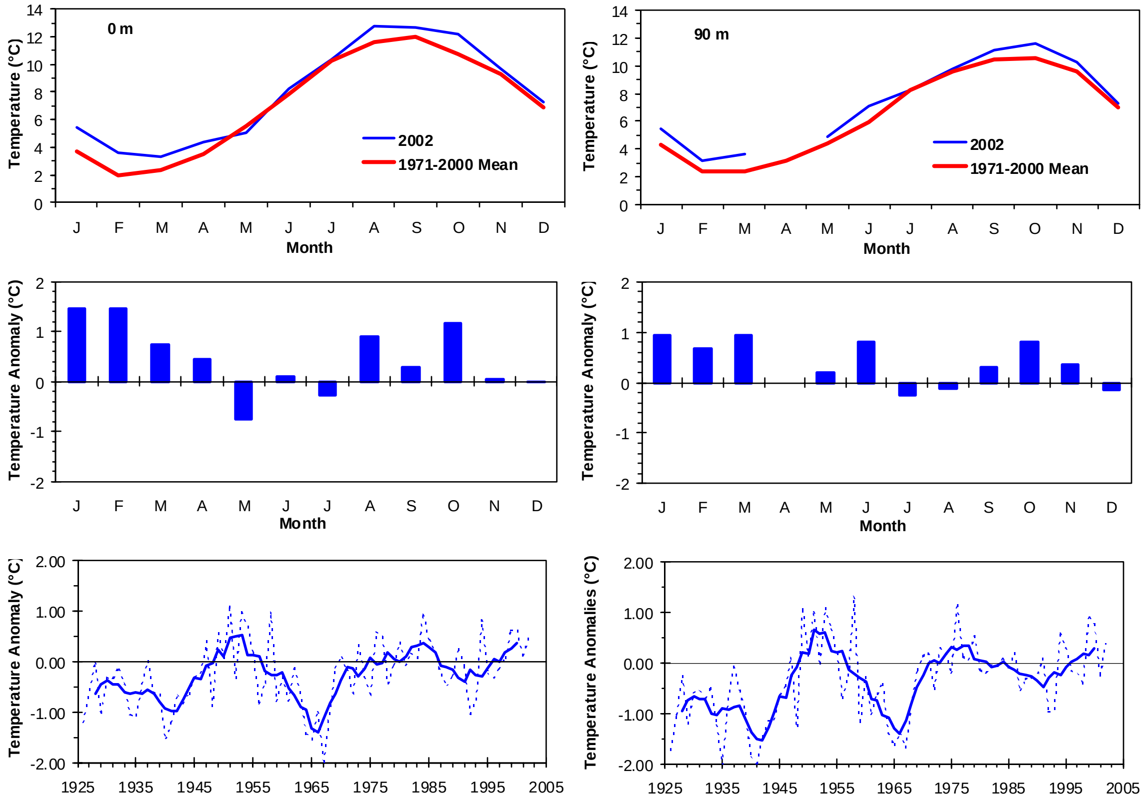


Fig. 4. The monthly mean temperatures for 2002 (solid line; top panels) and their long-term means (dashed line; top panels), the monthly anomalies relative to the long-term means for 1971-2000 (middle panels) and in the bottom panels are the time series of the annual means (dashed lines) and their 5-year running means (solid line) for Prince 5, 0 m (left) and 90 m (right).

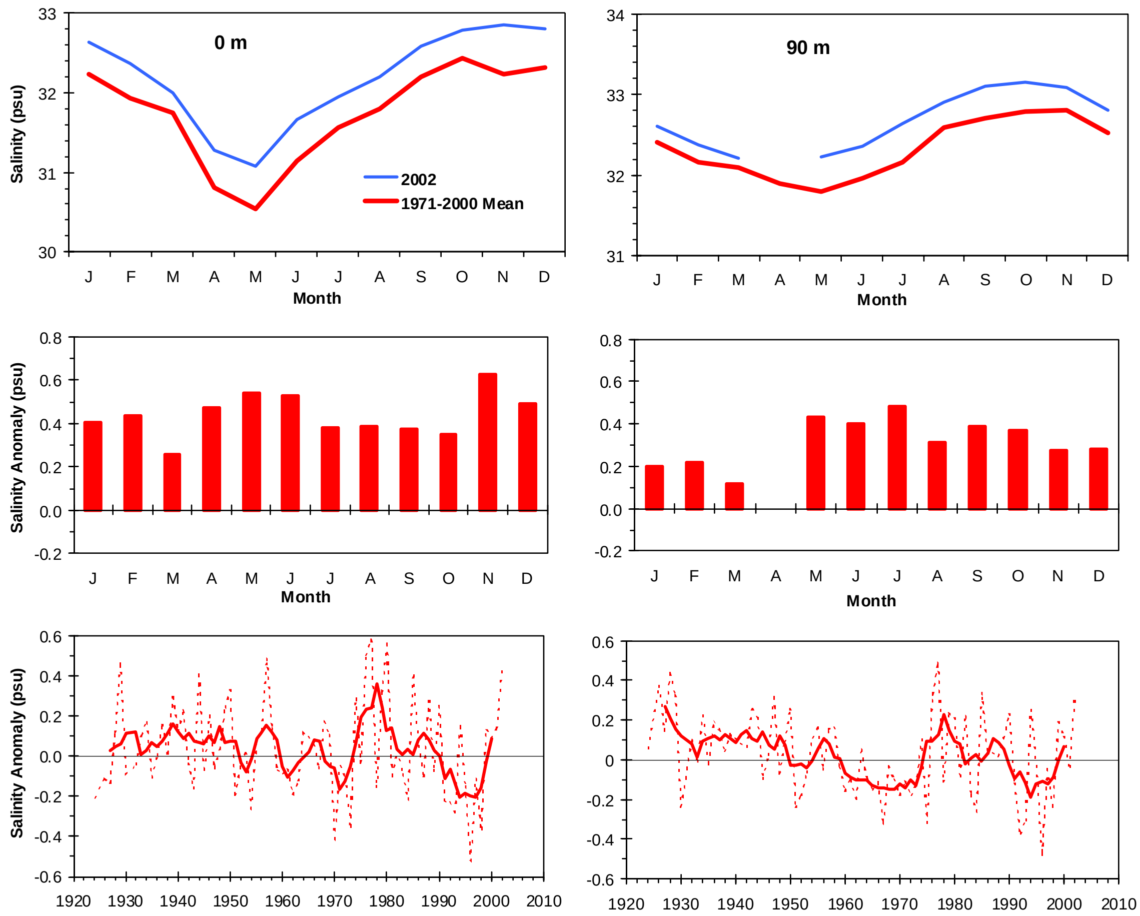


Fig. 5. The monthly mean salinities for 2002 (solid line; top panels) and their long-term means (dashed line; top panels), the monthly anomalies relative to the long-term means for 1971-2000 (middle panels) and in the bottom panels are the time series of the annual means (dashed lines) and their 5-year running averages (solid line) for Prince 5, 0 m (left) and 90 m (right).

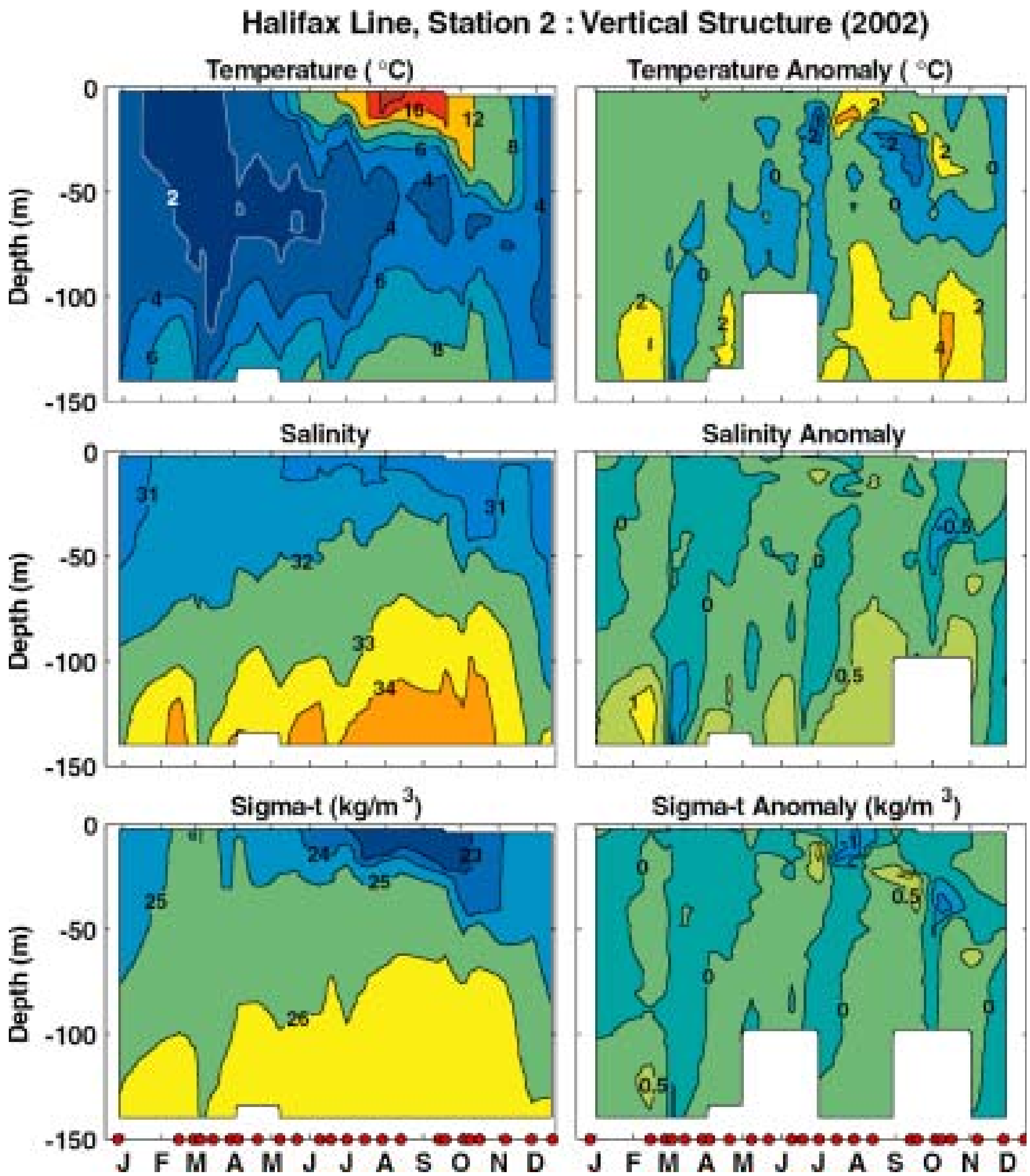
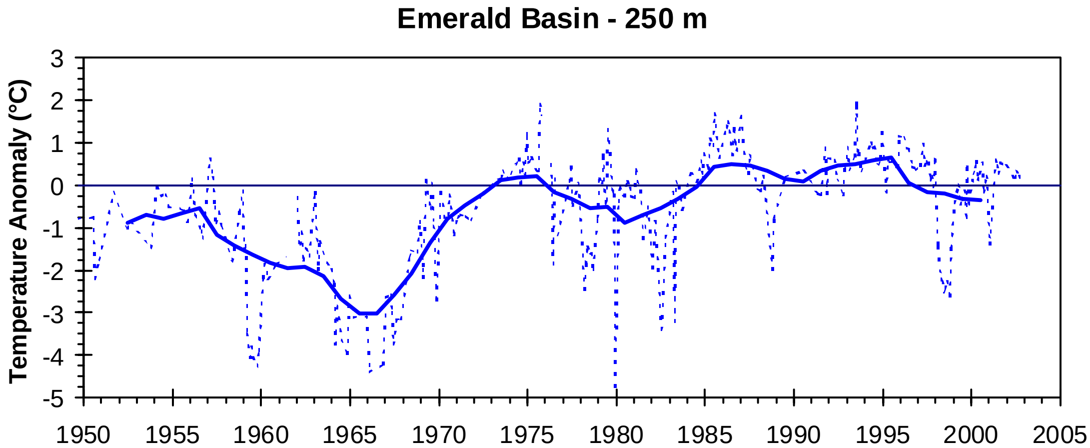


Fig. 6. Contours by depth of the 2002 temperature, salinity and density (sigma-t) (left) and their anomalies (right) at the standard station H2. The circles at the bottom of the figure indicate sampling dates.



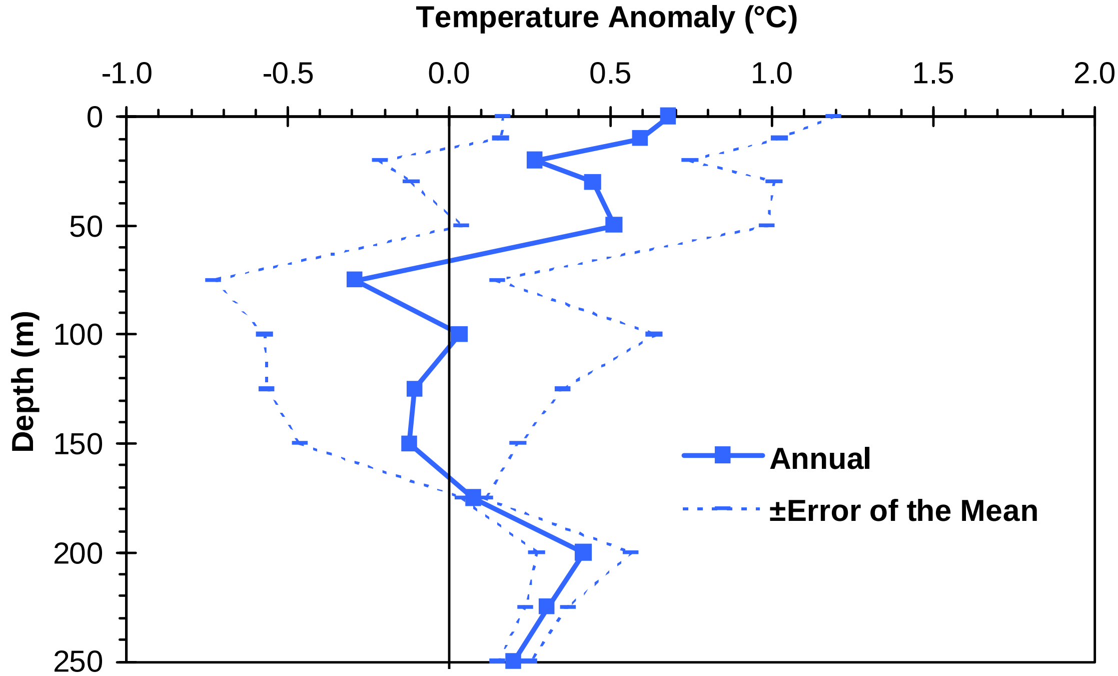


Fig. 7. Time series of available monthly mean temperature anomalies at 250 m in Emerald Basin (dashed line) and their 5-year running means (solid line) in the top panel. The bottom panel shows the annual temperature anomalies for 2002 as a function of depth. The dashed lines represent the standard errors of the mean based upon the available monthly anomalies.

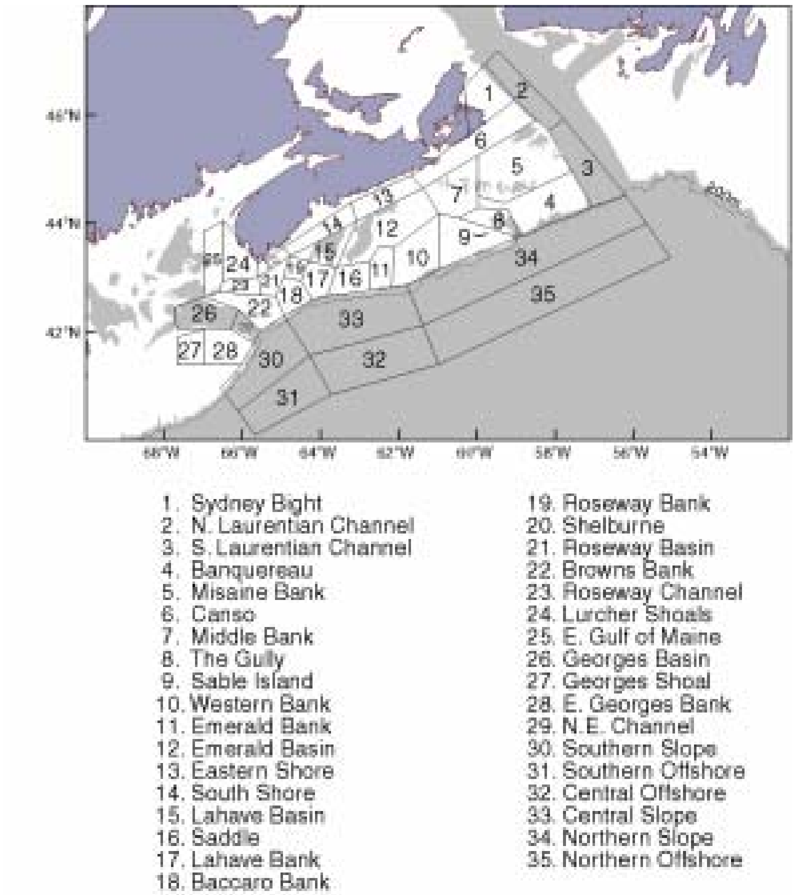


Fig. 8. Areas on the Scotian Shelf and eastern Gulf of Maine from Drinkwater and Trites (1987).

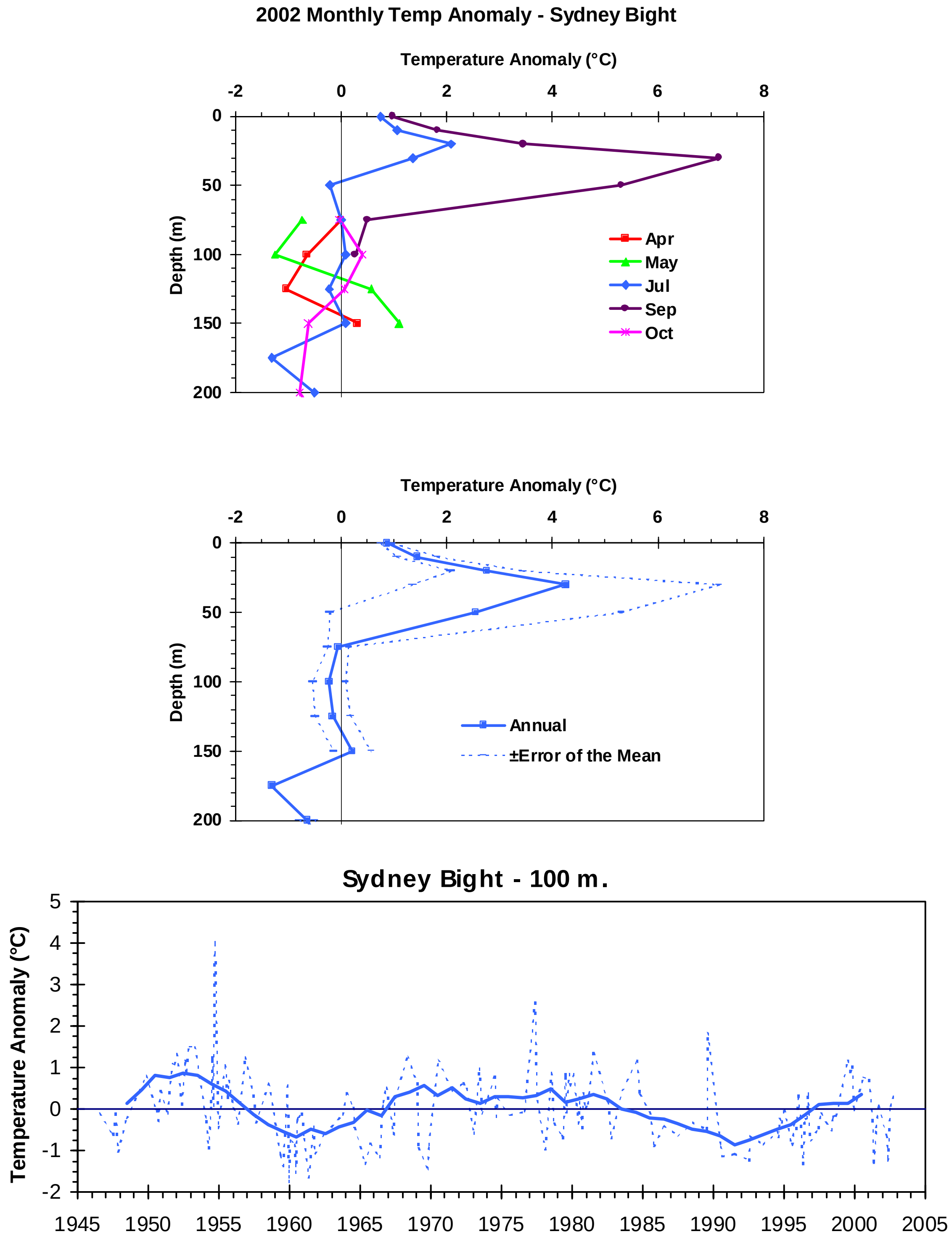


Fig. 9. The 2002 monthly temperature anomaly profiles (top panel), the annual anomalies with the standard error of the mean (middle panel) and the monthly mean temperature anomaly time series (dashed line) and the 5-yr running mean of the estimated annual anomalies (solid line) at 100 m (bottom panel) for Sydney Bight (area 1-Fig. 8).

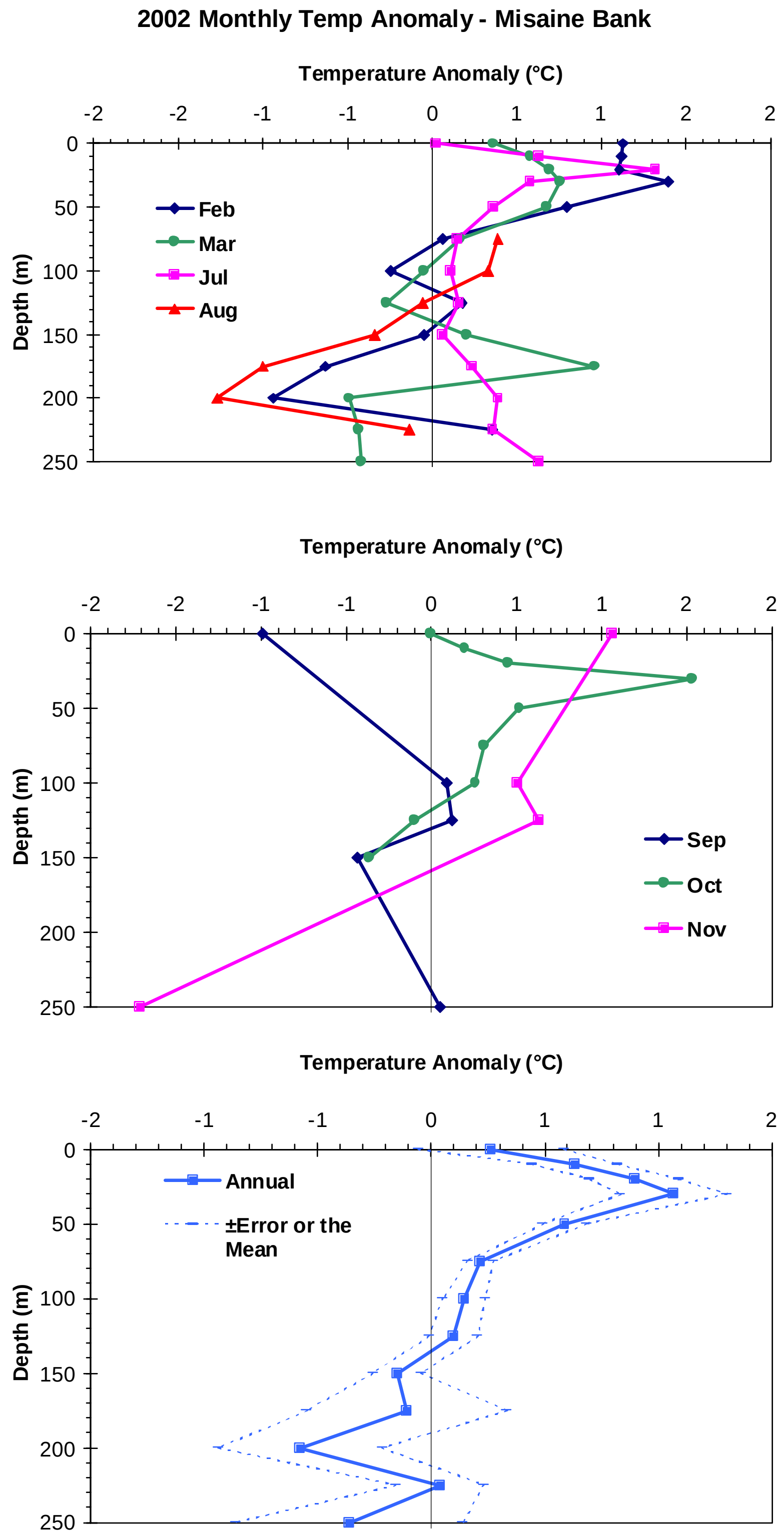


Fig. 10. The 2002 monthly temperature anomaly profiles (top two panels) and the annual anomalies with the standard error of the mean (bottom panel) for Misaine Bank (area 5-Fig. 8).

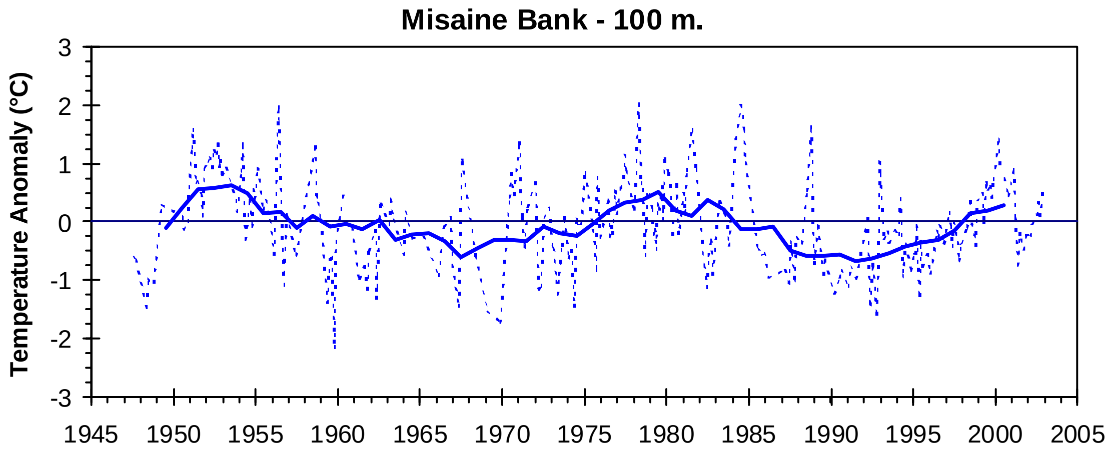


Fig. 11. The monthly mean temperature anomaly time series (dashed line) and the 5-yr running mean of the estimated annual anomalies (solid line) at 100 m for Misaine Bank (area 5-Fig. 8).

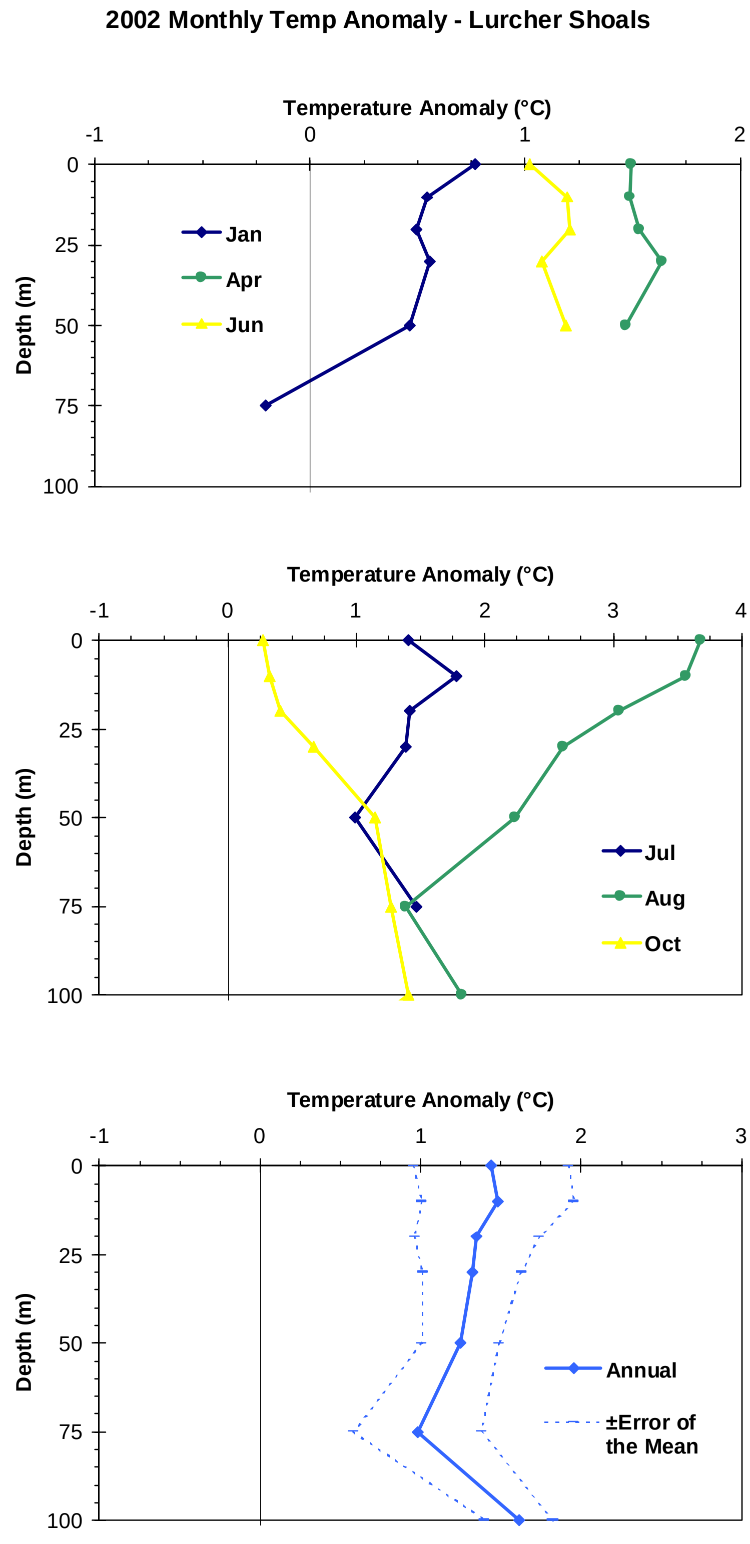


Fig. 12. The 2002 monthly temperature anomaly profiles (top two panels) and the annual anomalies with the standard error of the mean (bottom panel) for Lurcher Shoals (area 24-Fig. 8).

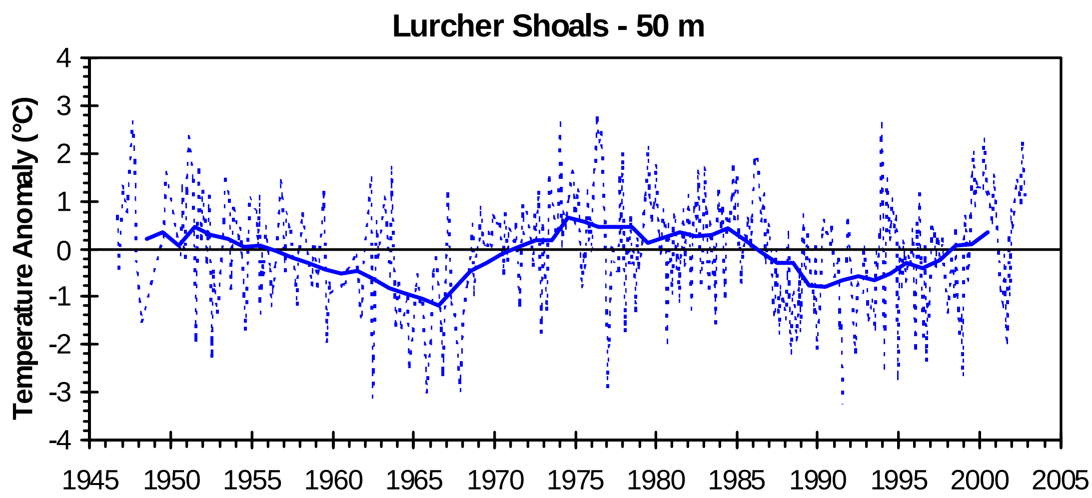


Fig. 13. The monthly mean temperature anomaly time series (dashed line) and the 5-yr running mean of the estimated annual anomalies (solid line) at 50 m for Lurcher Shoals (area 24-Fig. 8)

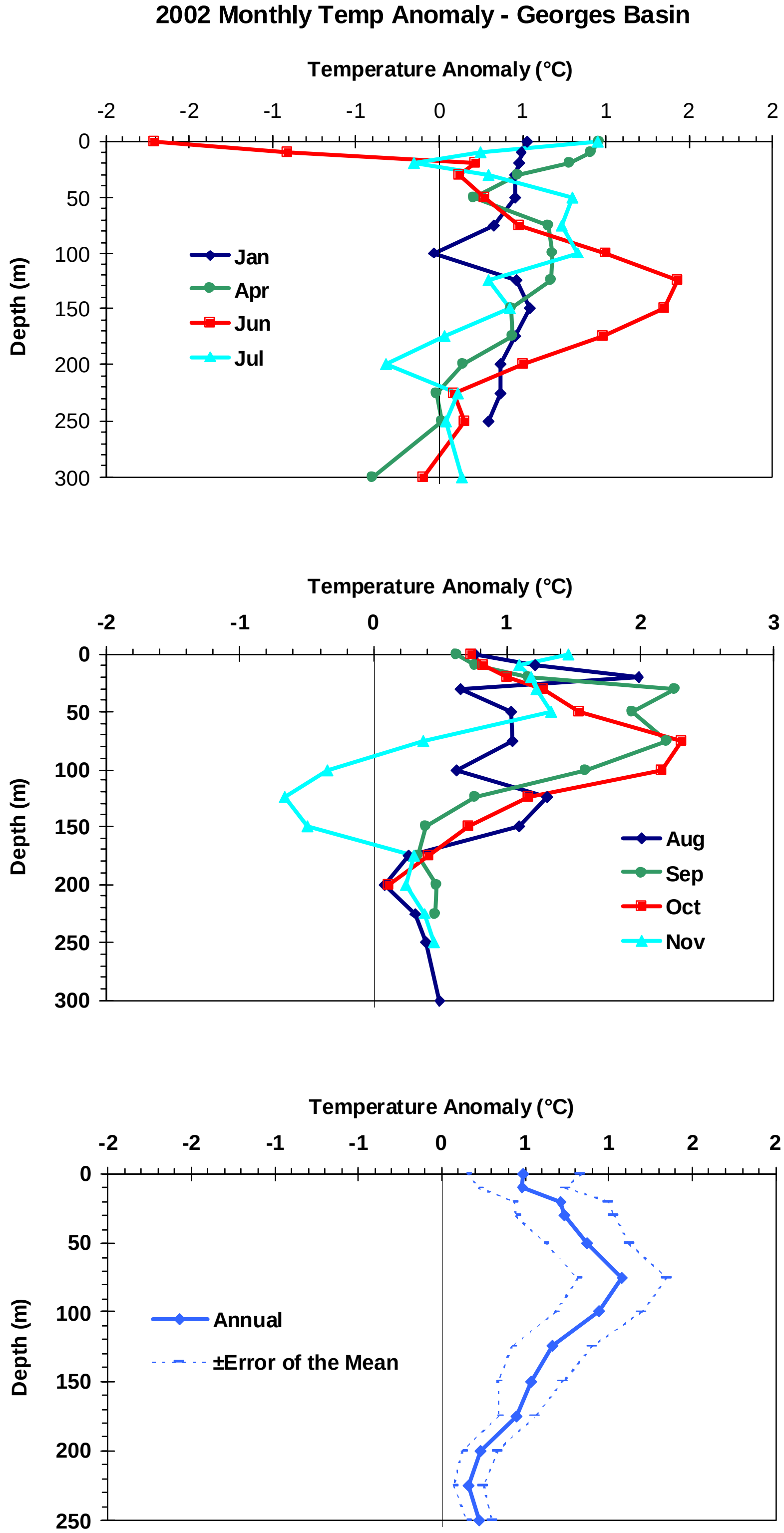


Fig. 14. The 2002 monthly temperature anomaly profiles (top two panels) and the annual anomalies with the standard error of the mean (bottom panel) for Georges Basin (area 26-Fig. 8).

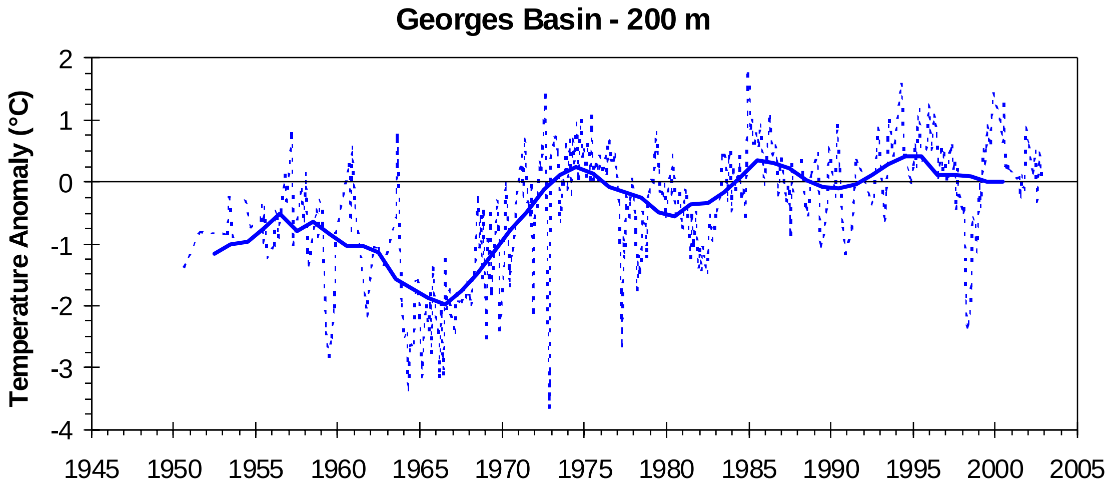


Fig. 15. The monthly mean temperature anomaly time series (dashed line) and the 5-yr running mean of the estimated annual anomalies (solid line) at 200 m in Georges Basin (area 26-Fig. 8).

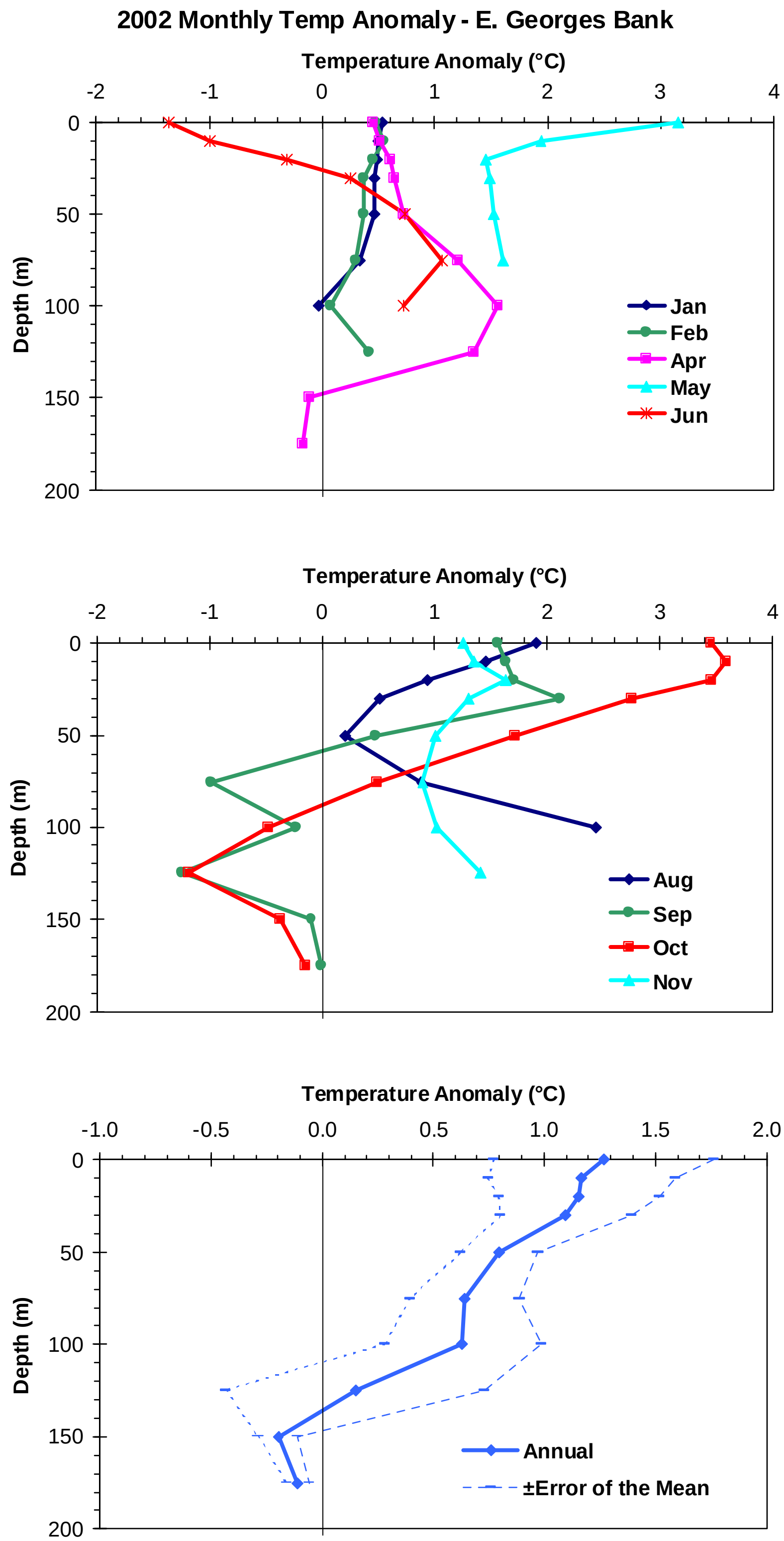


Fig. 16. The 2002 monthly temperature anomaly profiles (top two panels) and the annual anomalies with the standard error of the mean (bottom panel) for Eastern Georges Bank (area 28-Fig. 8).

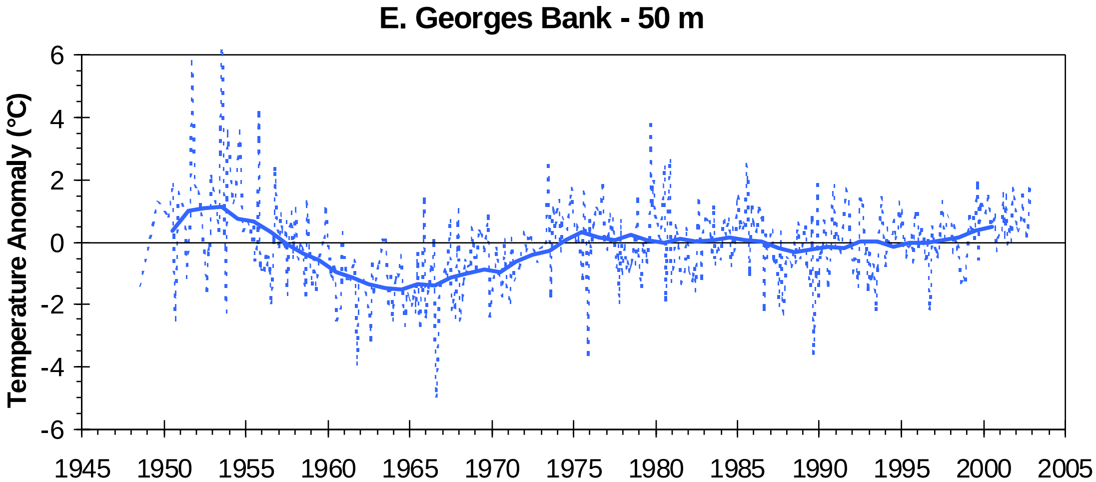


Fig. 17. The monthly mean temperature anomaly time series (dashed line) and the 5-yr running mean of the estimated annual anomalies (solid line) at 50 m in Eastern Georges Bank (area 28-Fig. 8).

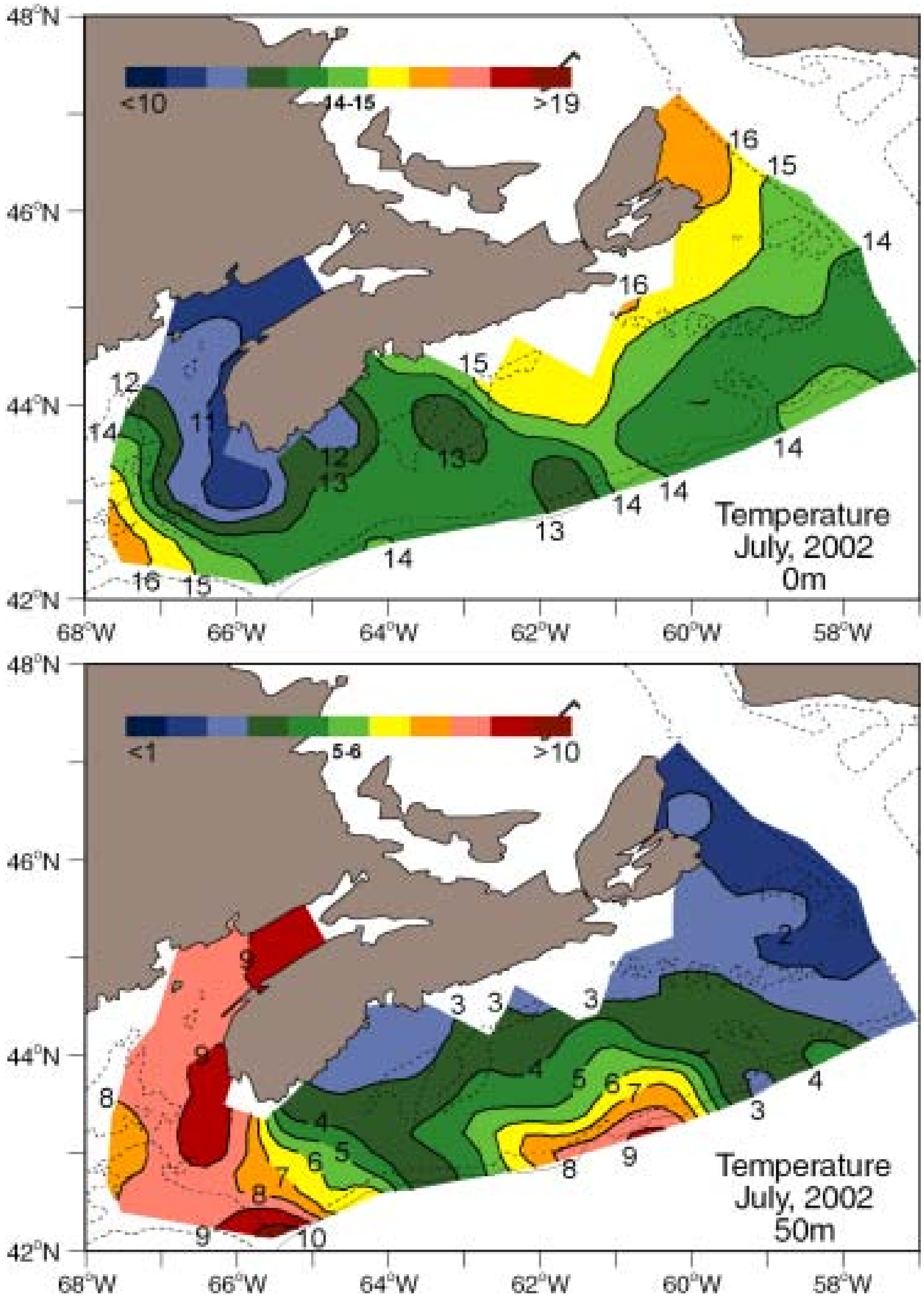


Fig.18a. Contours of temperatures at the surface (top panel) and 50 m (bottom panel) during the 2002 July groundfish and ITQ surveys.

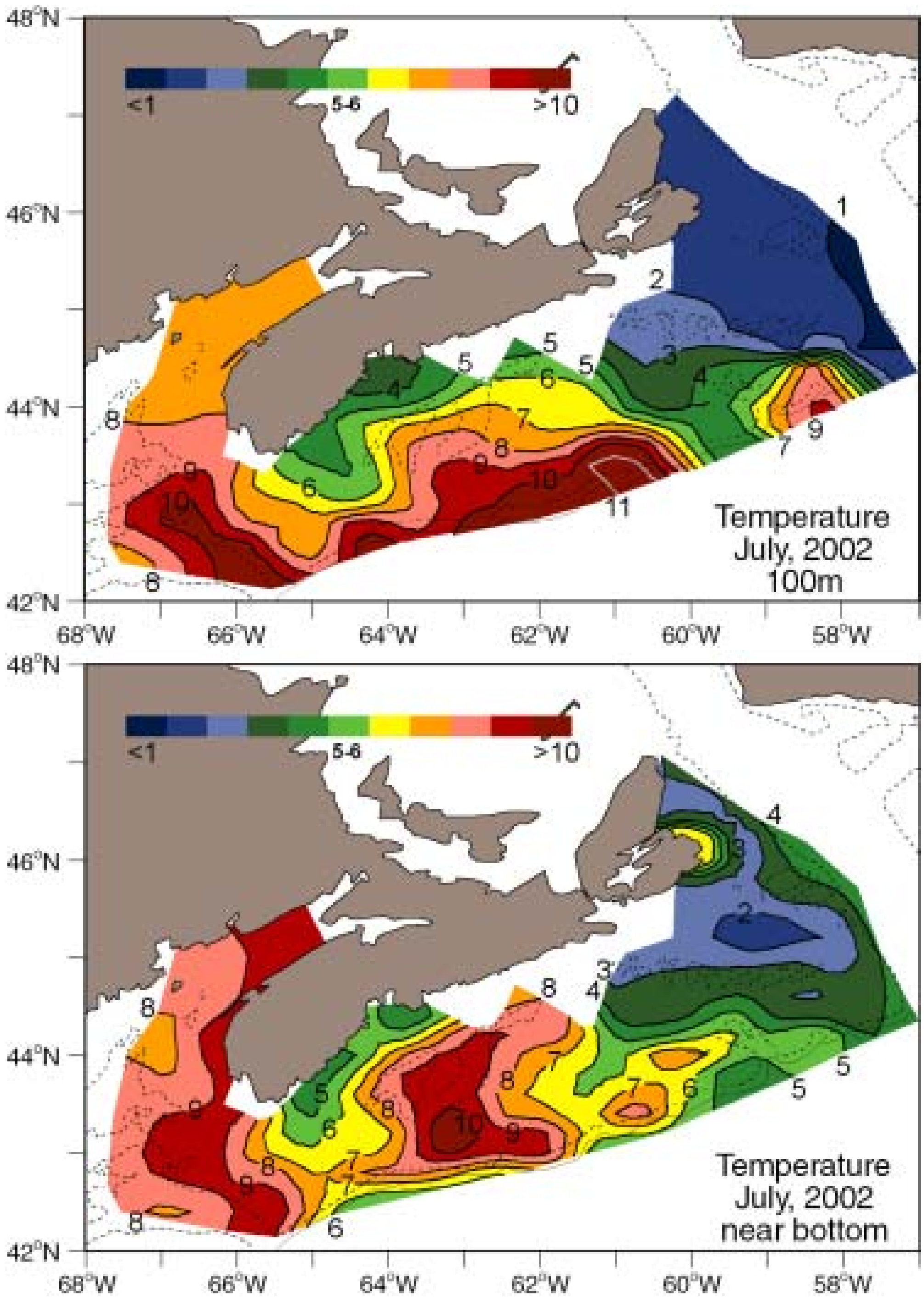


Fig.18b. Contours of temperatures at 100 m (top panel) and near bottom (bottom panel) during the 2002 July groundfish and ITQ surveys.

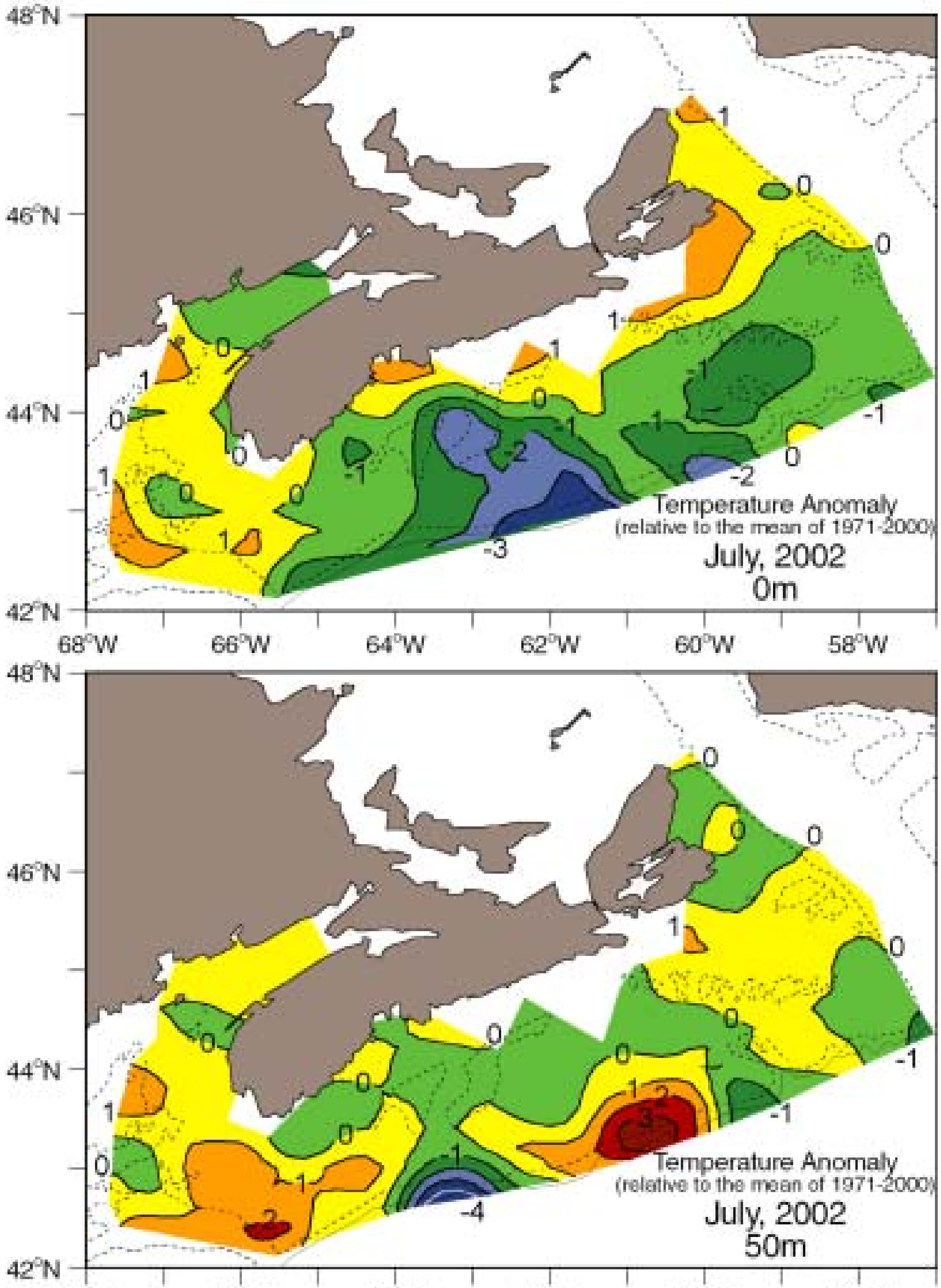


Fig.19a. Contours of temperature anomalies at the surface (top panel) and 50 m (bottom panel) during the 2002 July groundfish and ITQ surveys.

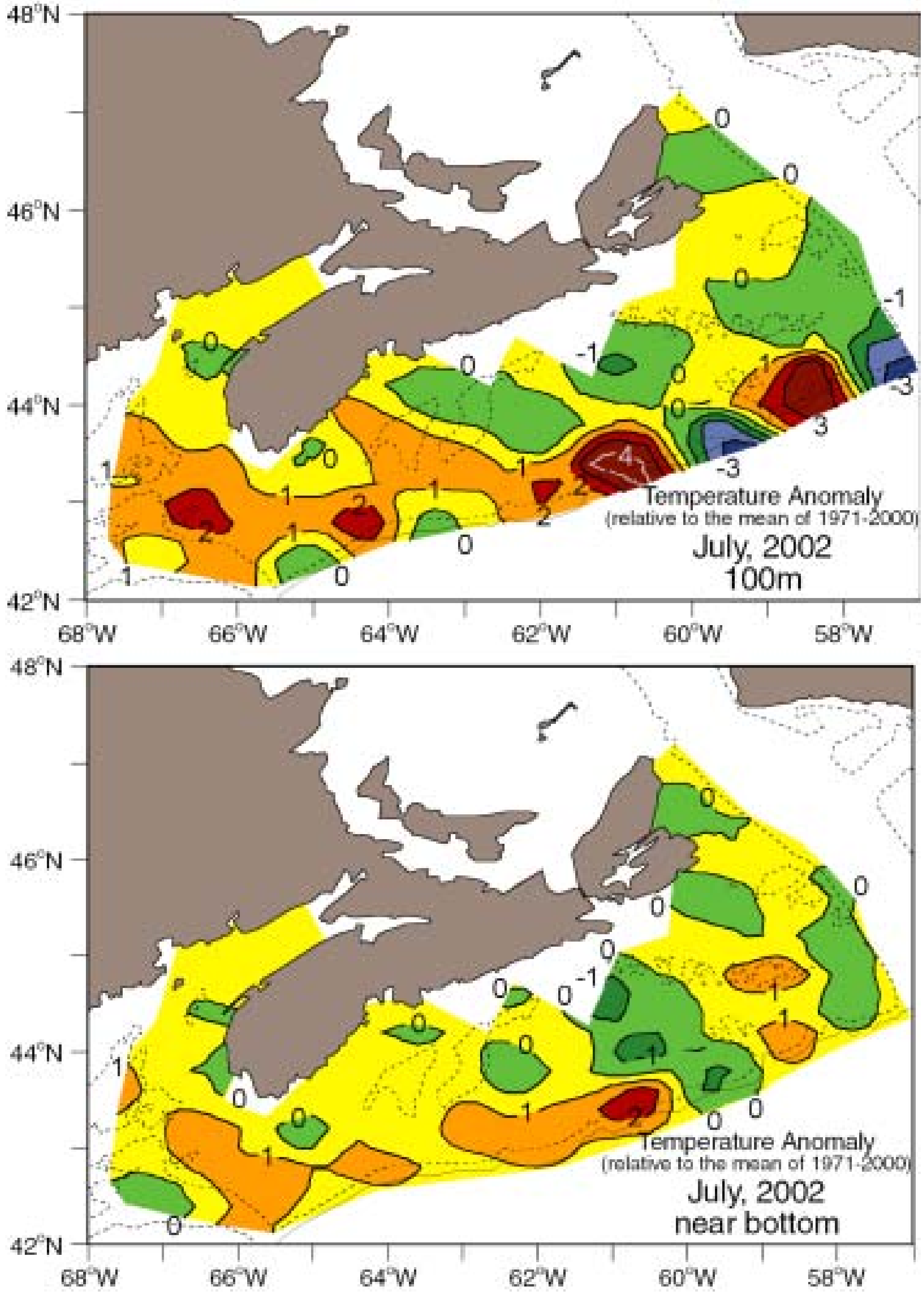


Fig.19b. Contours of temperature anomalies at 100 m (top panel) and near bottom (bottom panel) during the 2002 July groundfish and ITQ surveys.

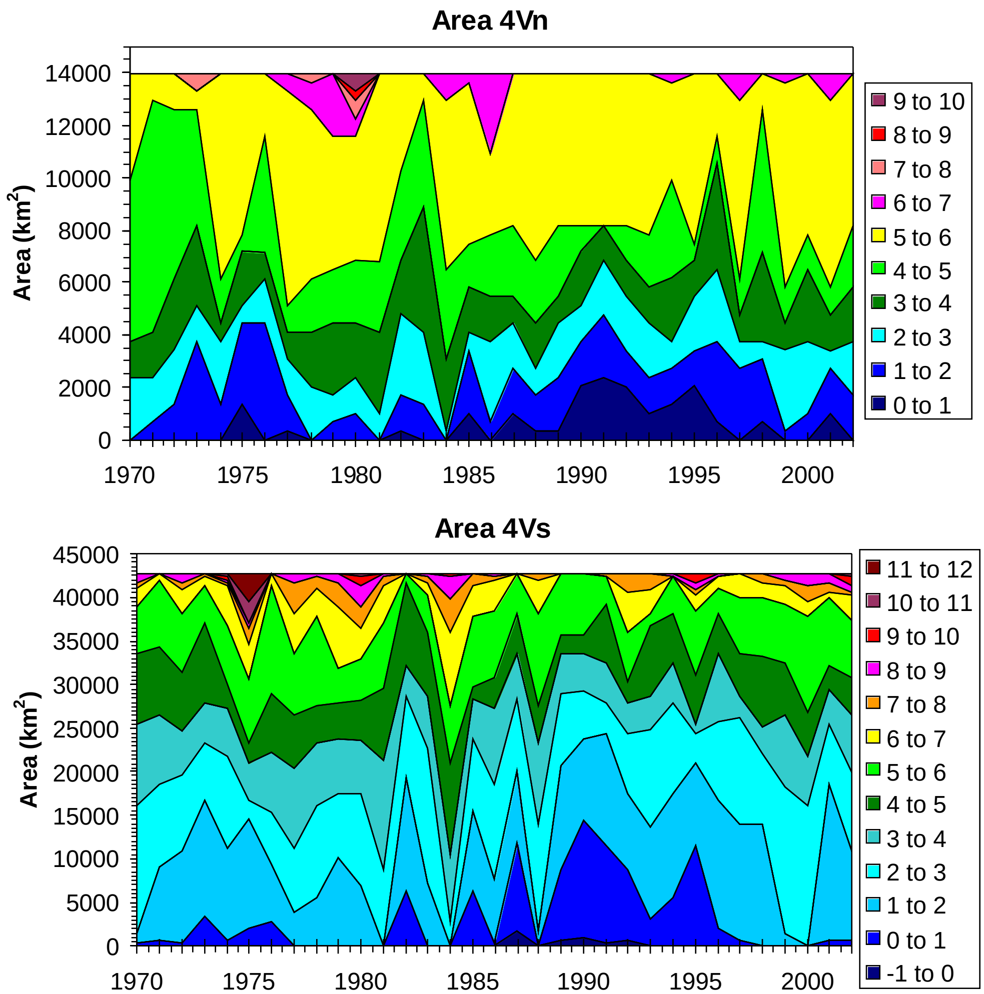


Fig.20a. The time series of the area of the bottom for each 1 degree temperature range for NAFO Subareas 4Vn (top panel) and 4Vs(bottom panel).

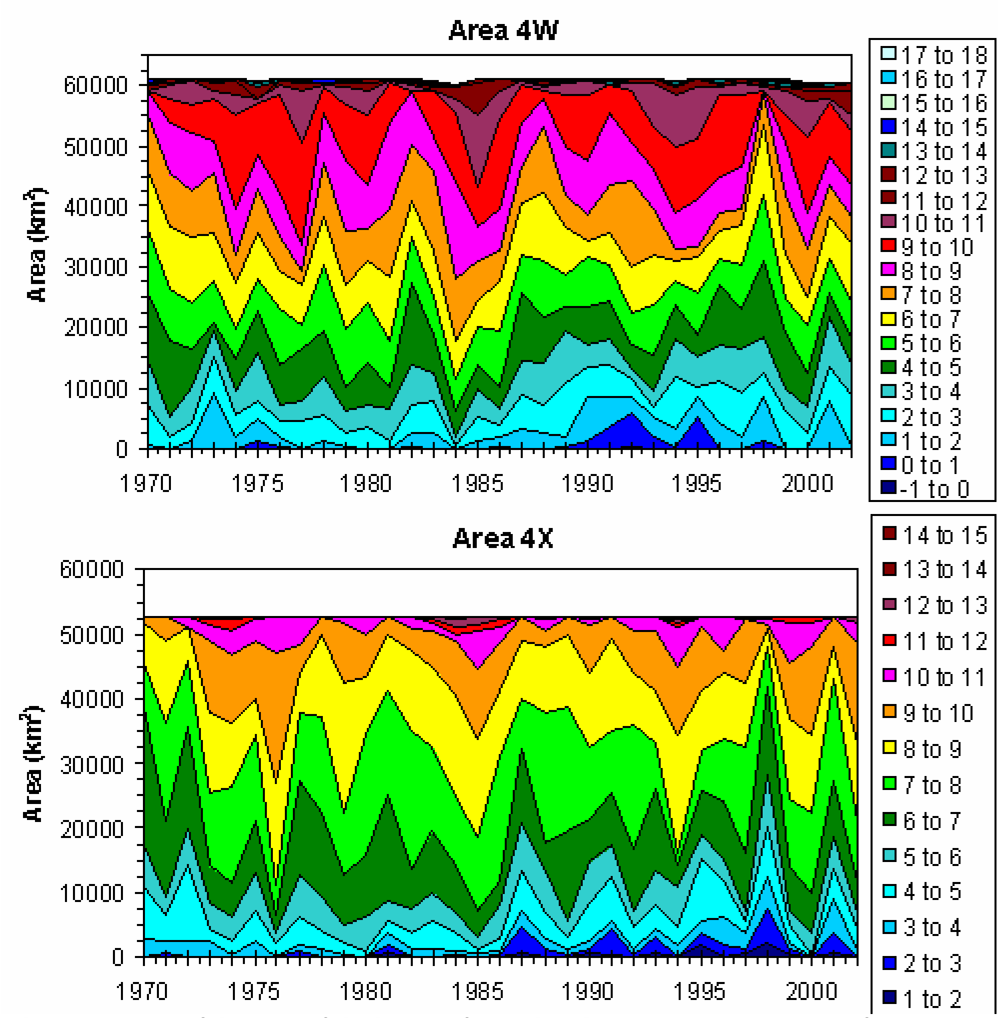


Fig.20b. The time series of the area of the bottom for each 1 degree temperature range for NAFO Subareas 4W (top panel) and 4X(bottom panel).

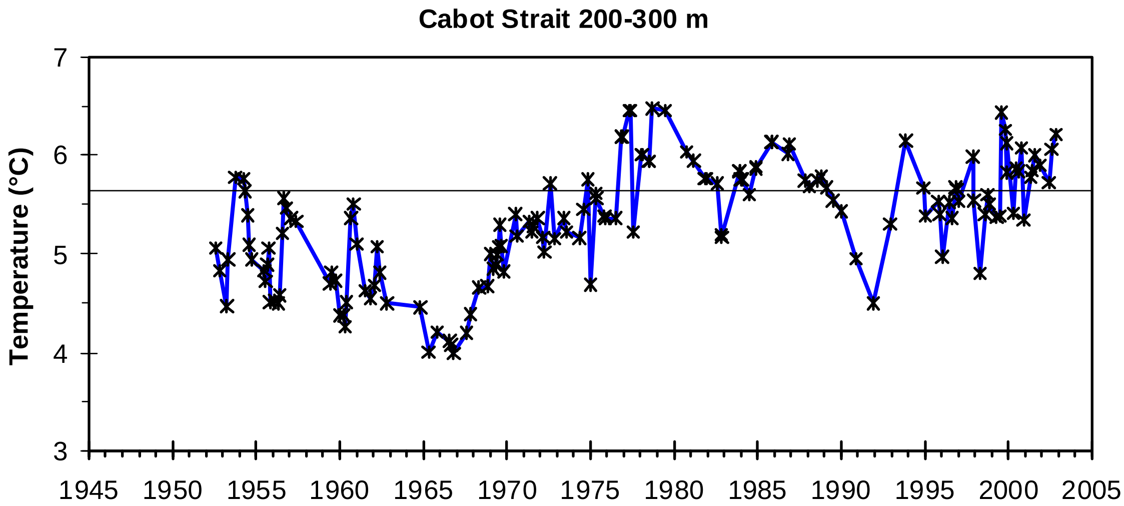


Fig.21. Average temperature over the 200-300 m layer in Cabot Strait. The horizontal line indicates the long-term mean during 1971-2000.

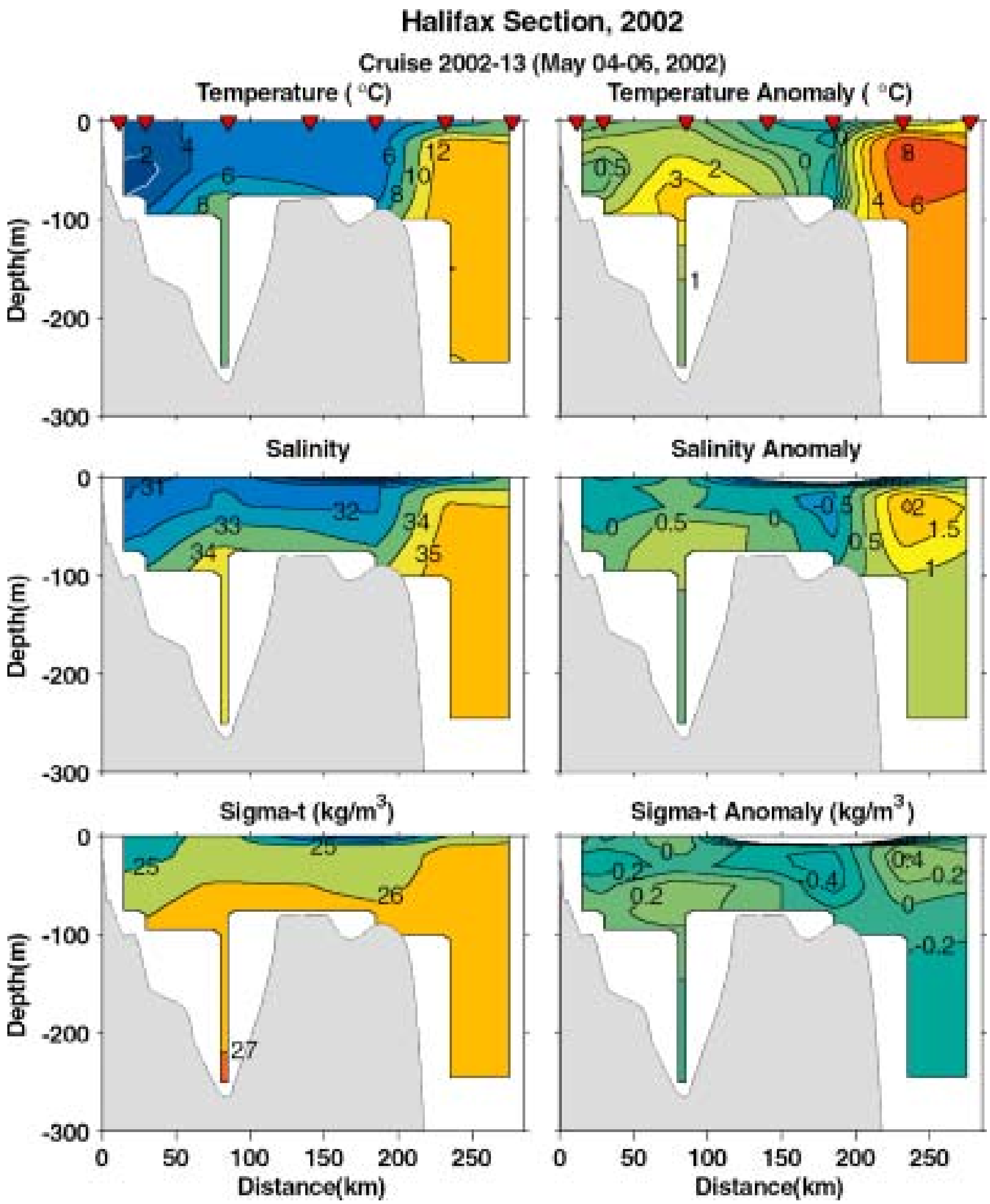


Fig. 22. Contours by depth of the temperature, salinity and density (sigma-t) (left) and their anomalies (right) along the Halifax Line during May 2002.

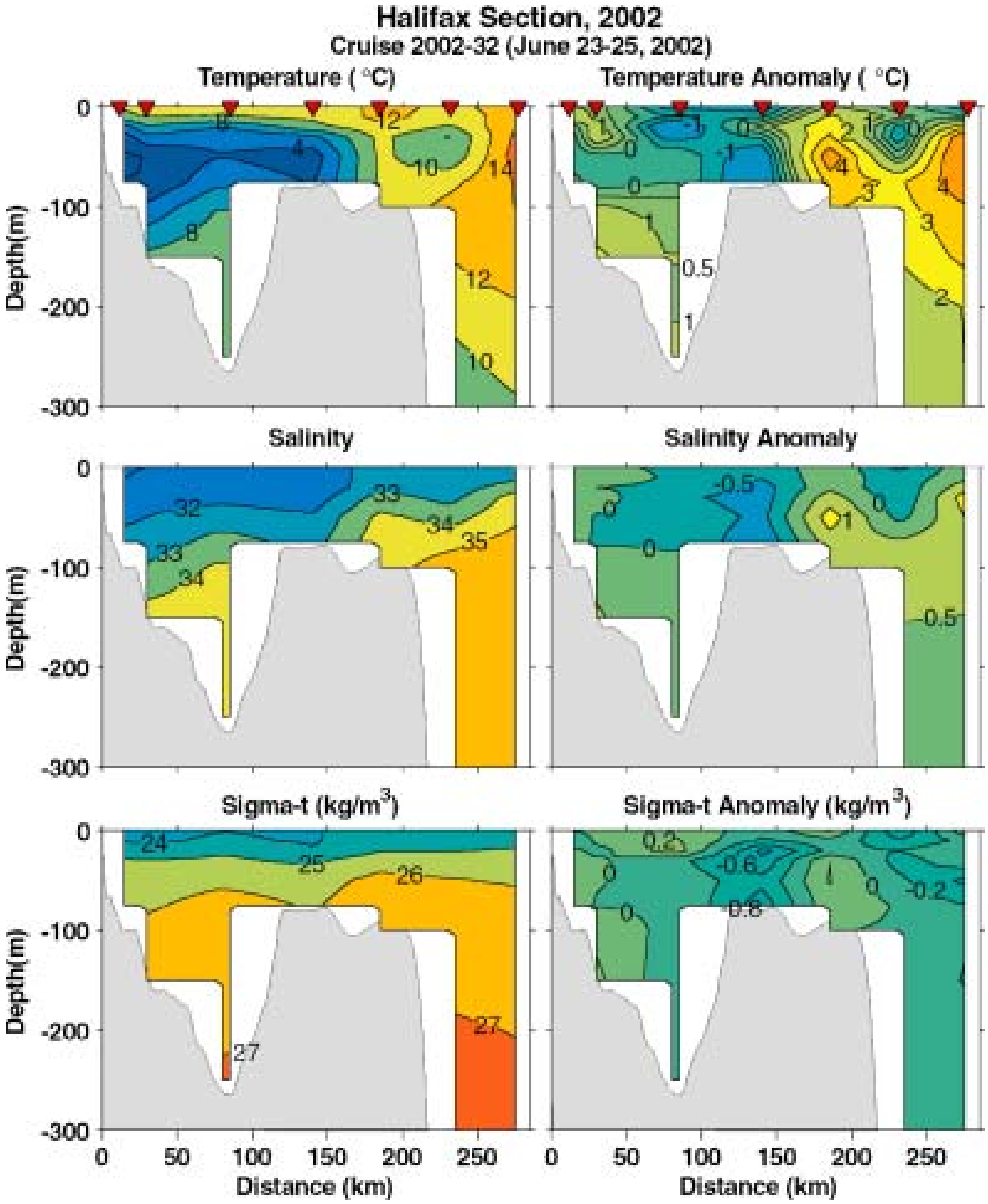


Fig. 23. Contours by depth of the temperature, salinity and density (sigma-t) (left) and their anomalies (right) along the Halifax Line during June 2002.

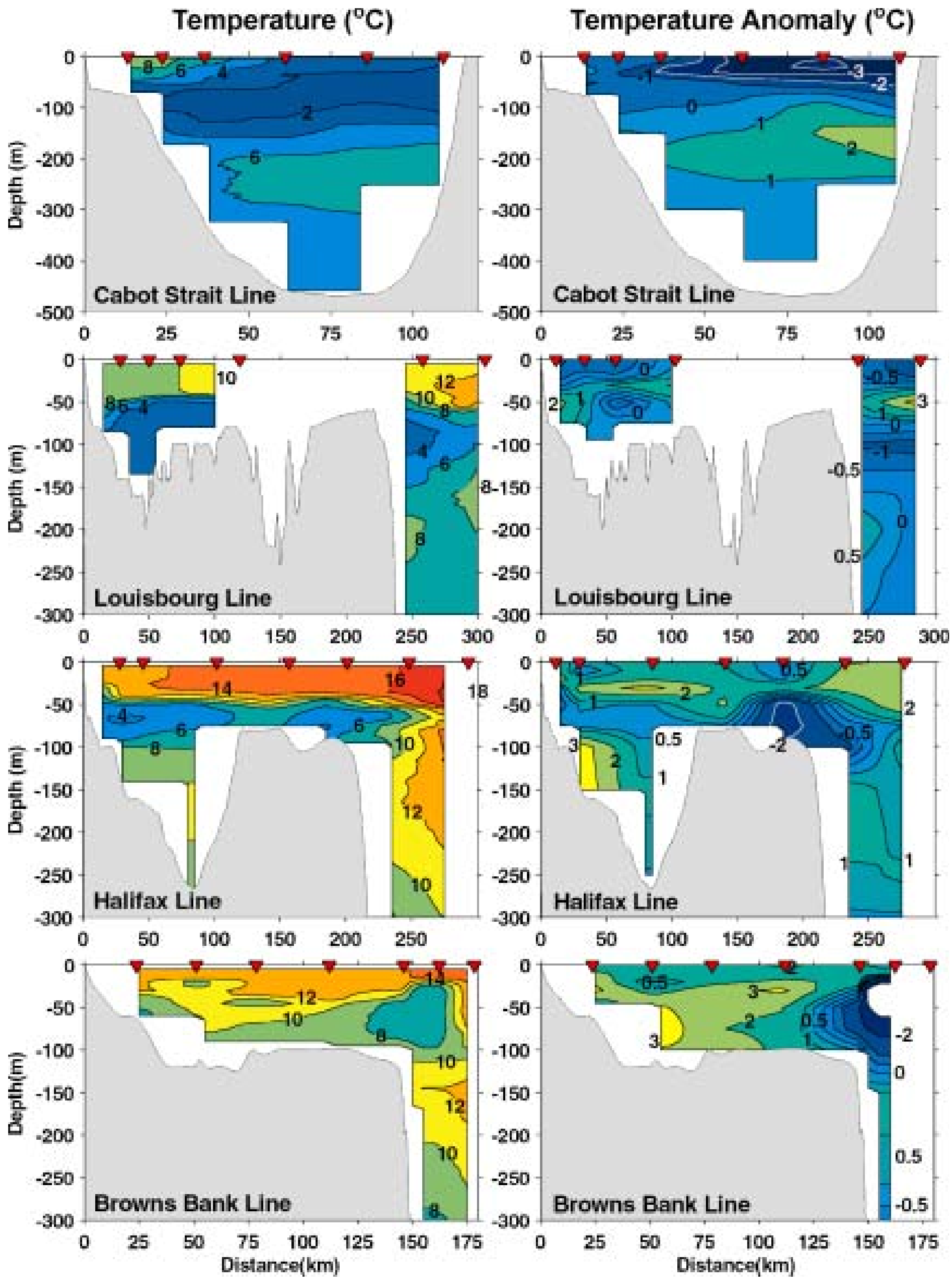


Fig. 24a. Temperatures and temperature anomalies on the Cabot Strait, Louisbourg, Halifax and Browns Bank Lines (Fig. 1) for October-November 2002.

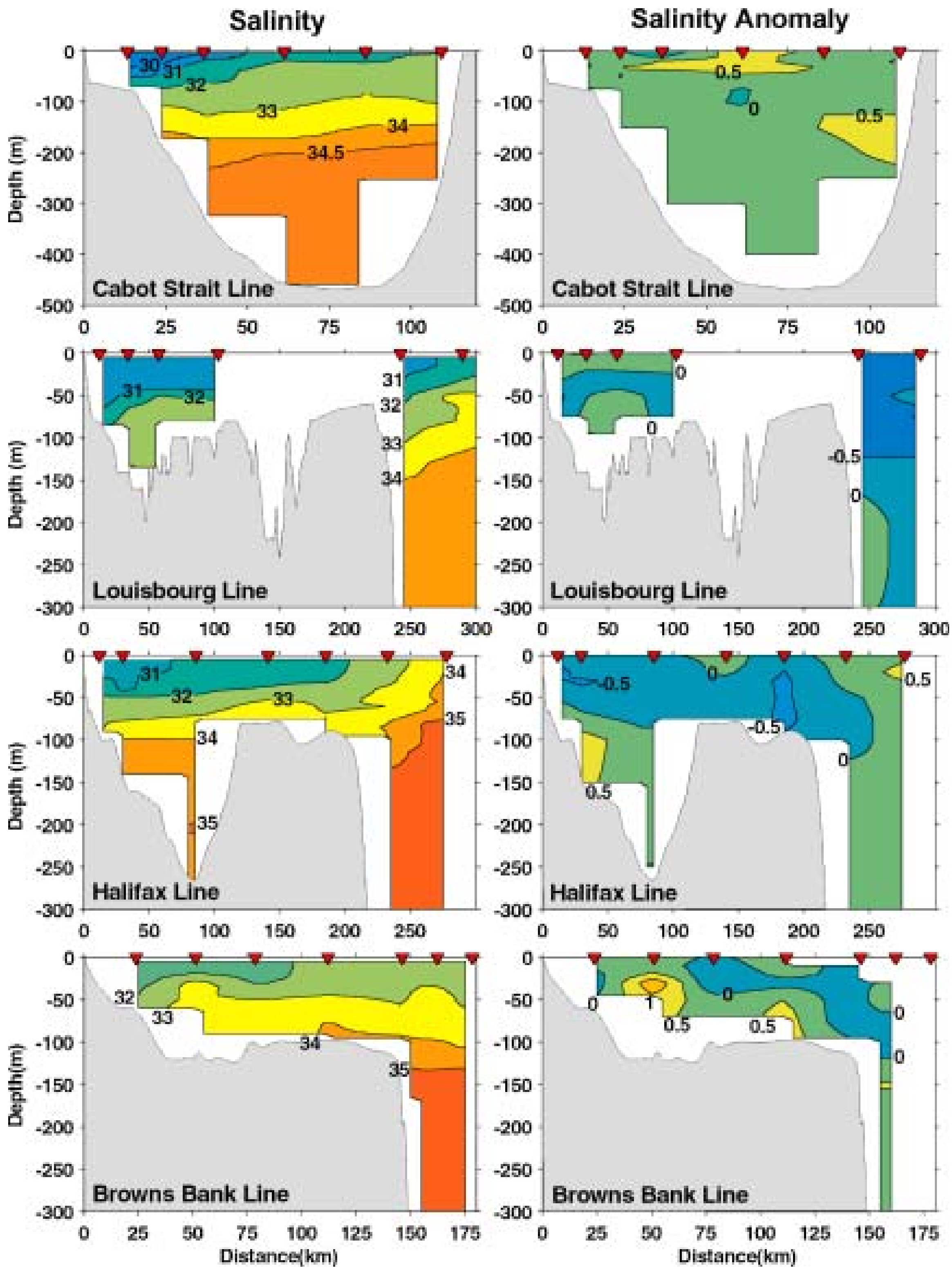


Fig. 24b. Salinities and salinity anomalies on the Cabot Strait, Louisbourg, Halifax and Browns Bank Lines for October-November 2002.

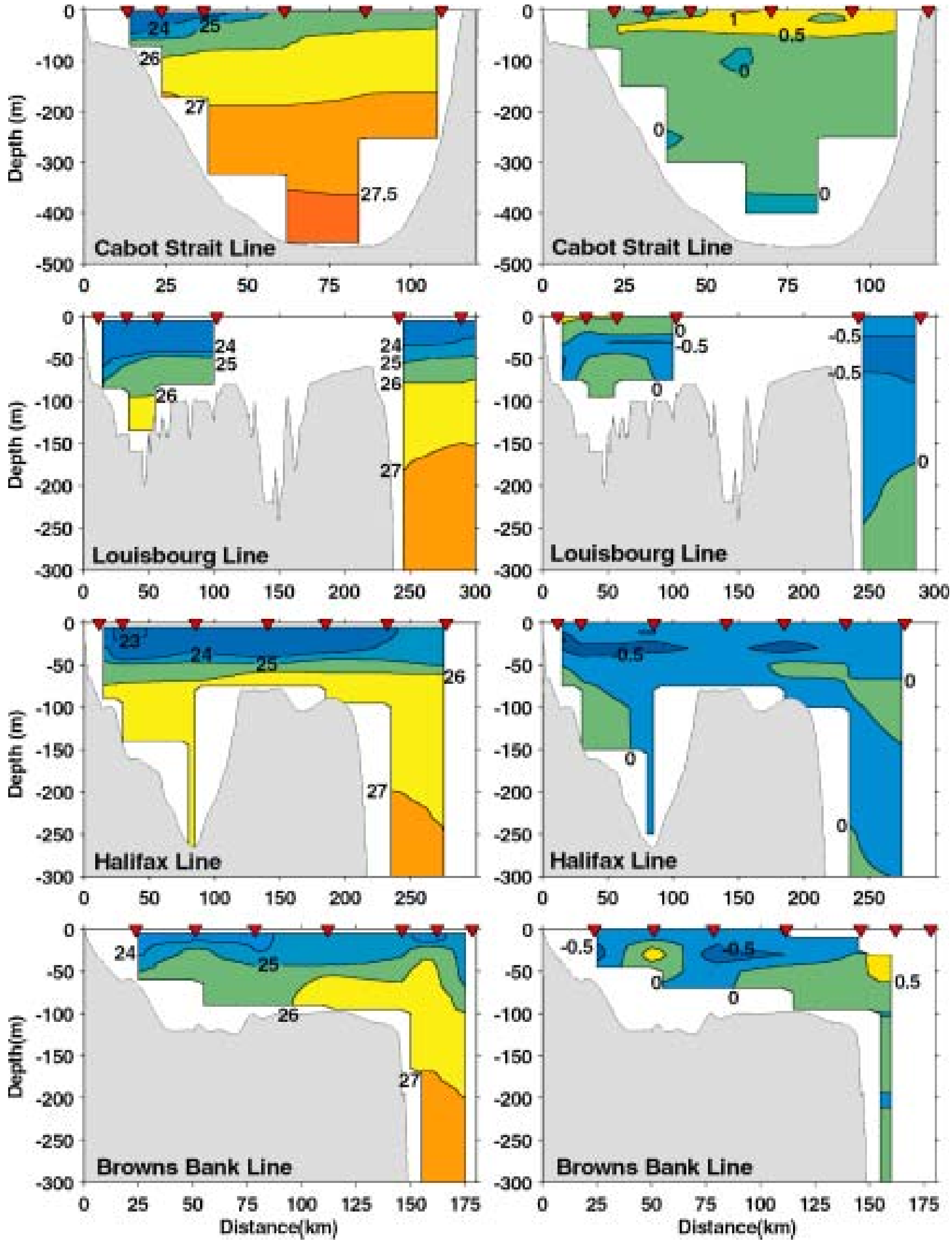


Fig. 24c. Densities and density anomalies on the Cabot Strait, Louisbourg, Halifax and Browns Bank Lines for October-November 2002.

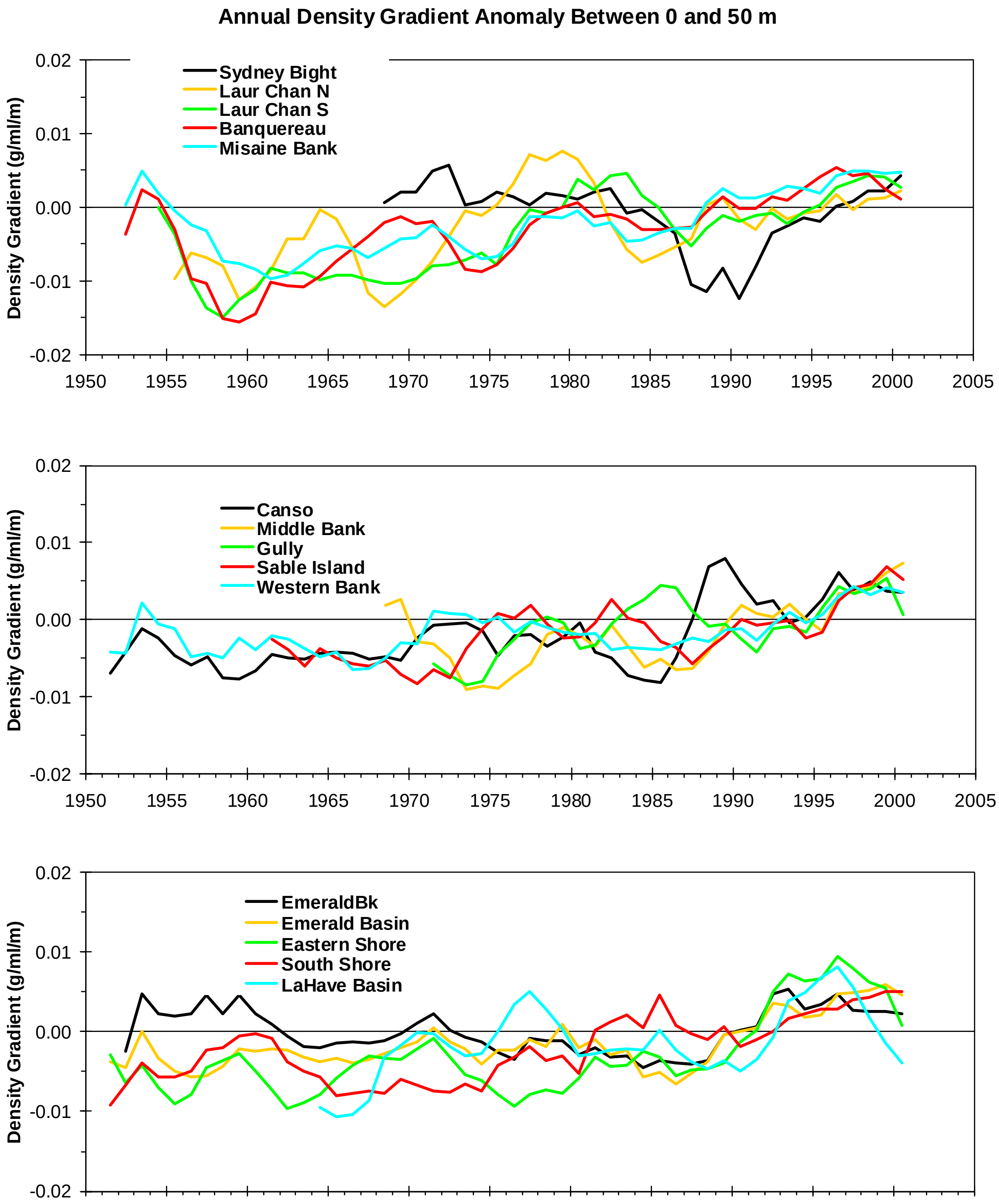


Fig.25a. Five-yr running means of the annual anomalies of the density gradient between the surface and 50 calculated for the areas 1-15 in Fig. 8.

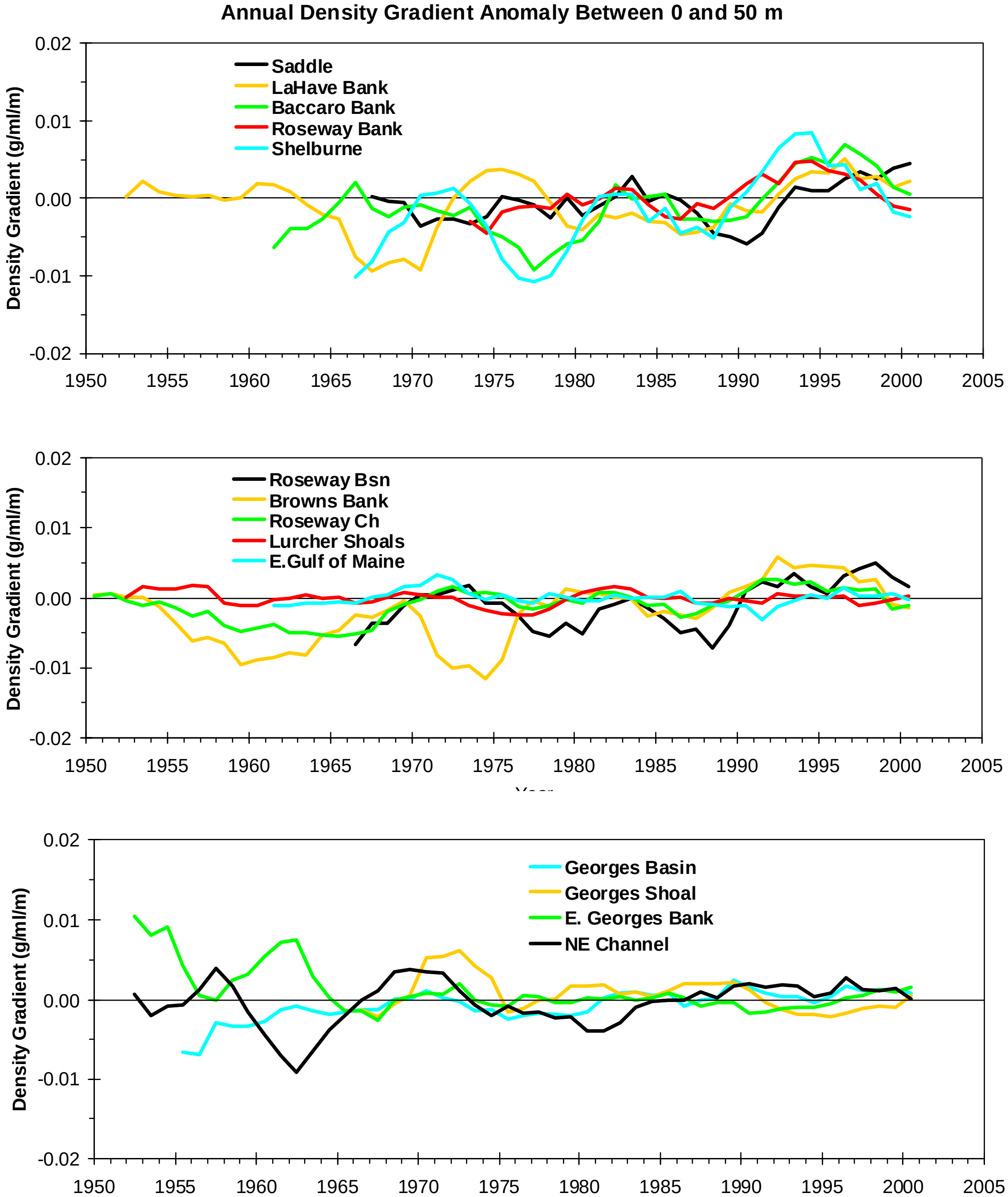


Fig.25b. Five-yr running means of the annual anomalies of the density gradient between the surface and 50 calculated for the areas 16-29 in Fig. 8.

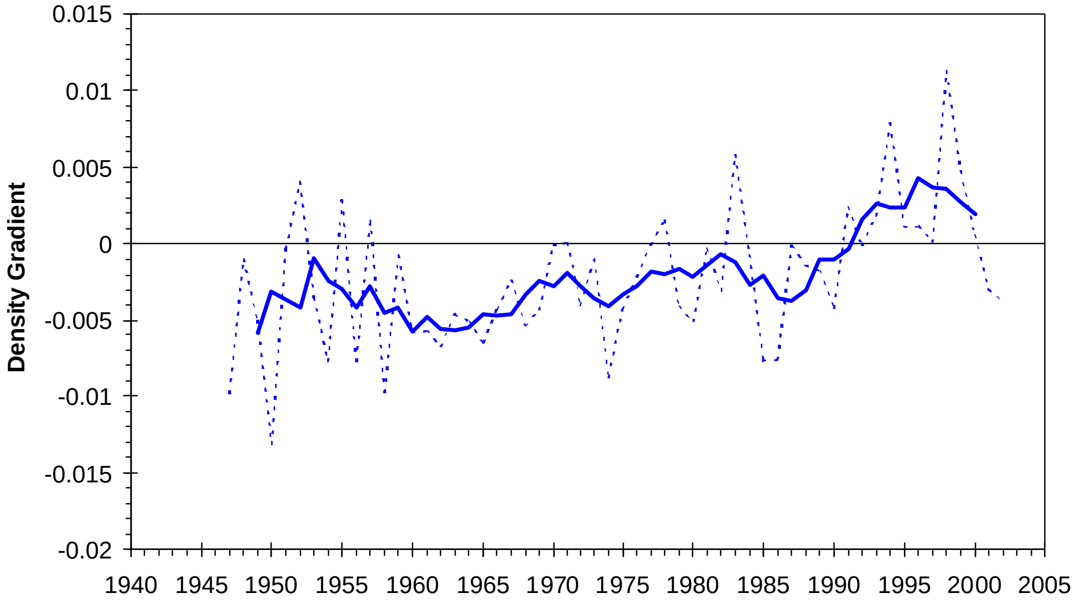


Fig. 25c. The mean annual (dashed line) and 5-yr running mean (heavy solid line) of the stratification index (0-50 m density gradient) averaged over the Scotian Shelf (areas 4-23 inclusive). The short horizontal lines for each year represent the standard deviations of the different areas.

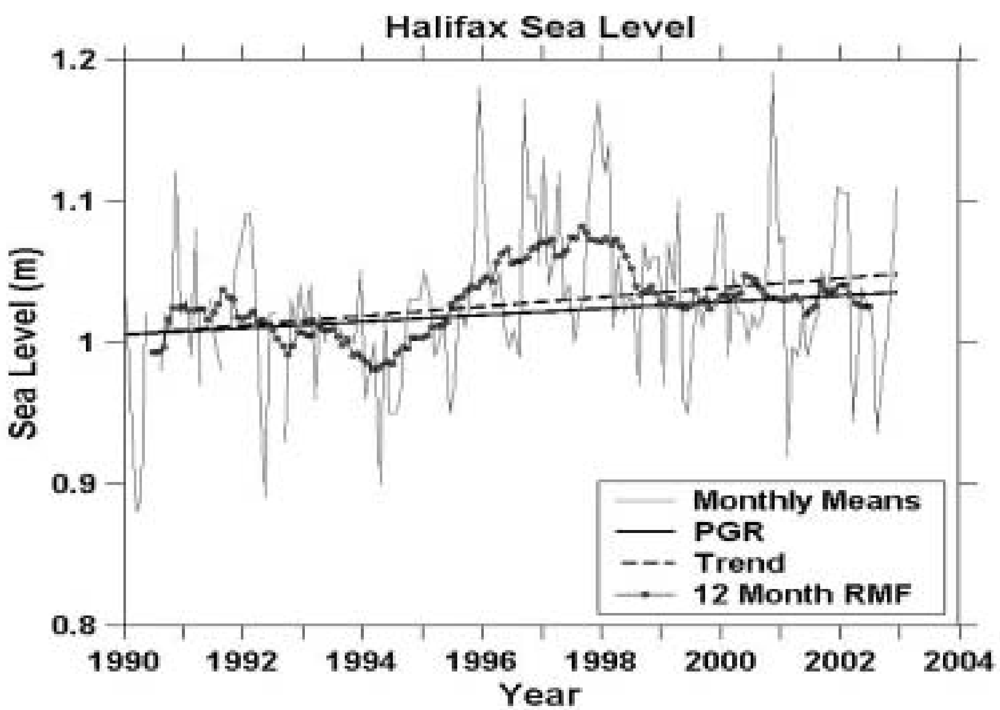
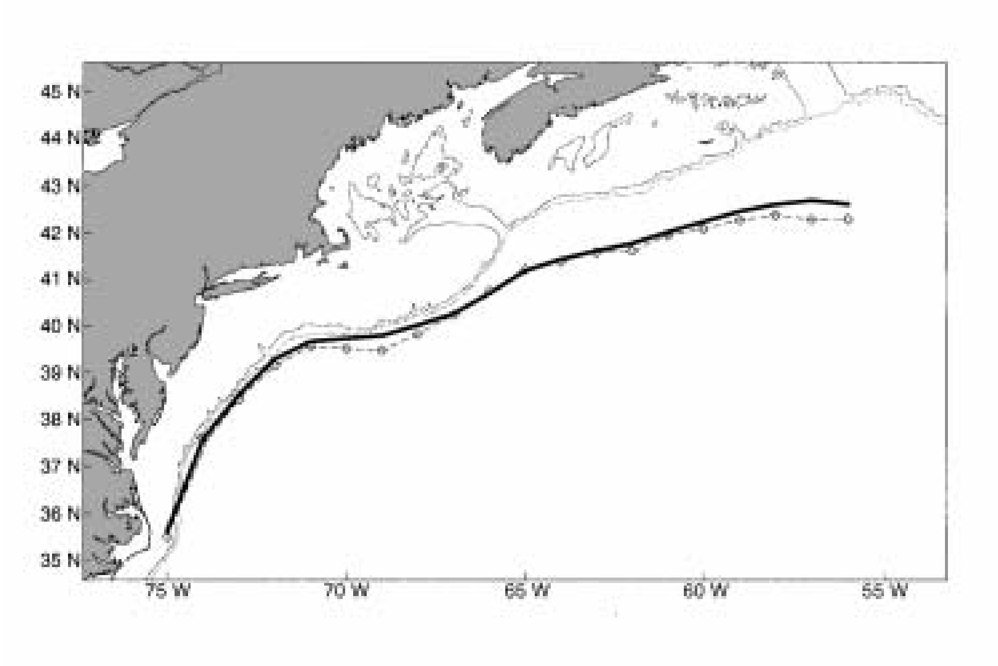


Fig. 26. The time series of the monthly means and a 12 month running mean of the sea level elevations at Halifax, along with the observed linear trend and that predicted by a model from Post Glacial Rebound.



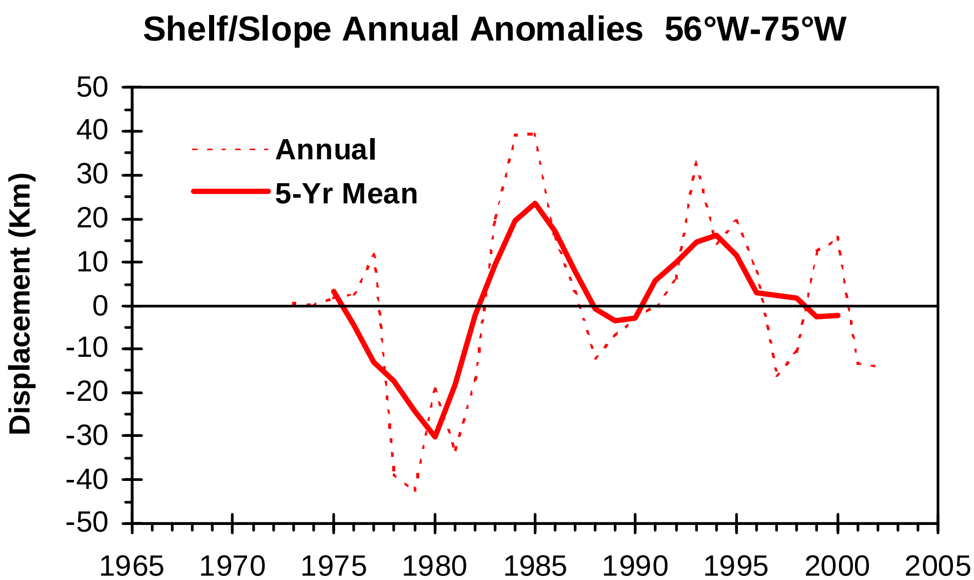
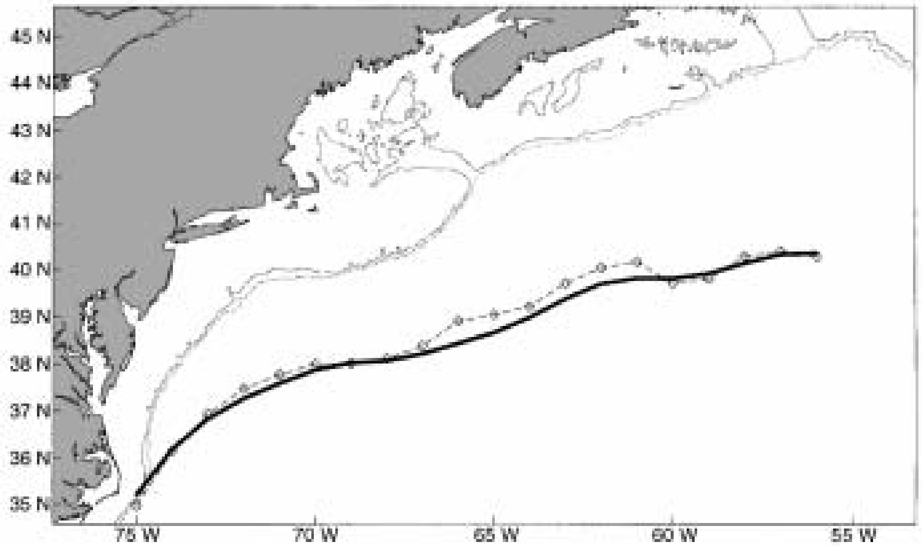


Fig.27. The 2002 (dashed line) and long-term mean (1973-2000; solid line) positions of the shelf/slope front (top panel) and the time series of the annual anomaly of the mean (56°-75°W) position of the shelf/slope front (bottom panel).



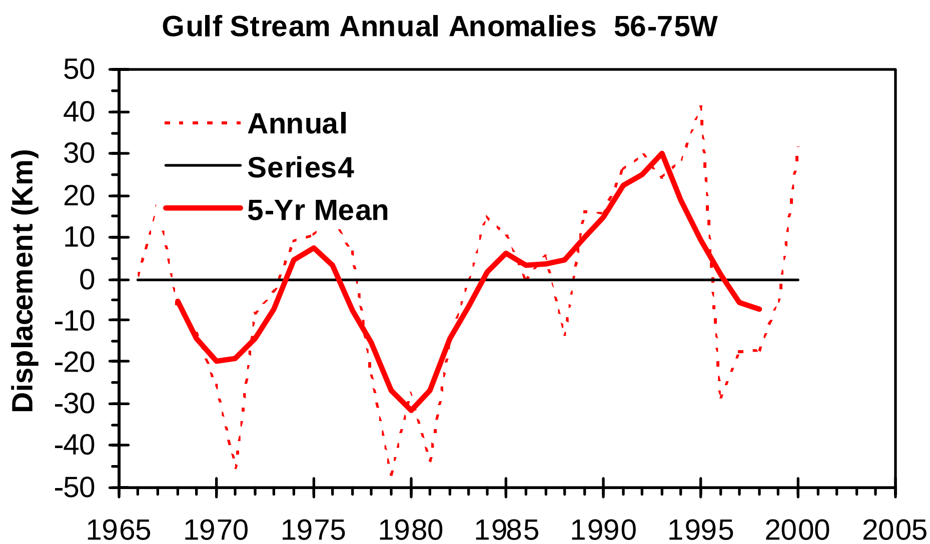


Fig.28. The 2002 (dashed line) and long-term mean (1973-2000; solid line) positions of the northern edge of the Gulf Stream (top panel) and the time series of the annual anomaly of the mean (56°-75°W) position of the Gulf Stream front (bottom panel).