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Physical Oceanographic Conditions on the Scotian Shelf and in the eastern Gulf of Maine (NAFO areas 4V,W,X) during 2006

B. Petrie, R. G. Pettipas, W. M. Petrie and V. V. Soukhovtsev

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 2006 indicates that the temperatures were generally ~1°C above normal. This contrasts with 2005 when cooler conditions prevailed. St. Andrews sea surface temperature was 1.31°C above normal making 2006 the warmest in 86 years. At Prince 5, which is 90 m deep, monthly mean temperatures were generally above normal by about 1.1 to 1.3°C. The annual temperatures at 0 and 90 m were the second warmest and warmest in 82 years. Salinities anomalies were -0.02 (0 m) and 0.14 (90 m). Halifax sea surface temperature was 0.3°C above normal, making 2006 the 17th warmest in 81 years. At Halifax Station 2 from 0 to 140 m, temperature anomalies were generally 1°C above normal; salinity anomalies were near normal. Sydney Bight and Misaine Bank had typical temperature anomalies of 1.3 and 0.7°C in the upper 100 m; Emerald Basin, 0.8°C from 0-250 m, Lurcher Shoals, 1.4°C from 0-50 m, Georges Basin, 0.6°C from 0-300 m, and eastern Georges Bank, 0.1°C from 0-50 m, all showed positive anomalies at most depths. Observations from standard sections in April and October on the Scotian Shelf support the conclusion of generally above normal temperatures over the shelf. The overall temperature anomaly for the combined areas of 4Vn,s, 4W and 4X from the July groundfish survey was 0.74°C, an increase of 2.1°C from the record cold values in 2004 and the third warmest year in 37. The overall stratification was above normal for the Scotian Shelf region in 2006.

Introduction

This document describes temperature and salinity characteristics of Scotian Shelf and Gulf of Maine waters during 2006 (see Fig. 1 for the study area). The results are derived from data obtained at coastal 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 temperature and salinity (CLIMATE) database[1], which is updated monthly from the national archive at the Marine Environmental Data Service (MEDS) in Ottawa. Our analyses use data archived up to 22 January 2007; only data up to the end of 2006 are discussed. Additional hydrographic data were obtained directly from DFO fisheries surveys.

In order to detect long-term trends, we have removed the potentially large seasonal cycle by determining the monthly differences, i.e. the anomalies, from the long-term means. In some cases, we use the standardized anomaly (anomaly/standard deviation). Where possible, long-term monthly and annual means have been calculated for the base period 1971-2000. This follows the recommendations of the Northwest Atlantic Fisheries Organization (NAFO, 1983) and the Fisheries Oceanography Committee of DFO.

Meteorological, sea ice and satellite-derived sea surface temperature (SST) information for eastern Canada during 2006 are described in Petrie et al. (2007). The monthly air temperature anomalies for the Scotian Shelf were

[1] http://www.mar.dfo-mpo.gc.ca/science/ocean/database/data_query.html

consistently above normal during 2006 with an annual value of 1.4°C for Sable Island and 1.8°C for Shearwater (Halifax); the monthly values were variable in the Gulf of Maine with annual anomalies of 1.1°C for Yarmouth, 1.6°C for Saint John and 0.8°C for Boston. Annually averaged SSTs were above normal for the eastern and central Scotian Shelf by 1.2°C to 1.6°C, the western Scotian Shelf to Bay of Fundy by 0.4 to 1.1°C and Georges Bank by only 0.1°C. Ice cover and volume for the Scotian Shelf were substantially below normal in 2006, in fact it was the 3rd lowest ice cover for the Jan-April period in 38 years.

Coastal Sea Surface Temperatures

Monthly averages of coastal sea surface temperature for 2006 were available at St. Andrews (New Brunswick) and Halifax (Nova Scotia). The monthly mean temperature anomalies relative to the 1971-2000 long-term averages at each site for 2005 and 2006 are shown in Fig. 2.

At St. Andrews, all months in 2006 featured positive anomalies with the largest anomaly (relative to the monthly standard deviations) in February, 2.6 standard deviations above normal. The 2006 annual anomaly was 1.3°C, the warmest in 86 years. The monthly anomalies at Halifax were a mixture of positive and negative values with an overall annual mean of 0.3°C (0.66 SD), making 2006 the 17th warmest in 81 years.

The time series of annual anomalies have changed remarkably at both sites since 2004: the annual average surface temperature at St. Andrews has increased by 2.1°C, while at Halifax temperatures warmed by 1.3°C.

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. The weak vertical temperature gradients over its 90 m depth is due to the strong tidal mixing within the Bay.

In 2006, monthly mean temperatures ranged from a minimum in March of 3.4°C at the surface to a maximum in October of 12.4°C (Fig. 3, 4). Monthly temperature anomalies were positive throughout the year especially at the start and end. The pattern was similar at 90 m but with weak negative values in August and September. The annual mean temperatures have high interannual variability with evidence of strong long-term trends at the surface and 90 m (Fig. 4). In 2006, the annual temperature anomalies at 0 and 90 m were about 1.1°C and 1.2°C. At 0 m, 2006 was the 2nd warmest in the 82 year record, surpassed only by 1951; at 90 m, it was the warmest in 82 years. Note that an October value is missing at 90 m and the annual anomaly at this depth was based on the average of 11 monthly anomalies. Using the other months in 2006 at 0 and 90 m to estimate the missing value gives an even higher annual anomaly at 90 m.

The salinity at Prince 5 had a broad minimum in the spring at the surface (~30.6 in June) and at 90 m (31.97 in June; Fig. 3, 5). The salinity anomalies were variable through most of 2006 and had typical amplitudes of 0.2. The annual salinity anomalies were slightly negative from 0-70 m but became positive near the bottom; the anomaly was -0.02 at the surface and 0.14 at 90 m. These values represent an increase of the average annual salinity by 0.3-0.4 since 2004. The density (sigma-t) variability was strongly linked to temperature. Density was below normal at all depths, though the anomaly near the bottom was very small.

Halifax Line Station 2

As part of the Atlantic Zone Monitoring Program (AZMP), a standard monitoring site was established in 1998 on the Scotian Shelf at Station 2 on the Halifax Line (Fig. 1). This station, hereafter referred to as H2, is about 150 m deep and is situated approximately 30 km off the entrance to Halifax Harbour at the northern edge of Emerald Basin. There were 19 occupations of H2 in 2006, 3 more than in 2005, the year with the fewest samples since the AZMP program started.

Surface temperatures at H2 ranged from 0.3°C in March to 18.4°C in July and August 2006 (Fig. 6). Near-bottom (140 m) temperatures were between 4.25°C and 9.46°C throughout the year with an average value of 7.3°C, a higher range of values than observed in 2005. Relative to the long-term means, annual average temperatures were above

normal at all depths by 0.3°C to 1°C. The Cold Intermediate Layer (CIL), which was thicker than usual at H2 in 2005 (Petrie et al. 2006), was not as extensive in 2006, forming an ~60 m layer during the late spring to fall period. The CIL typically has a temperature range from about 1°C to 6°C depending on the time of the year.

Salinity anomalies were small in 2006 with a mixture of above and below normal values in the upper 100 m through the year and generally above normal values from 100 m to the bottom. The largest annual anomaly was about 0.25 at 150 m.

In the surface layers, stratification began to develop in June increasing in intensity until August-September. During autumn, the warmer and fresher surface layer was gradually mixed down to ~35 m, before sampling ended. Density anomaly variations alternated between negative and position values from the surface to the bottom.

Scotian Shelf and Gulf of Maine Temperatures

We present monthly and annual mean conditions for 2006 at standard depths for 6 selected areas (averaging data by month within these areas) and compare them to the long-term averages (1971-2000). Data are not available for each month in each area; in some areas, the 2006 annual means are based upon as few as 3 monthly averaged profiles.

The areas are Sydney Bight, Misaine Bank, Emerald Basin, Lurcher Shoal, Georges Basin and eastern Georges Bank, representative areas of the Scotian Shelf and Gulf of Maine (Fig. 7). The results are displayed as monthly and annual (the average of the monthly anomalies) anomalies in 2006 (Fig. 8) and as time series plots for a selected depth in each region (Fig. 9).

The majority of monthly profiles for the six areas had positive temperature anomalies during 2006. This was particularly so for the Scotian Shelf sites. In Sydney Bight (area 1, Fig. 7) off eastern Cape Breton, the annual profile had above normal temperature anomalies of 0.3°C to 2.1°C (Fig. 8). Misaine Bank annual temperature anomalies were in the range of 0.1°C to 1.3°C. With profiles in all months, Emerald Basin annual values were from 0.4°C to 1.7°C; anomalies were generally higher at shallow depths and decreased towards bottom. Lurcher Shoals had above normal temperatures of 0.8°C to 1.8°C. The Georges Basin annual anomaly profile featured a mid-depth maximum and an overall range of about 1°C: from -0.1 at the surface, the only depth with a negative value, to 1.0°C at 150 m. Georges Bank anomalies also had negative values and small anomalies ranging from -0.1°C to 0.4°C.

Figure 9 shows the time series of temperature anomalies for one depth from each of the 6 regions. There has been a remarkable change since 2004, a year with generally colder than normal conditions and having the lowest composite index for the region since 1970. For five of the six time series, the annual temperature anomalies have increased since 2004. The 100 m temperature anomalies for Sydney Bight and Misaine Bank have risen by about 1.25°C (2006 minus 2004 observation). The Emerald Basin 250 m record reflects the influence of slope water on the Scotian Shelf and was the only exception to the overall trend – between 2004 and 2006 the 250 m temperature fell by 0.1°C. Lurcher Shoals temperature anomalies (50 m) increased by 2.2°C, the largest change of the six sites. The temperature change was more modest, 0.34°C in Georges Basin. Even though the annual anomaly was slightly negative on eastern Georges Bank in 2006, it represented an increase of nearly 1.5°C from its 2004 value.

Temperatures during the Summer Groundfish Surveys

The broadest spatial coverage of the Scotian Shelf is obtained during the annual DFO groundfish survey, usually in July. A total of 213 CTD stations were taken during the 2006 survey and an additional 86 bottom temperature stations were obtained as part of the ITQ (Individual Transferable Quota) fleet survey. The groundfish survey takes 1 month to complete with the area west of Halifax sampled first and the area east of Halifax sampled second. The 1971-2000 July temperature climatology is dominated by these surveys which are conducted in the same way every year. Thus we expect the anomalies to be largely unaffected by this temporal sampling bias.

The 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 at deeper depths. Data near the interpolation grid point are weighted proportionately more than those farther away. Temperatures were optimally estimated for 0, 50, 100 m and near bottom (Fig. 10). Maximum depths for the interpolated

temperature field were limited to 1000 m off the shelf. The 2006 temperature anomalies relative to the July 1971-2000 means were also computed at the same four depths (Fig. 11).

The broad spatial pattern of near-surface temperatures in July 2006 featured the warmest waters in Sydney Bight (18°C) that extended, with slightly decreasing values, over the eastern half of the Shelf to Halifax; the coldest temperatures (11-13°C) were found near the mouth of the Bay of Fundy, and represent an increase of about 2°C from 2005 (Fig. 10a). The cooler surface temperatures in this region compared to the Scotian Shelf are due in part to the intense bottom-generated vertical mixing caused by the strong tidal currents. The surface temperatures in July 2006 were dominated by warmer than normal values over the entire survey area (Fig. 11a).

The temperatures at 50 m ranged from 2°C to over 10°C with the coldest waters in the northeast and the warmest waters off Browns Bank and in the Gulf of Maine and Bay of Fundy (Fig. 10a). The lower temperatures over the inner half of the shelf mark the CIL, which was similar to the one seen in 2005 but not as extensive. The higher temperatures towards the outer edge of the Shelf in the central region reflect the influence of Slope Waters. 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. Similar to the near-surface temperatures, the 50 m anomalies were predominantly positive, ranging from 0°C to >3°C above normal (Fig. 11b). The largest anomalies (~2-3°C) occurred over the central Shelf and Browns Bank.

The temperatures at 100 m ranged from <2°C on the northeastern Scotian Shelf to 10°C along the shelf break (Fig. 10b). The warmer waters encroach onto the shelf with strong NE-SW horizontal gradients evident on the eastern Shelf. The temperatures are elevated as well in the eastern Gulf of Maine. This pattern contrasts to the one from the 2005 survey which featured strong temperature gradients along the shelf break rather than across the shelf. The 2006 anomaly pattern at 100 m, like the two shallower depths, was dominated by positive values.

Near-bottom temperatures ranged from ~3°C on Misaine Bank in the northeastern Scotian Shelf to ~9°C in Emerald Basin and 10°C in the upper Bay of Fundy (Fig. 10b). In Emerald Basin, the high temperatures are due to the penetration of Warm Slope Water, 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 the 1971-2000 means, the near-bottom temperatures were predominantly warmer than normal over the Scotian Shelf with a small patch of slightly colder than normal water off southwestern Nova Scotia (Fig. 11b).

The interannual variability can be summarized by determining the average bottom temperatures in each region (Fig. 12). All areas in 2006 featured average bottom temperatures that were well above the 1971-2000 norms. Areas 4Vn and 4Vs were 0.64°C (1.3 standard deviations) and 0.58°C (0.8 SD) above normal and the 5th and 8th warmest in 37 years. Areas 4W and 4X were 0.84 (1.3 SD) and 0.78°C (1.1 SD) above normal, in both cases the 4th warmest in 37 years. Combining the 4 NAFO areas (accounting for the different area sizes), we find an overall bottom temperature anomaly of 0.74°C (1.37 SD), the 3rd warmest year in 37. In 2004, the overall bottom temperature anomaly was -1.35°C (-2.5 SD), the coldest year from 1970 to present.

Standard Sections

The hydrographic observations from the Cabot Strait, Louisbourg, Halifax and Browns Bank lines (Fig. 1) from the spring and fall are shown in Fig. 13a-e. The anomalies corresponding to these data were calculated for the date on which they were collected. In April-May, 0-100 m temperatures were 0-2°C across the Cabot Strait and Louisbourg sections, and 3-6°C across the Browns Bank and the Halifax sections to the shelf break (Fig. 13a). Temperature anomalies were mostly positive on all 4 sections with the larger values over the slope on the Halifax and Browns Bank sections. Salinities anomalies were divided more evenly between positive and negative values with the highest values over the slope on the Halifax section and evidence of spillover into Emerald Basin (Fig. 13b).

In June a repeat occupation of the Halifax section shows that changes have occurred (Fig. 13c). The major difference is found over the shelf break and slope in the form of strong negative temperature and salinity anomalies in the upper 100 m. Shelf waters, marked by the 33 isohaline, have moved offshore from their position in the May survey.

In October, except for the outer shelf, slope area on the Halifax section, the temperature anomalies were generally positive (Fig. 13d). In particular, the Browns Bank section featured a large area with temperatures 2-3^{o}C above normal. A remnant cold intermediate layer (CIL) from 50 m to the bottom and extending from the coast to offshore of the shelf break is evident on the Louisbourg section. The CIL on the Halifax section was confined to the inner 2 stations; over the shelf break there was a large area of low temperature, low salinity water characteristic of Gulf of St. Lawrence outflow (Fig. 13d, e). Except for the outer shelf, shelf break and slope on the Halifax section, the salinities tended to be above normal.

Density Stratification

Stratification of the near surface layer influences physical and biological processes in the ocean. We examined the variability in stratification by calculating the density (sigma-t) difference between 0 and 50 m. The density differences were based on monthly mean density profiles calculated for each area in Fig. 7. The long-term monthly mean density gradients for 1971-2000 were estimated; these were subtracted from the individual monthly values to obtain monthly anomalies. Annual anomalies were estimated by averaging all available monthly anomalies within a calendar year. This could be misleading if, in a particular year, most data were collected in months when stratification was weak, while in another year, sampling was in months when stratification was strong. However, initial results, whereby the observations were normalized by dividing the anomalies by the monthly standard deviation, were qualitatively similar to the plots presented here. The 5-year running means of the annual anomalies were then calculated for subareas 4-23 on the Scotian Shelf (Fig. 14). These anomalies were weighted by the surface areas of the subareas. The monthly and annual means are highly variable but the 5-yr running means feature some distinctive trends.

The dominant feature of the 5-year means is weak stratification in the 1960s and the stronger stratification during the 1990s throughout the Scotian Shelf (Fig. 14). In 2006, there was considerable spatial variability of the stratification index in the region: stronger stratification was generally found on the eastern and western shelf, weaker stratification in the central region and Lurcher Shoal area. The average stratification parameter for areas 4-23 was above normal in 2006 (Fig. 14) and slightly higher than in 2005.

Summary

A review of physical oceanographic conditions on the Scotian Shelf and in the Gulf of Maine and adjacent offshore areas during 2006 indicates that the temperatures were generally ~1^{o}C above normal. This contrasts with 2005 when cooler conditions prevailed. St. Andrews sea surface temperature was 1.31^{o}C above normal making 2006 the warmest in 86 years. At Prince 5, which is 90 m deep, monthly mean temperatures were generally above normal by about 1.1 to 1.3^{o}C. The annual temperatures at 0 and 90 m were the second warmest and warmest in 82 years. Salinities anomalies were -0.02 (0 m) and 0.14 (90 m). Halifax sea surface temperature was 0.3^{o}C above normal, making 2006 the 17th warmest in 81 years. At Halifax Station 2 from 0 to 140 m, temperature anomalies were generally 1^{o}C above normal; salinity anomalies were near normal. Sydney Bight and Misaine Bank had typical temperature anomalies of 1.3 and 0.7^{o}C in the upper 100 m; Emerald Basin, 0.8^{o}C from 0-250 m, Lurcher Shoals, 1.4^{o}C from 0-50 m, Georges Basin, 0.6^{o}C from 0-300 m, and eastern Georges Bank, 0.1^{o}C from 0-50 m all showed positive anomalies at most depths. Observations from standard sections in April and October on the Scotian Shelf support the overall conclusion of generally above normal temperatures over the shelf. The overall temperature anomaly for the combined areas of 4Vn,s, 4W and 4X from the July groundfish survey was 0.74^{o}C, an increase of 2.1^{o}C from the record cold values in 2004 and the third warmest year in 37. The overall stratification was above normal for the Scotian Shelf region in 2006.

A graphical summary of many of the time series already shown indicates that the periods 1987-1993 and 2003-2004 were predominantly colder than normal and 1999-2000 was warmer than normal (Fig. 15, upper panel). The period 1979-1986 also tends to be warmer than normal but, except for 1984, not as dominantly so as 1999-2000. In this figure, annual anomalies based on the 1971-2000 means have been normalized by dividing by the 1971-2000 standard deviations for each variable. The results are displayed as the number of standard deviations above (red) and below (blue) normal. During predominantly warmer or colder than normal periods, there are sometimes systematic exceptions to the overall pattern. For example, for the eastern and central Scotian Shelf (Misaine, Emerald, 4Vn, 4Vs), temperatures in 2005 were above normal whereas most other variables were below normal. In 2006, all variables except Georges Bank 50 m temperature were above normal.

The mosaic plot can be summarized as a combination bar and line-scatter plot (Fig. 15, lower panel). We have selected "profiles" for the eastern (Misaine), central (Emerald) and western (Lurcher) Scotian Shelf, the Bay of Fundy (Prince 5) and Georges Bank. In addition, we have included the spatially comprehensive but temporally limited July groundfish survey bottom temperatures (4Vn,s, 4W and 4X) and surface temperatures for Halifax and St. Andrews because of their long-term nature. The bar components are colour coded by variable so that for any year the contribution of each variable can be determined and systematic spatial variability seen. The height of each variable's contribution to the bar depends on its magnitude. The positive components are stacked on the positive side, the negative components on the negative side. The sum of the normalized anomalies (difference between the positive and negative stacks) is shown as a black line connecting grey circles. This is a measure of whether the year tended to be colder or warmer than normal and can serve as an overall climate index. The cold periods of 1987-1993 and 2003-2004 and the warm period of 1999-2000 are apparent. Systematic differences from the overall tendency as noted above are also apparent. The overall index value for 2006 make it the warmest year in the 37 year record. Moreover the change that has occurred since 2004 is striking.

Acknowledgements

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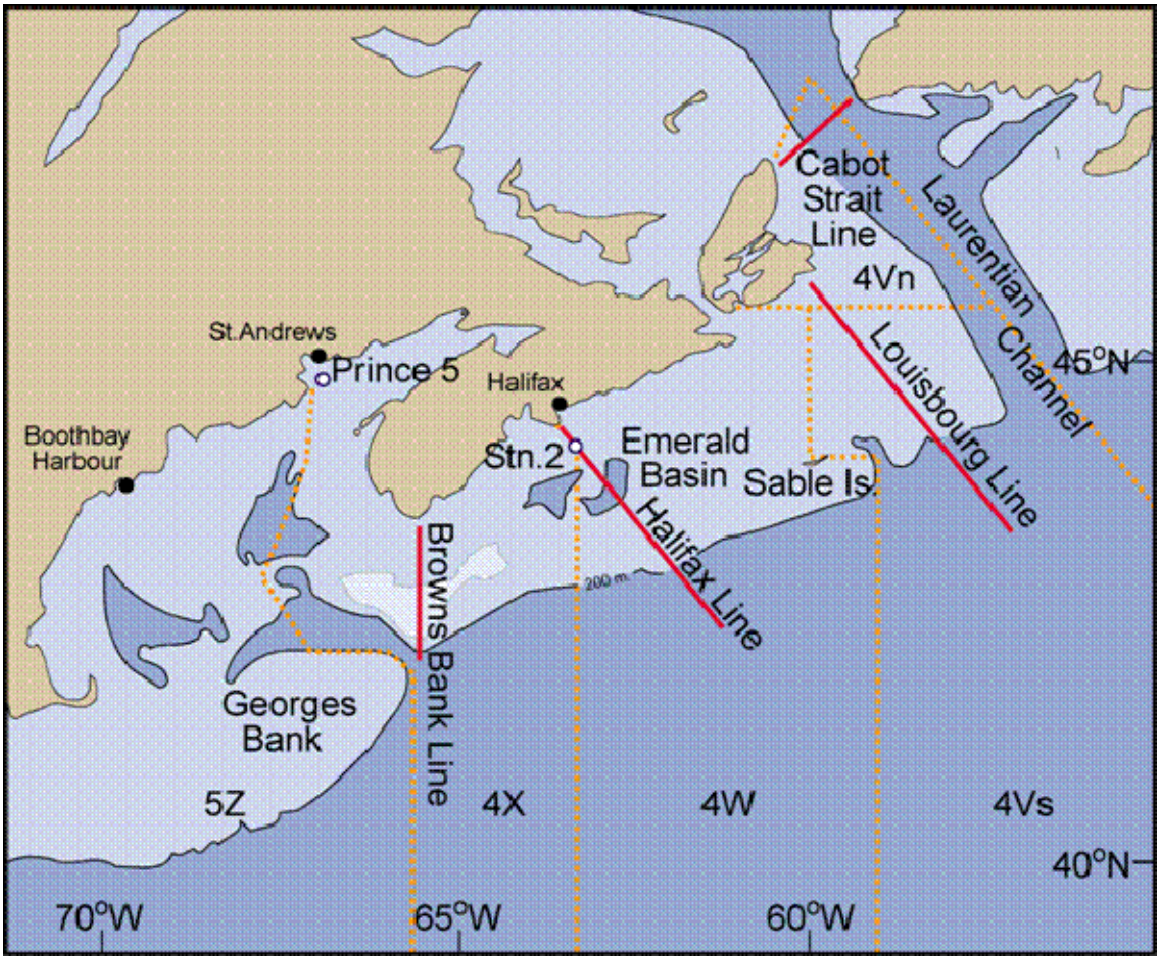

Fig. 1. The Scotian Shelf and the Gulf of Maine showing hydrographic stations, standard sections and topographic features. The dotted lines indicate the boundaries of the NAFO Subareas.

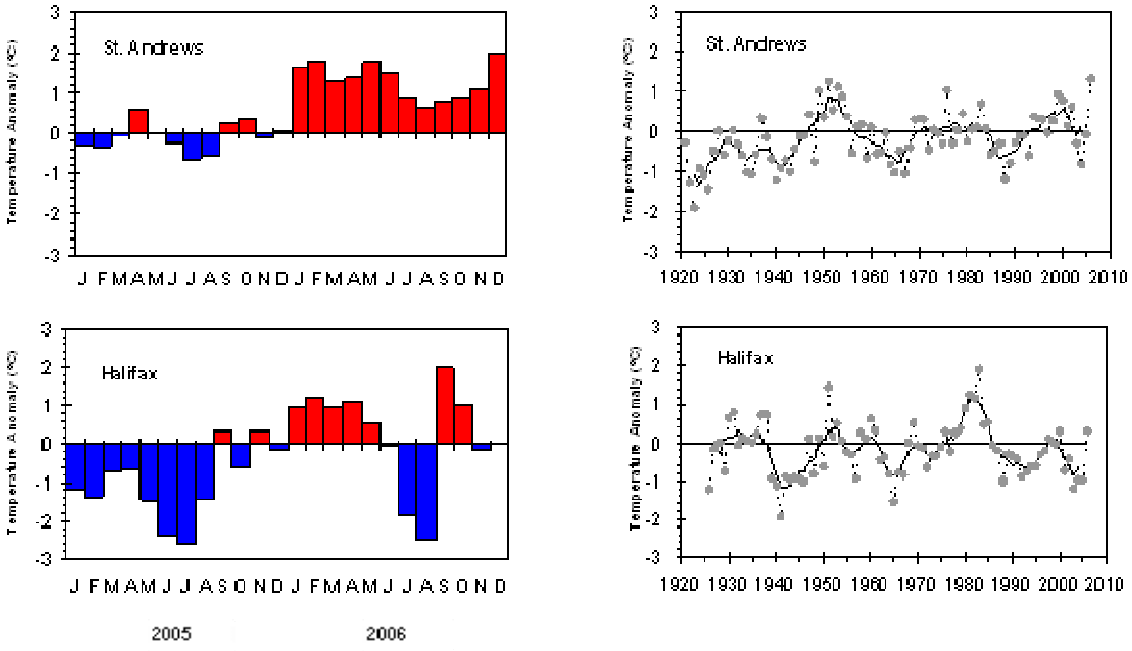

Fig. 2. The monthly sea surface temperature anomalies during 2005 and 2006 (left) and the annual temperature anomalies and their 5-year running means (right) for St. Andrews and Halifax Harbour. Anomalies are relative to the 1971-2000 means.

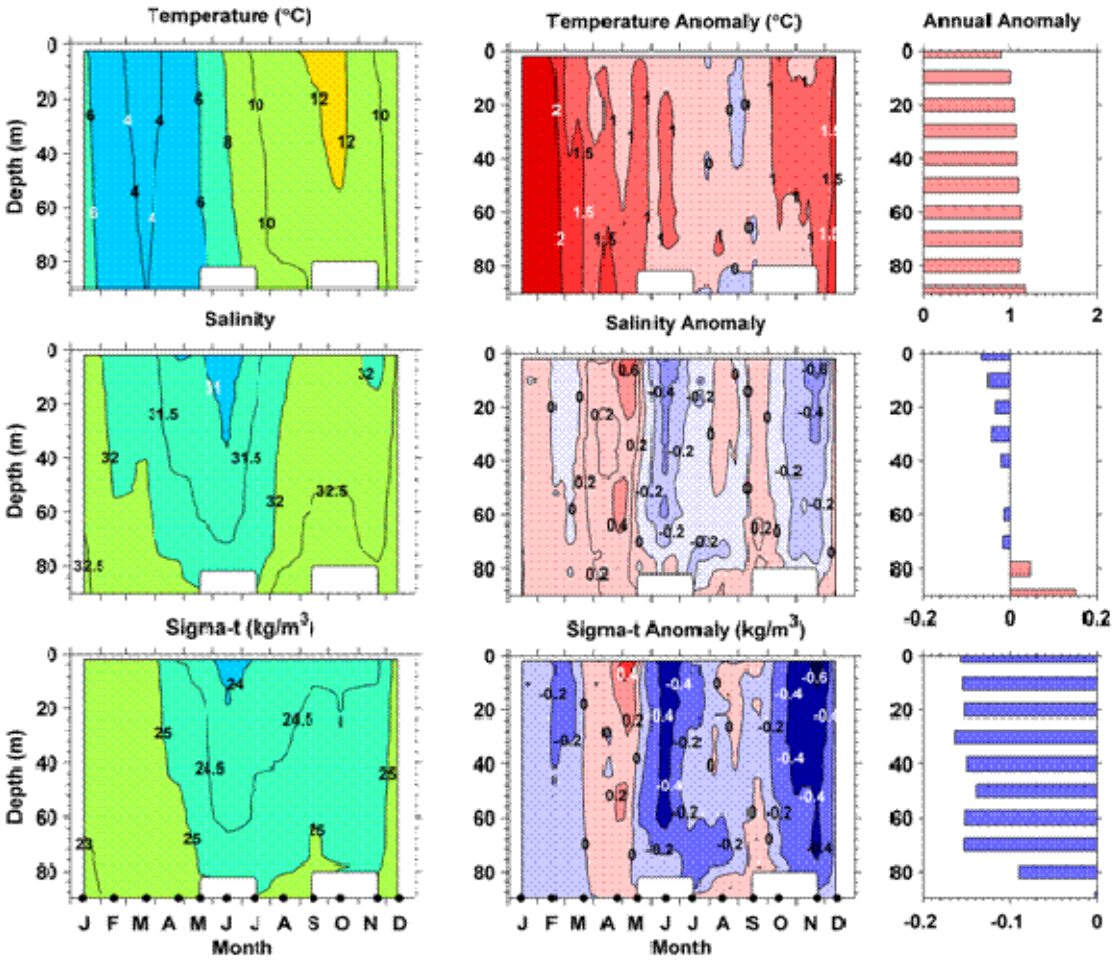

Fig. 3. Contours of temperature, salinity and sigma-t and their anomalies at Prince 5 as a function of depth during 2006 relative to the 1971-2000 means. Blue (red) indicates below (above) normal anomalies. The bar chart shows the annual anomalies.

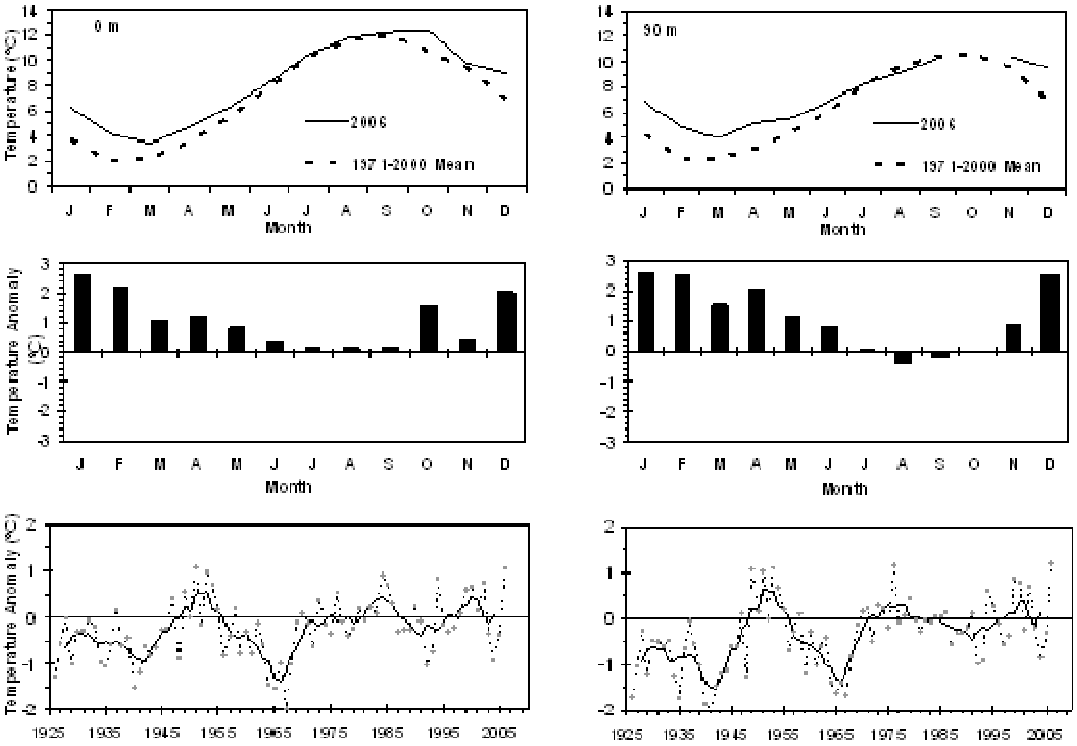

Fig. 4. The monthly mean temperatures for 2006 (solid line; top panels) and their long-term means (dashed line; top panels), the monthly anomalies relative to the long-term means for 1971-2000 (middle panels) and in the bottom panels are the time series of the annual means (dashed lines) and their 5-year running means (solid line) for Prince 5, 0 m (left) and 90 m (right).

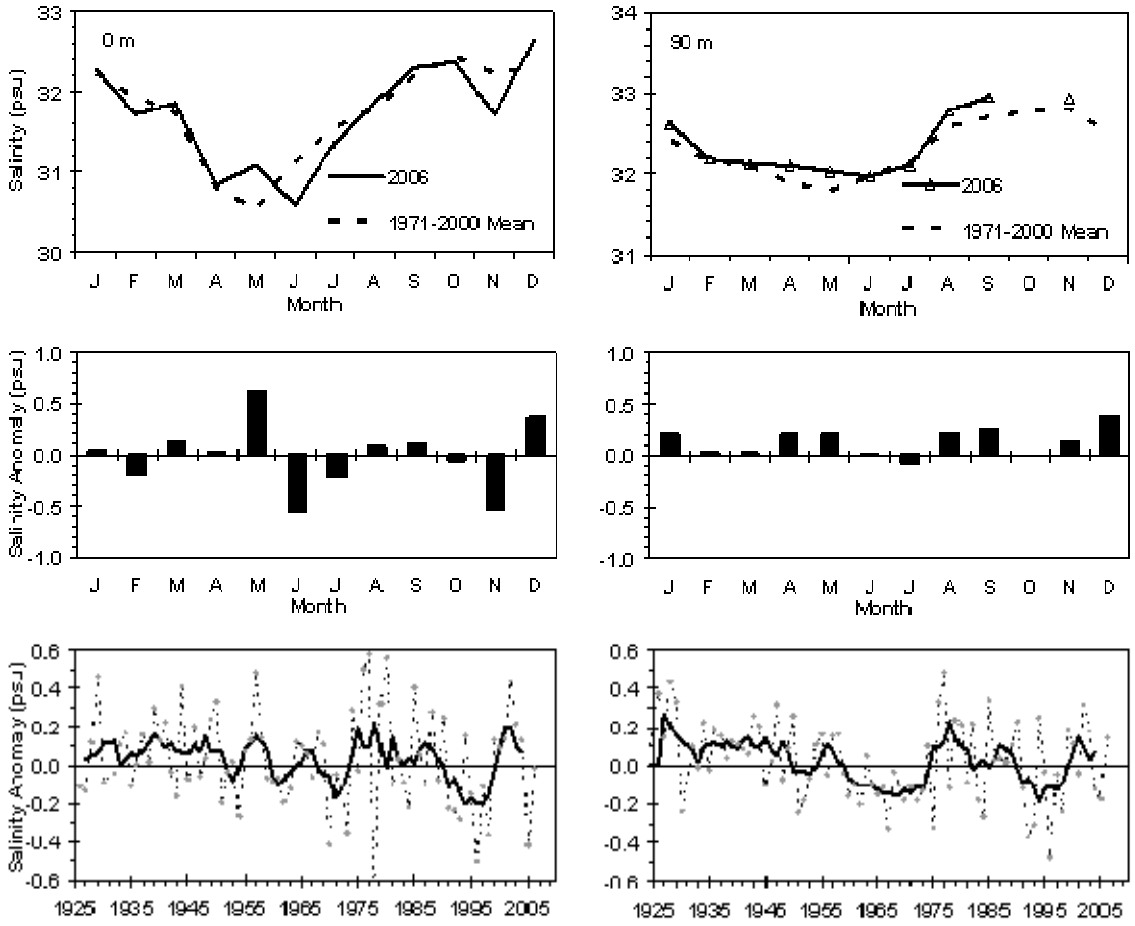

Fig. 5. The monthly mean salinities for 2006 (solid line; top panels) and their long-term means (dashed line; top panels), the monthly anomalies relative to the long-term means for 1971-2000 (middle panels) and in the bottom panels are the time series of the annual means (dashed lines) and their 5-year running averages (solid line) for Prince 5, 0 m (left) and 90 m (right).

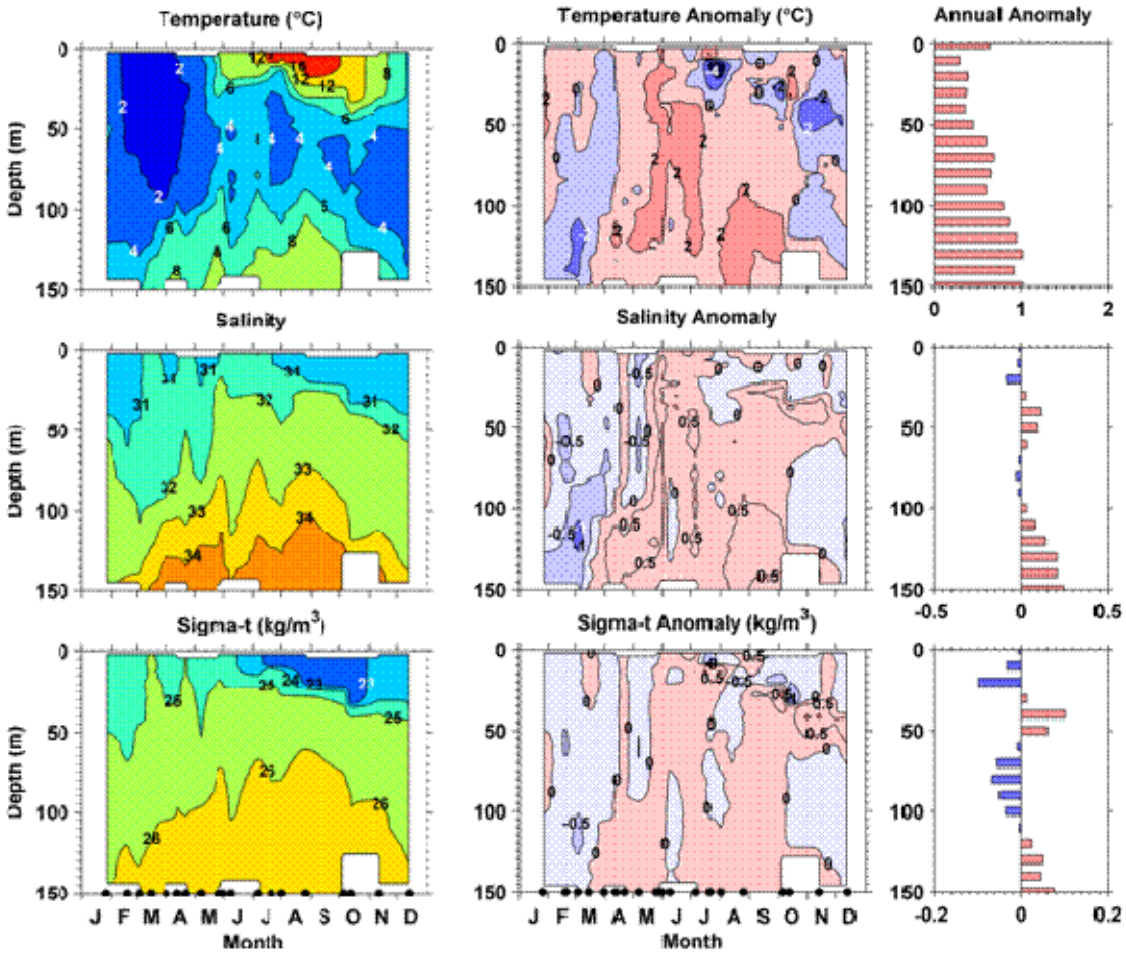

Fig. 6. Contours of the 2006 temperature, salinity and density (sigma-t) (left) and their anomalies (right) at the fixed station Halifax Section Station 2. Blue (red) indicates below (above) normal anomalies. The bar chart shows the annual anomalies.

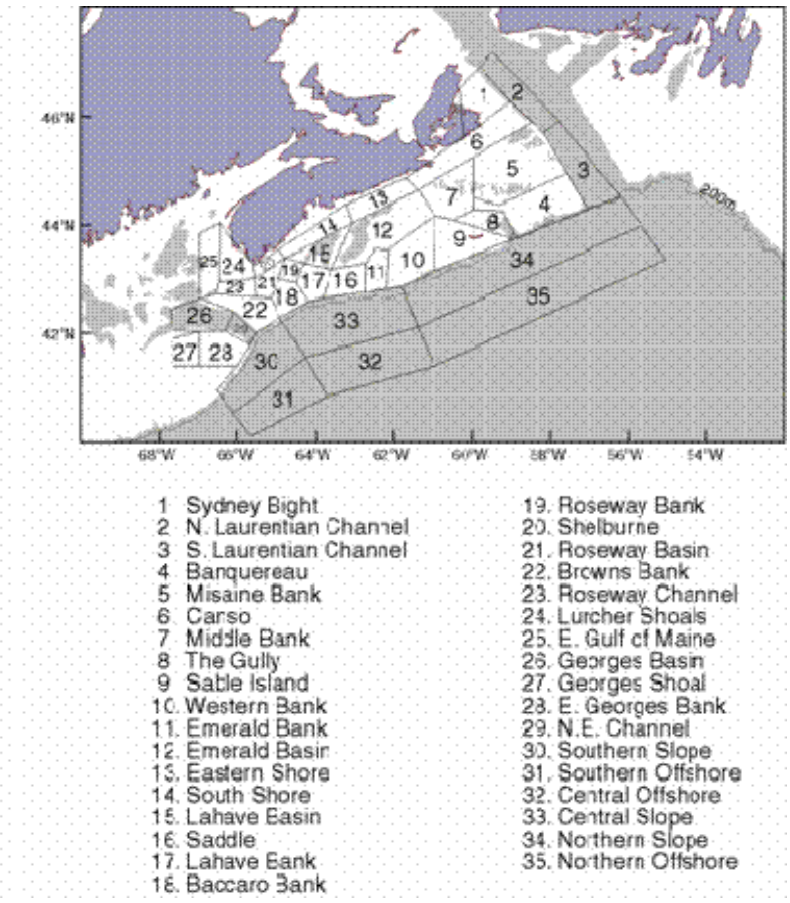

Fig. 7. Areas on the Scotian Shelf and eastern Gulf of Maine from Drinkwater and Trites (1987).

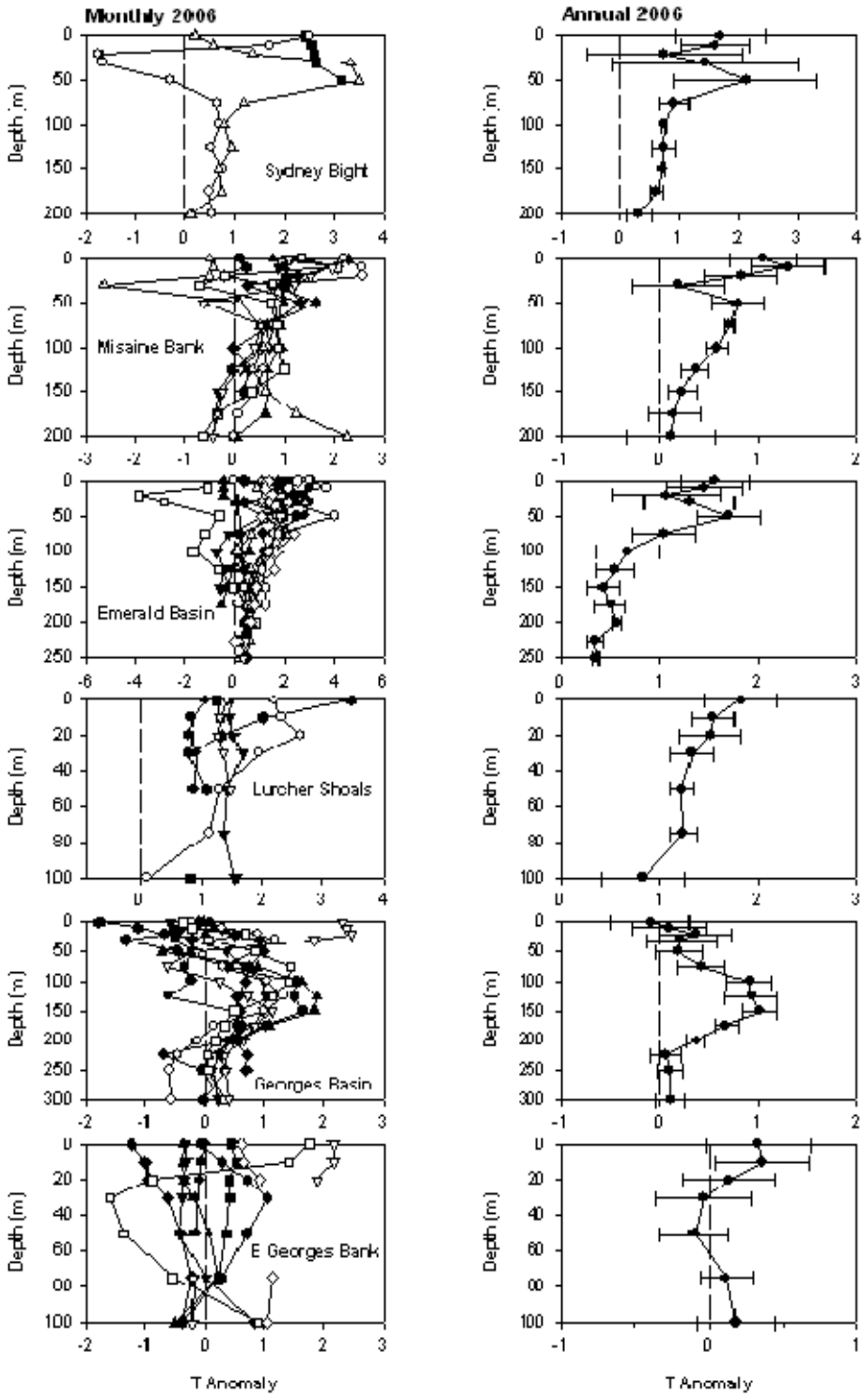

Fig. 8. Monthly (left) and annual (±std. error, right) temperature anomaly profiles for selected locations. Symbol order for monthly profiles is filled dot, square, up triangle, down triangle, diamond, hexagon for January-June,, then open symbols in the same order for July-December.

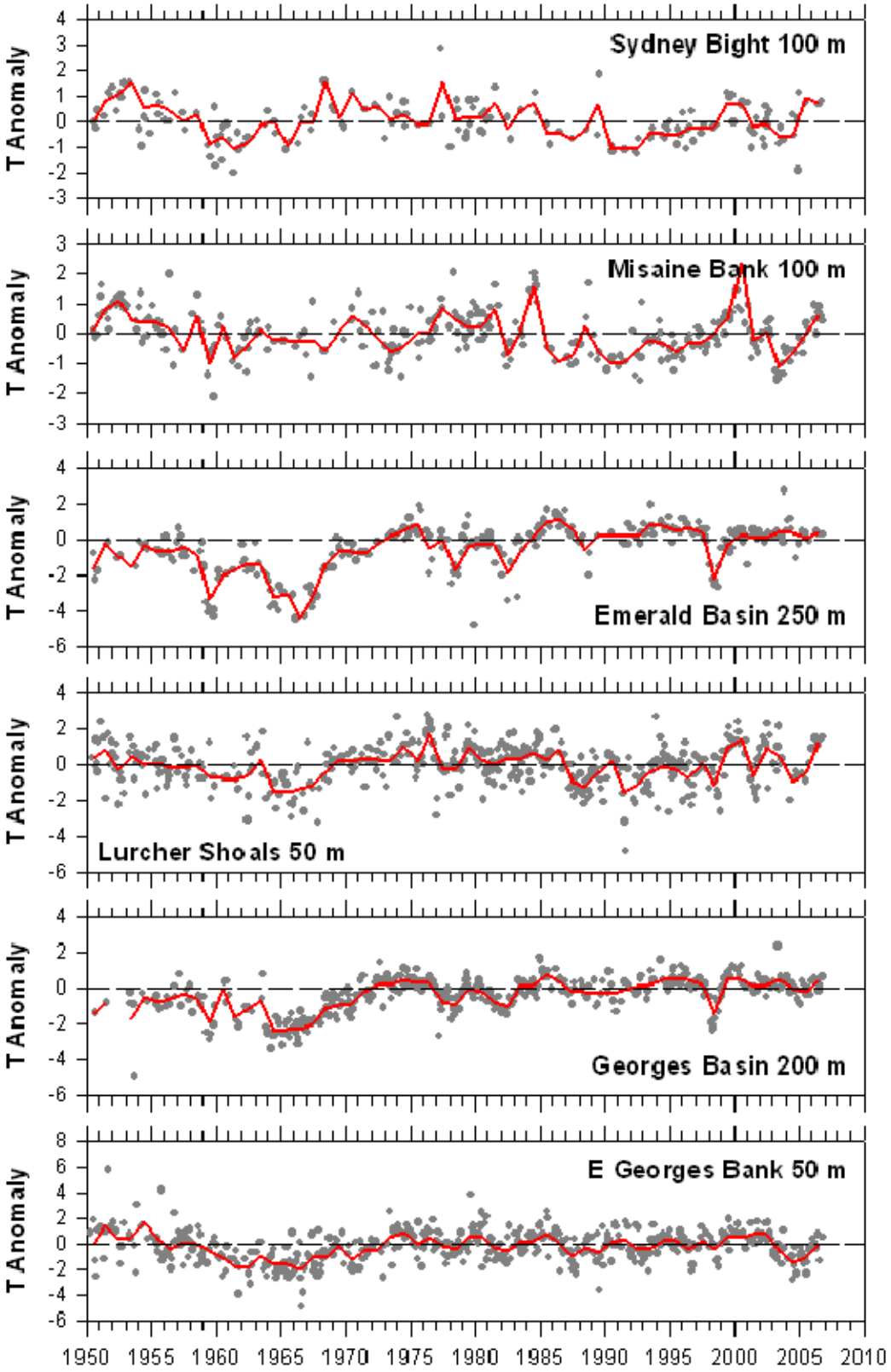

Fig. 9. The monthly mean temperature anomaly time series (grey dots) and the estimated annual anomalies (solid line) at 6 sites on the Scotian Shelf and in the Gulf of Maine (see Fig. 7).

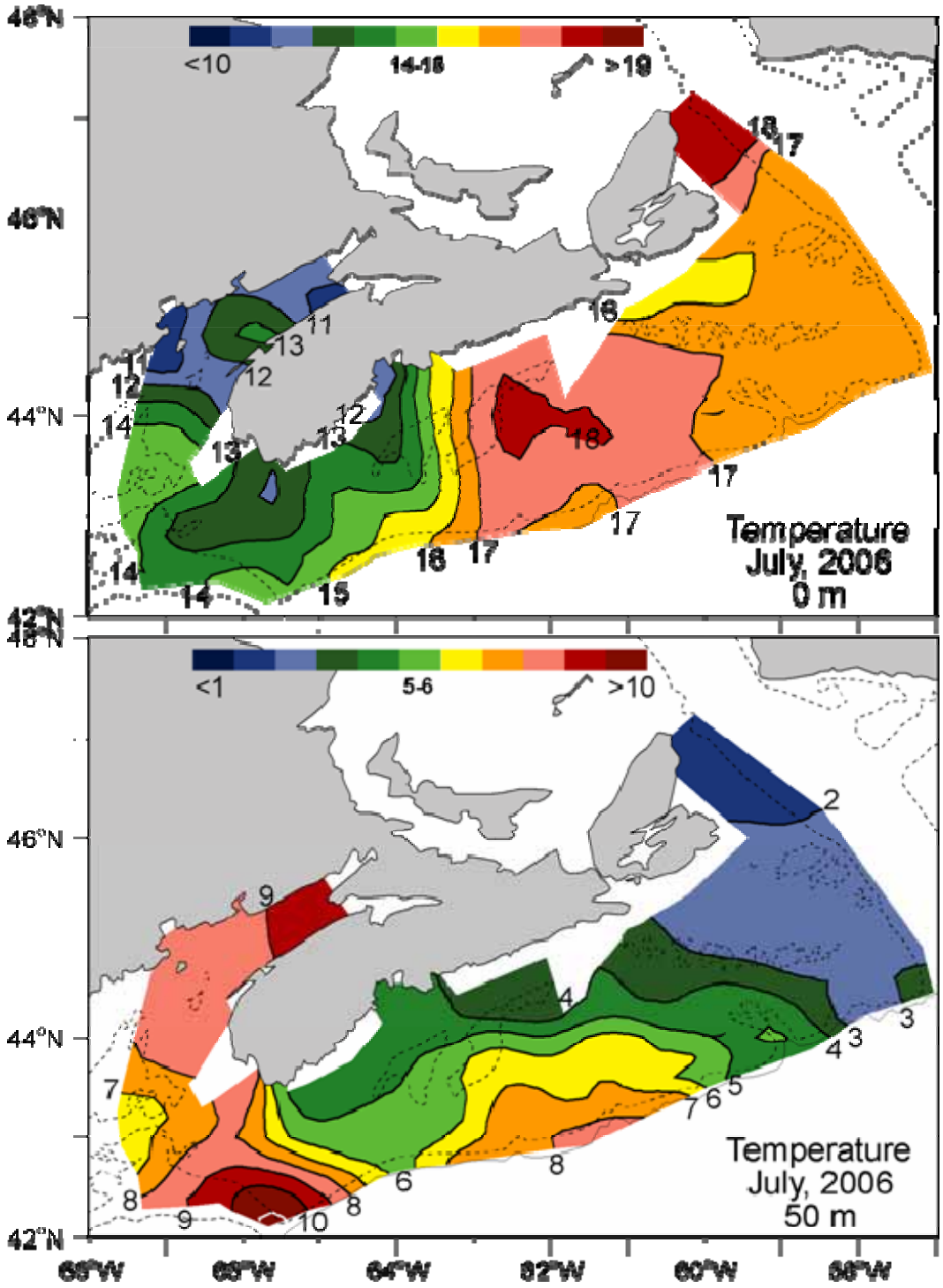

Fig.10a. Contours of temperatures at the surface (top panel) and 50 m (bottom panel) during the 2006 July groundfish and ITQ surveys.

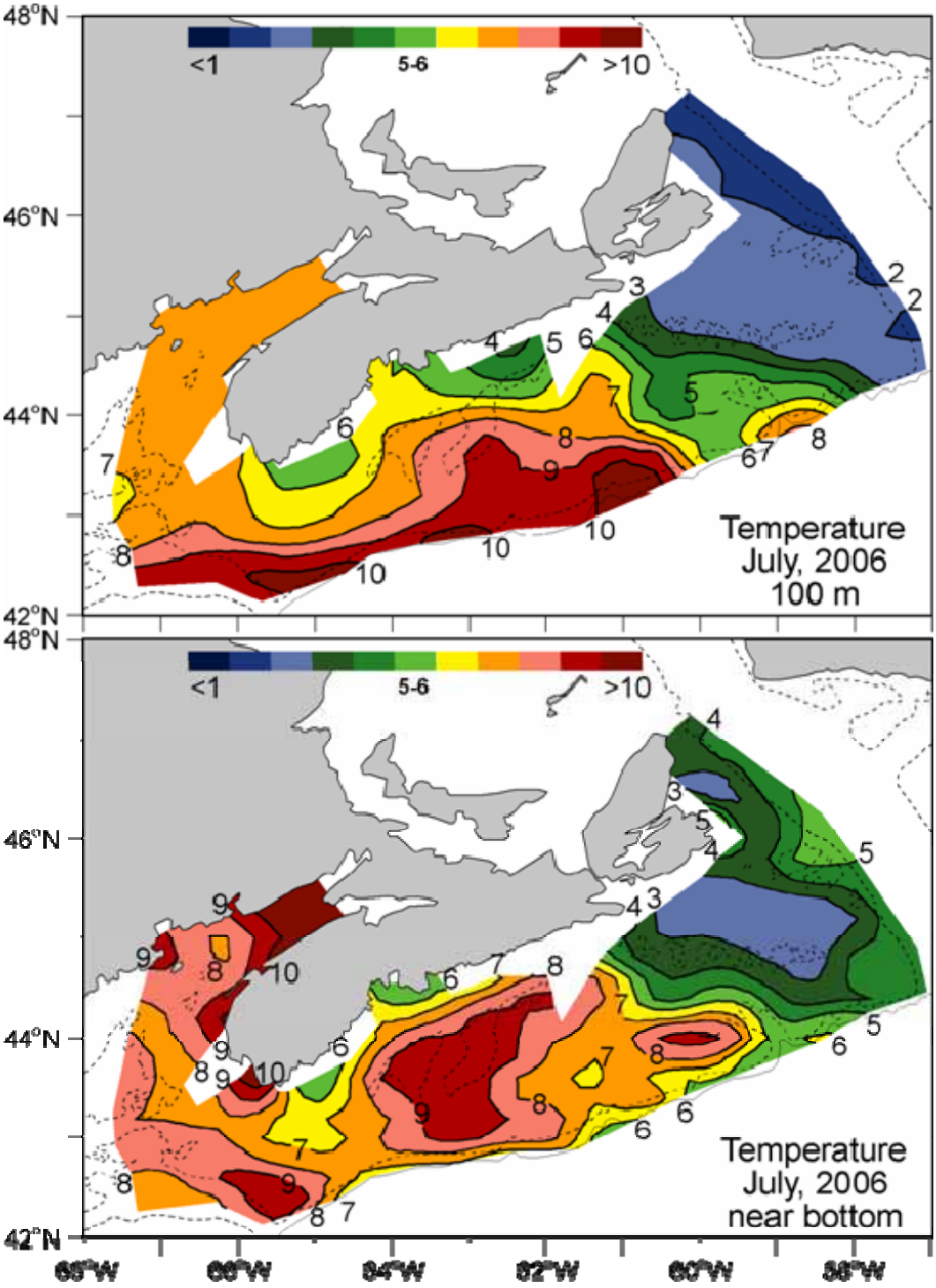

Fig. 10b. Contours of temperatures at 100 m (top panel) and near bottom (bottom panel) during the 2006 July groundfish and ITQ surveys.

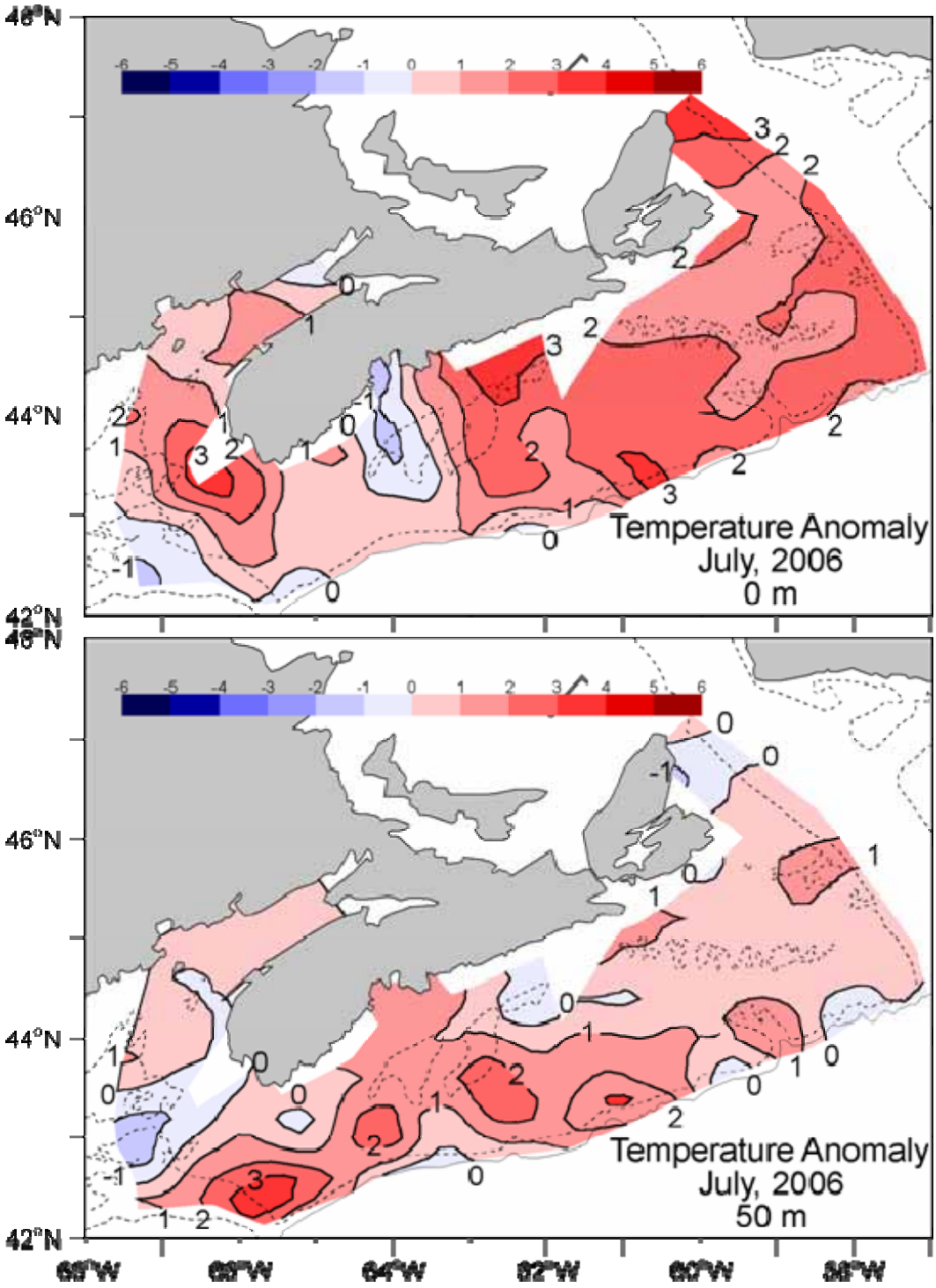

Fig. 11a. Contours of temperature anomalies at the surface (top panel) and 50 m (bottom panel) during the 2006 July groundfish and ITQ surveys.

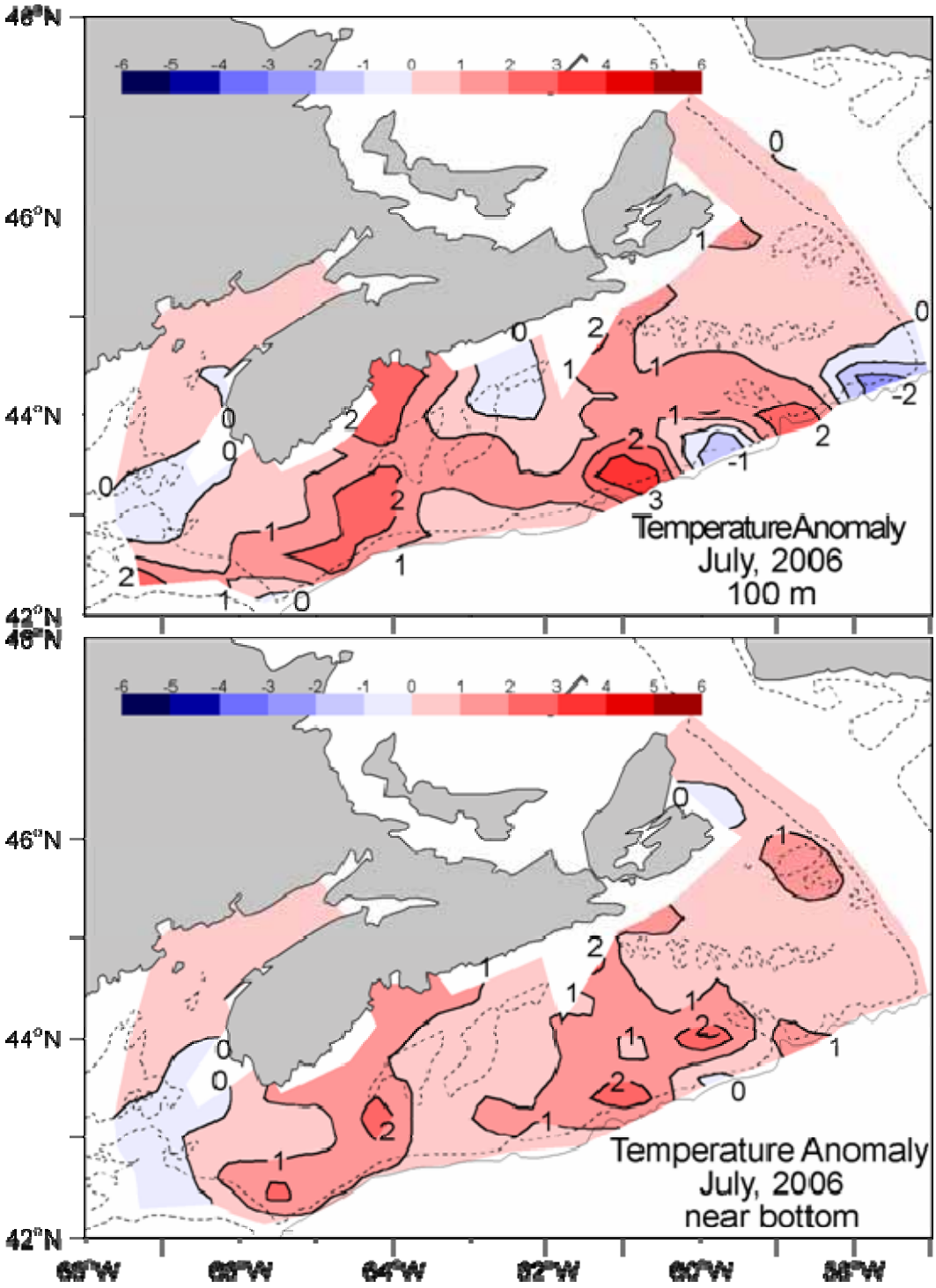

Fig. 11b. Contours of temperature anomalies at 100 m (top panel) and near bottom (bottom panel) during the 2006 July groundfish and ITQ surveys.

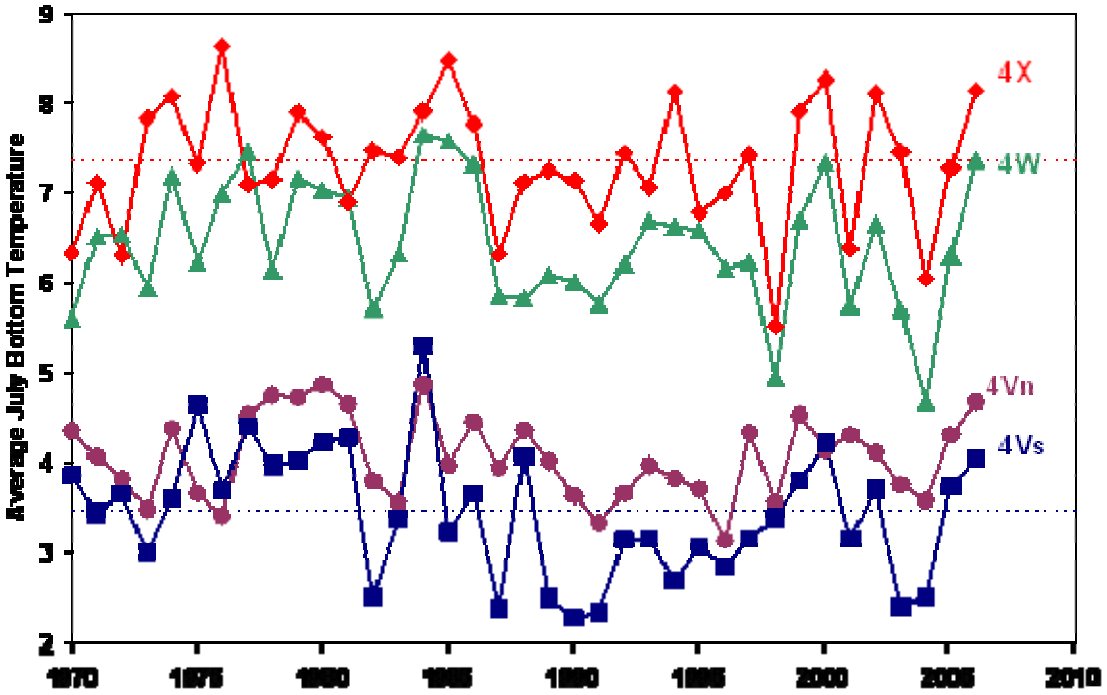

Fig. 12. Time series of annual mean bottom temperatures from areas 4Vn, 4Vs, 4W and 4X. The horizontal lines are the 1971-2000 means.

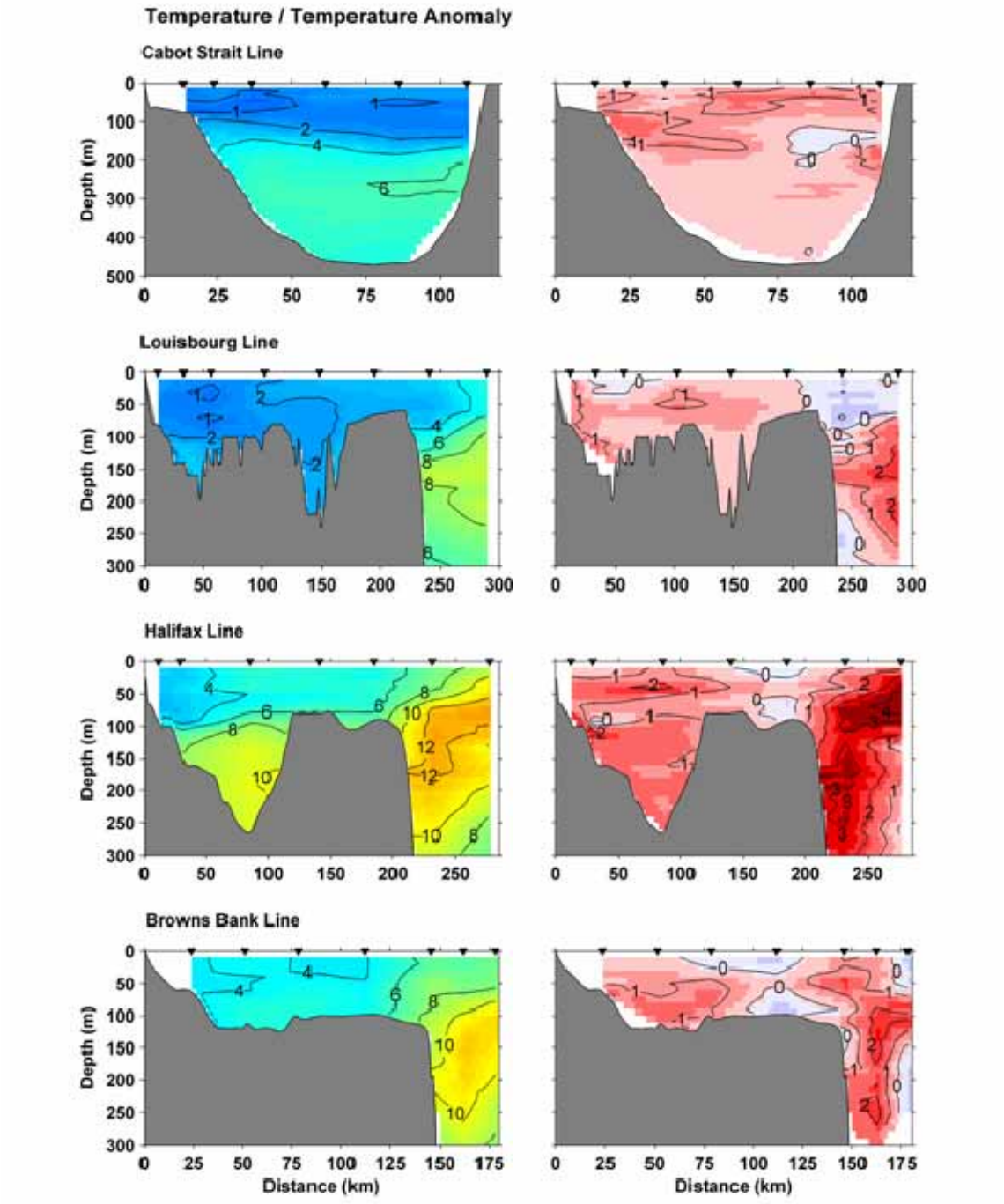

Fig. 13a. Temperature and temperature anomalies for standard Scotian Shelf sections, April-May 2006.

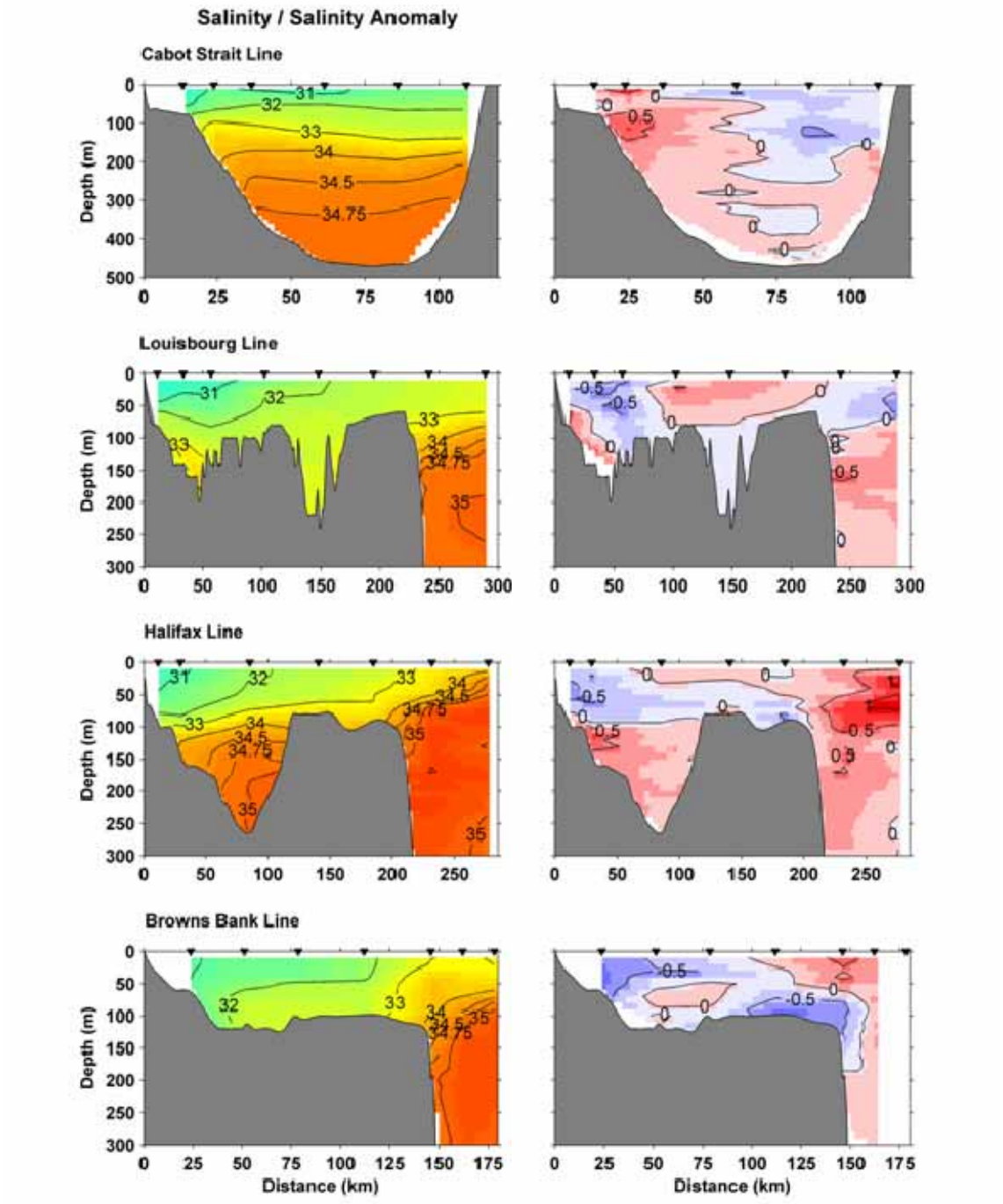

Fig. 13b. Salinity and salinity anomalies for standard Scotian Shelf sections, April-May 2006.

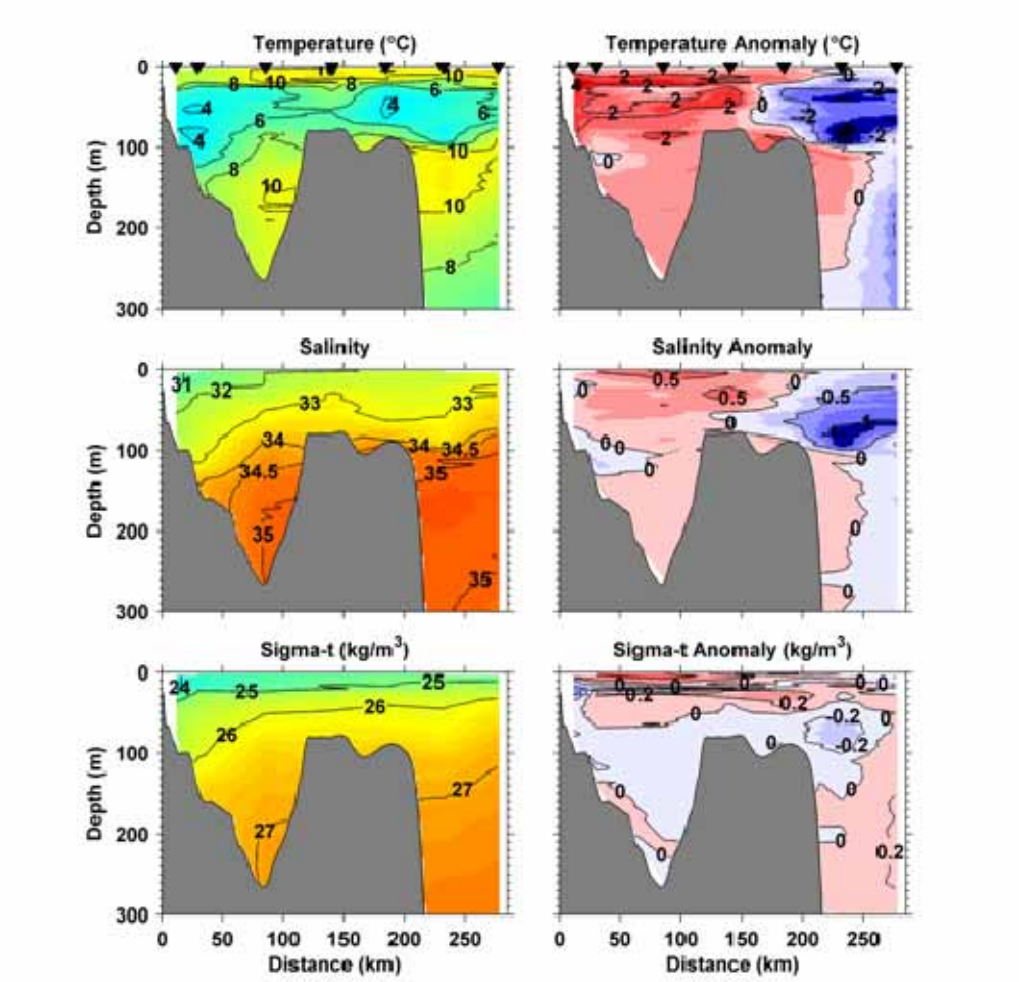

Fig. 13c. Temperature, salinity and sigma-t and their anomalies for the Halifax Section, June 2006.

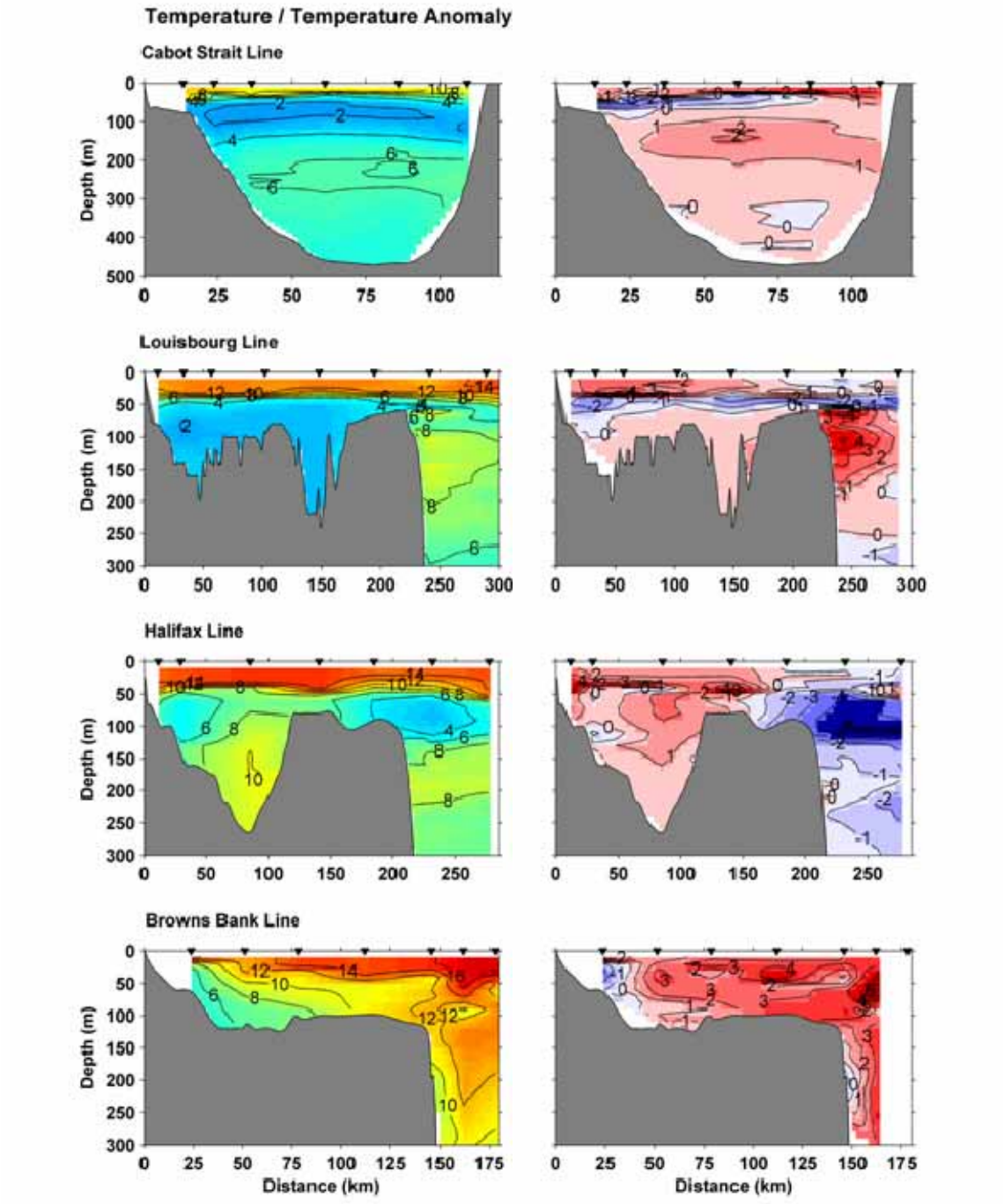

Fig. 13d. Temperature and temperature anomalies for standard Scotian Shelf sections, October 2006.

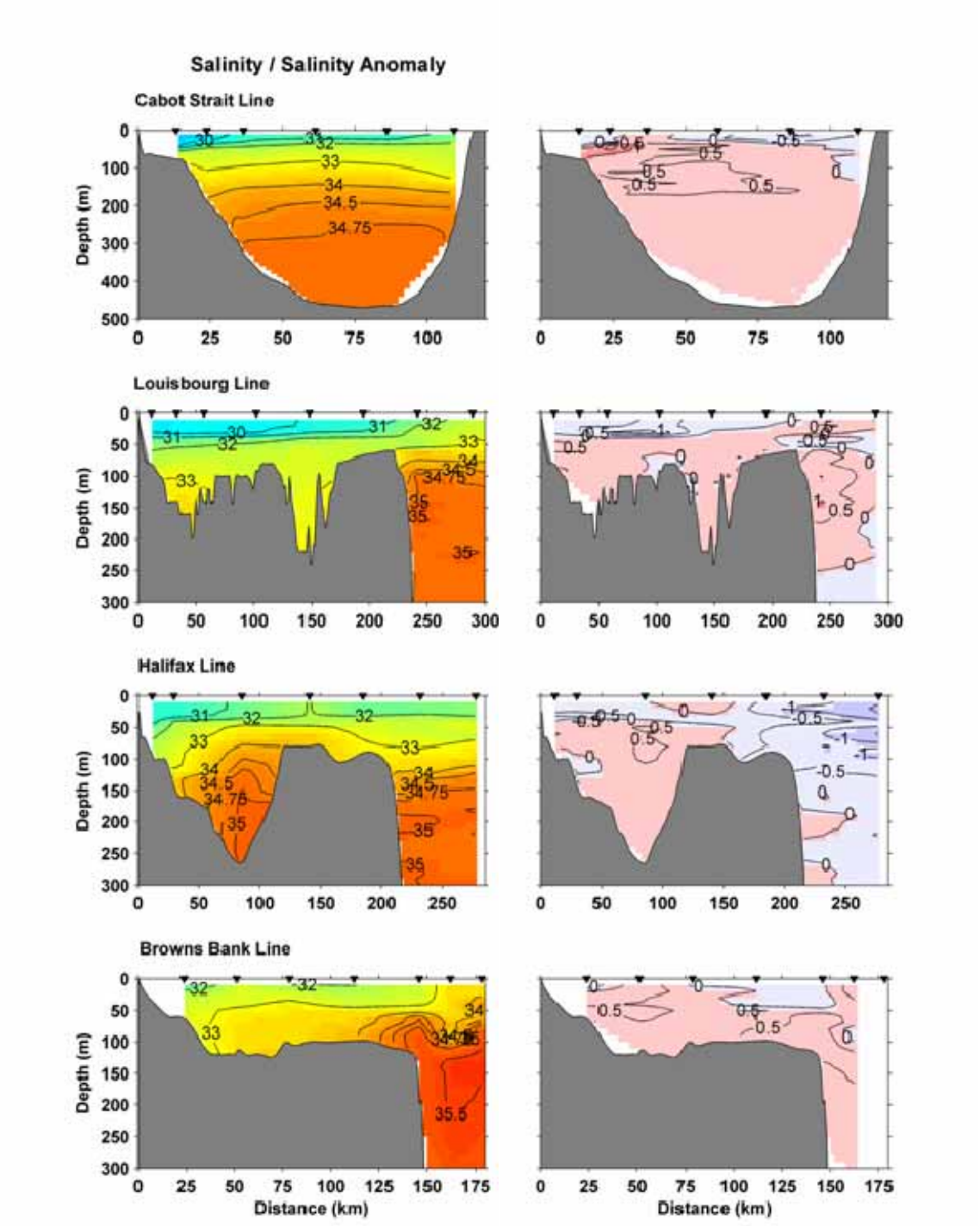

Fig. 13e. Salinity and salinity anomalies for standard Scotian Shelf sections, October 2006

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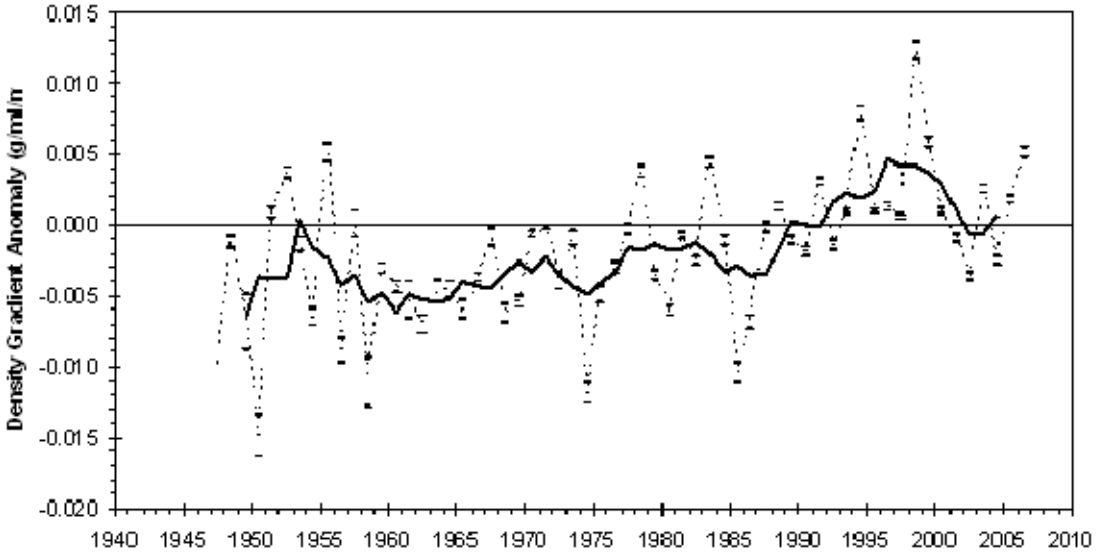

Fig. 14. The mean annual (dashed line) and 5-yr running mean (heavy solid line) of the stratification index (0-50 m density gradient) averaged over the Scotian Shelf (areas 4-23 inclusive). The short horizontal lines for each year represent the standard errors of the different areas.

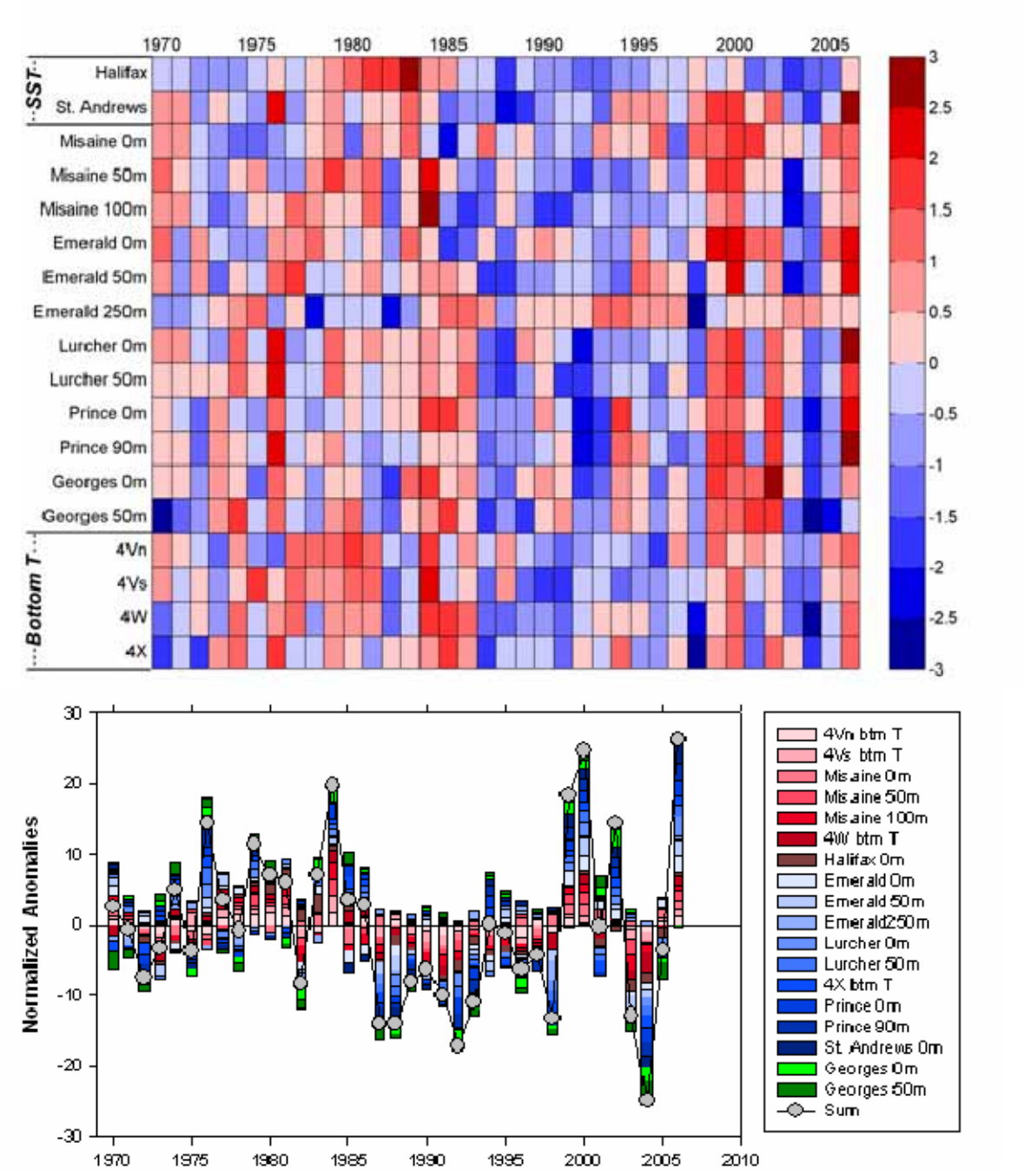

Fig. 15. Normalized annual anomalies of bottom temperatures and temperatures at discrete depths for the Scotian Shelf-Gulf of Maine region (upper panel). The normalized anomalies are the annual anomalies based on the 1971-2000 means, divided by the standard deviation. The scale represents the number of standard deviations an anomaly is from normal; blue indicates below normal, red above normal. The contributions of each of the normalized anomalies are shown as a bar chart and their summation as a time series (grey circles, black line; lower panel).