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Research Document 2008/017

Document de recherche 2008/017

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Physical Oceanographic Conditions on the Scotian Shelf and in the Gulf of Maine during 2007

Conditions océanographiques physiques sur le plateau néo-écossais et dans le golfe du Maine en 2007

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This document is available on the Internet at:

Ce document est disponible sur l'Internet à:

http://www.dfo-mpo.gc.ca/csas/

ISSN 1499-3848 (Printed / Imprimé)

Canada

ABSTRACT

A review of physical oceanographic conditions on the Scotian Shelf and in the Gulf of Maine and adjacent offshore areas during 2007 indicates that the annual average temperatures were generally lower than in 2006, one of the warmest years on record. This decline brought annual values to near normal at the mouth of the Bay of Fundy, Sydney Bight and eastern Scotian Shelf area. The central and western Shelf, the subsurface temperatures from the July groundfish survey and the spring and fall AZMP sections generally featured below normal temperatures by about 1^{o}C, but with extreme anomalies as large as 6^{o}C below normal over the upper continental slope.

The St. Andrews annual sea surface temperature was normal in 2007, a marked decline from 2006, the warmest year in the 87 year time series. At 90 m deep AZMP fixed station site Prince 5, monthly anomalies varied from -1.3^{o}C to +2.7^{o}C. The annually averaged temperatures at 0 and 90 m were normal. Annual salinity anomalies were +0.3 (0 m) and +0.1 (90 m). The annual Halifax sea surface temperature was 1^{o}C below normal, making 2007 the 10th coolest in 82 years. At Halifax Station 2, temperature anomalies were generally 1^{o}C below normal from 0 to 140 m; salinity anomalies were near normal from the surface to 100m, and about 0.5 above normal from 100 m to the bottom. Misaine Bank had weak, annual temperature anomalies varying from -0.5 to +0.3^{o}C in the upper 100 m; Emerald Basin anomalies were negative at all depths ranging from -0.1 to -1.8^{o}C from 0-250 m, with the larger anomalies from 30 m to the bottom. Lurcher Shoals annual anomalies varied from +0.6^{o}C near the surface to a minimum of -0.8^{o}C from 50 to 75 m. Georges Basin annual anomalies were quite uniform and about -0.9^{o}C from 0 to 300 m. the eastern Georges Bank annual anomalies ranged from +0.4^{o}C at 0 m to -0.7^{o}C from 30 to 100 m. The outstanding feature of the observations from standard sections in April and October on the Scotian Shelf was the widespread negative anomalies over the shelf, particularly at the shelf break on the spring sections. Cabot Strait deep-water (200-300 m) temperatures were near normal. The overall temperature anomaly for the combined NAFO areas of 4Vn, 4Vs, 4W and 4X from the July groundfish survey was -0.8^{o}C, a decrease of 1.5^{o}C from the 2006 value and the largest decrease in the 38 year record. The overall stratification was above normal for the Scotian Shelf region in 2007. The Shelf/Slope front was about 30 km south of its long-term mean position; the Gulf Stream front was within 1 km of its mean position. A composite index for the region indicates that 2007 was the 7th coldest overall of the past 38 years. This represents the largest single year decline of the composite index in the 38 year record.

RÉSUMÉ

D'après un examen des conditions océanographiques physiques observées en 2007 sur le plateau néo-écossais et dans le golfe du Maine ainsi que dans les secteurs extracôtiers adjacents, les températures moyennes annuelles ont été en général inférieures à celles de 2006, l'une des années les plus chaudes dans les registres. Ce déclin a ramené les valeurs annuelles presque à la normale à l'entrée de la baie de Fundy, dans la baie de Sydney et dans le secteur est du plateau néo-écossais. Dans le centre et l'ouest du plateau, les températures sous la surface enregistrées pendant le relevé sur le poisson de fond de juillet et aux sections de printemps et d'automne du PMZA ont présenté en général des températures d'environ 1 °C inférieures à la normale, mais avec des anomalies extrêmes aussi grandes que 6 °C sous la normale dans la partie supérieure du talus continental.

La température annuelle à la surface de la mer à St. Andrews a été normale en 2007, affichant un déclin marqué par rapport à 2006, année la plus chaude de la série chronologique de 87 ans. À la station fixe Prince 5 du PMZA (90 m de profondeur), les anomalies mensuelles ont varié de -1,3 à +2,7 °C. Les températures, ramenées à une moyenne annuelle, ont été normales à 0 et à 90 m. Les anomalies annuelles de la salinité ont été de +0,3 (0 m) et de +0,1 (90 m). La température annuelle à la surface de la mer à Halifax a été de1 °C inférieure à la normale, faisant de 2007 la 10^{e} année la plus fraîche en 82 ans. À la Station 2 de Halifax, les anomalies de la température ont été dans l'ensemble de 1 °C sous la normale entre 0 et 140 m; les anomalies de la salinité ont été presque normales de la surface jusqu'à 100 m et d'environ 0,5 au-dessus de la normale de 100 m jusqu'au fond. Le banc de Misaine a affiché des anomalies de la température annuelle faibles, variant de -0,5 à +0,3 °C dans les 100 premiers mètres; les anomalies dans le bassin d'Émeraude ont été négatives à toutes les profondeurs, variant de -0,1 à -1,8 °C entre 0 et 250 m, les anomalies plus grandes étant enregistrées de 30 m jusqu'au fond. Les anomalies annuelles sur le haut-fond Lurcher ont varié de +0,6 °C près de la surface à un minimum de -0,8 °C entre 50 et 75 m. Les anomalies annuelles dans le bassin Georges ont été assez uniformes et d'environ -0,9 °C entre 0 et 300 m. Les anomalies annuelles dans l'est du banc Georges ont varié de +0,4 °C, à 0 m, jusqu'à -0,7 °C, entre 30 et 100 m. Les anomalies négatives répandues sur le plateau néo-écossais, en particulier à la hauteur du rebord du plateau vis-à-vis des sections de printemps, constituent la caractéristique marquante des observations faites sur les sections standard en avril et en octobre. Les températures des eaux profondes du détroit de Cabot (200-300 m) ont été près de la normale. L'anomalie globale de la température pour les zones combinées 4Vn, 4Vs, 4W et 4X de l'OPANO observée au cours du relevé sur le poisson de fond de juillet était de -0,8 °C, une diminution de 1,5 °C par rapport à 2006 et la plus grande diminution enregistrée depuis 38 ans. Dans l'ensemble, la stratification a été supérieure à la normale dans la région du plateau néo-écossais en 2007. Le front du plateau/talus se trouvait à environ 30 km au sud de sa position moyenne à long terme; le front du Gulf Stream se trouvait quant à lui à moins de 1 km de sa position moyenne. Un indice composé pour la région indique que 2007 a été la 7^{e} année la plus froide depuis 38 ans. Il s'agit également du plus important déclin de l'indice composé observé pour une seule année depuis les 38 dernières années.

Introduction

This document describes temperature and salinity characteristics of Scotian Shelf and Gulf of Maine waters during 2007 (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 several times per year from the national archive maintained by Integrated Science Data Management (ISDM), Department of Fisheries and Oceans (DFO) in Ottawa. Our analyses use data archived prior to 10 October 2007. Additional hydrographic data were obtained directly from DFO fisheries surveys. We also provide information on the position of the Gulf Stream and the boundary between the shelf waters and the offshore slope waters.

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 divided by the standard deviation). Where possible, long-term monthly and annual means, and standard deviations 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) data for eastern Canada during 2007 are described in Petrie et al. (2008). The monthly air temperature anomalies for the Scotian Shelf and the Gulf of Maine were quite variable during 2007. On the other hand, the annual temperature anomalies were consistently within the normal range with values of +0.2°C for Sydney, -0.1°C for Sable Island and +0.2°C for Shearwater (Halifax), -0.2°C for Yarmouth, -0.3°C for Saint John and 0.0°C for Boston. All of these annual values were within 0.5 standard deviation (SD) of the 1971-2000 annually averaged temperatures. Annually averaged SST anomalies were positive for the eastern and central Scotian Shelf by 0.2°C to 0.3°C and the Bay of Fundy by 0.2°C, but all were within 0.5 SD of the long-term means. In contrast, the western Scotian Shelf, Lurcher Shoals and Georges Bank annual SST anomalies were negative by -0.8, -0.6 and -0.3°C, corresponding to 1.5, 1 and 0.5 SD from normal values.

Throughout this document, the oceanographic conditions observed in 2007 will be contrasted with those measured in 2006. The 2006 conditions are described by Petrie et al. (2007).

Temperature and salinity conditions in the Scotian Shelf, Bay of Fundy and Gulf of Maine regions are determined by many processes: heat transfer between the ocean and atmosphere, inflow from the Gulf of St. Lawrence supplemented by flow from the Newfoundland Shelf, exchange with offshore slope waters, local mixing, freshwater runoff, direct precipitation and melting of sea-ice. The Nova Scotia Current is the dominant inflow, originating in the Gulf of St. Lawrence and entering the region through Cabot Strait. The Current, whose path is strongly affected by topography, has a general southwestward drift over the Scotian Shelf and continues into the Gulf of Maine where it contributes to the counter-clockwise mean circulation. The water mass properties of shelf waters are modified by mixing with offshore waters from the continental slope.

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

These offshore waters are generally of two types, Warm Slope Water, with temperatures in the range of 8-13°C and salinities from 34.7-35.6, and Labrador Slope Water, with temperatures from 3.5°C to 8°C and salinities from 34.3 to 35. Shelf water properties have large seasonal cycles, east-west and inshore-offshore gradients, and vary with depth (Petrie et al. 1996).

Coastal Sea Surface Temperatures

Monthly averages of coastal SST for 2007 were available for 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 2006 and 2007 are shown in Fig. 2.

At St. Andrews, there was a marked change from the large. positive monthly anomalies in 2006 to a mixture of positive and negative anomalies in 2007, six of them within 0.5 SD of the monthly normals. The annual anomaly for the year was essentially 0°C, a significant decline from the 2006 value of +1.3°C, the warmest of the 87 year record. The 2007 monthly anomalies at Halifax tended to be more negative than in 2006; the annual anomaly of -1.0°C (-1.5 SD) was about 1.3°C cooler than in 2006. The Halifax annual mean SST temperature in 2007 was the 10th lowest in 82 years.

The decline of annual temperatures at St. Andrews and Halifax during 2007 has returned the times series to the conditions observed from about 2001-05, i. e. prior to the 2006 peak.

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. Beginning in the 1990s, a CTD (Conductivity, Temperature, Depth) profiler has been used. Up to and including 1997, there was one observation per month; 1998-2003 had multiple occupations per month; in 2004 sampling was reduced to once per month because of financial and personnel restrictions. For months with multiple measurements, the arithmetic mean was used to estimate the monthly mean temperature and salinity. A single or even several observations 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 features are likely real. The weak vertical temperature gradients over the 90 m depth are due to the strong tidal mixing within the Bay of Fundy.

In 2007, monthly mean temperatures ranged from a minimum in April of 2.5°C at the surface to a maximum in September of 12.1°C (Fig. 3, 4). Monthly temperature anomalies were strongly positive in January and February but tended to be negative throughout the rest of the year. The pattern was similar at 90 m because of the weak stratification. The annual mean temperatures have high interannual variability with evidence of strong long-term trends at the surface and 90 m (Fig. 4). In 2007, the annual temperature anomalies at 0 and 90 m were about 0°C. This represents a substantial change (~1.2°C) from 2006, when the annual temperatures at 0 and 90 m were the 2nd highest and the highest in the 83 year record.

The salinity at Prince 5 had a broad minimum in the spring at the surface (~31 in May and June) and at 90 m (31.7 in May and June; Fig. 3, 5). The salinity anomalies were typically positive early in 2007 and more variable, though generally very small, throughout the rest of the year. The annual salinity anomalies were slightly positive from 0-90 m, decreasing towards the bottom; the anomalies ranged from ~+0.1 to +0.3; these values are from +0.9 (surface) to +0.4 (90 m) SD of the 1971-2000 annual means. The density (sigma-t) variability followed the salinity pattern, positive anomalies at all depths with larger values near the surface.

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. Hydrographic measurements, presented here, are taken using a CTD; nutrient and biological samples are also collected. The long-term monthly means of temperature, salinity and density (sigma-t) were discussed in Drinkwater et al. (2000). There were 20 occupations of H2 in 2007, 1 more than in 2006 and 4 more than in 2005, the year with the fewest samples since 1998.

Surface temperatures at H2 ranged from -1.1°C in March to 18.1°C in August 2007 (Fig. 6). Near-bottom (140 m) temperatures were between 1.3°C and 6.9°C throughout the year with an average value of 4.8°C, a considerably cooler mean and range of values than observed in 2006 (range 4.3-9.5°C, average 7.3°C). Relative to the long-term means, annual average temperatures were below normal at all depths by 0.5°C to 2°C. The Cold Intermediate Layer (CIL, as defined by T<4°C) was thicker than in 2006 (Petrie et al. 2007), forming a ~100 m layer during the late spring to fall period. The CIL typically warms throughout the year and its defining temperature can vary from about 1°C to 6°C depending on the time of the year.

Salinity anomalies were small in 2006 in the upper 100m, with a mixture of above and below normal values; above normal values were found from 100 m to the bottom, where the largest anomaly of about +0.3 was observed. The pattern changed in 2007 with small anomalies in the upper 50 m and increasingly negative values towards the bottom, where a value of ~-0.5 was observed, coincident with the strongest temperature anomaly. Overall there was a freshening of the bottom waters by nearly 0.8 in 2007 relative to 2006. This coupled with the lower water temperatures implies that Labrador Slope Water could have played a greater role in the water mass structure on the shelf and upper slope.

In the surface layers, stratification began to develop in March-April with a surface to 50 m density difference of ~0.5 kg m^{-3}. From early April to early August the difference increased steadily to ~3.8 kg m^{-3}. Annual density anomalies alternated between positive and negative values from the surface to the bottom.

Dramatic changes in the depths of isohalines and isopycnals occurred between the March 18 and April 4 AZMP station profiles (Fig. 6). The depths of the 31, 31.5 and 32 isohalines decreased from 48, 68 and 131 m on March 18 to the surface, 39 and 61 m by

April 4. These are changes of 48, 29 and 70 m. Similarly, the 25 and 25.5 kg m^{-3} sigma-t surfaces rose from 52 and 124 m to the surface and 44 m, excursions of 52 m and 80 m. This could have been a wind-driven upwelling event or an onshore water movement resulting from other mechanisms.

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. 7). Petrie et al. (1996) updated their report using these same areas and all available hydrographic data. We present monthly mean conditions for 2007 at standard depths for six 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 Sydney Bight, Misaine Bank, Emerald Basin, Lurcher Shoals, Georges Basin and east Georges Bank, the 2007 annual means are based on 2, 9, 9, 6, 6 and 7 monthly averaged profiles. The series can have short period fluctuations or spikes with amplitudes of 1-2°C superimposed upon long-period trends. The spikes represent high frequency temporal or spatial variability and most often show little similarity between regions. These data must be interpreted carefully and appropriate weight given to any individual mean. The long period trends often show similarity over several areas. To better show the trends, we have estimated the annual mean anomaly based on averaging monthly anomalies within the year at selected depths. The resulting descriptions of temperature conditions in the six representative areas are displayed as monthly and annual (the average of the monthly anomalies) anomalies in 2007 (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 below normal temperatures, i.e. negative anomalies, during 2007. This was particularly so for the four westernmost sites. In Sydney Bight (area 1, Fig. 7) off eastern Cape Breton and by far the least sampled area, the annual profile tended towards positive anomalies at 30-50 m but the observations are too few to draw firm conclusions (Fig. 8). Misaine Bank annual temperature anomalies were small and typically about -0.2°C. Emerald Basin annual anomalies were negative at all depths and, from 30 to 250 m, about -1.3°C. Lurcher Shoals had below normal temperatures by up to 1°C from 30 to 75 m. Georges Basin annual anomalies were negative at all depths and nearly constant at -0.9°C from 30 to 300 m. The Georges Bank annual profile featured weak positive anomalies in the upper 10 m but became increasingly negative with depth, averaging about -0.7°C from 30 to 100 m.

The annual temperature anomalies in 2007 have decreased since 2006 for all six time series (Fig. 9). The 100 m temperature anomalies for Sydney Bight and Misaine Bank have decreased by 0.4 and 0.9°C in 2007 to near normal values. Temperatures moved to below normal in the four westernmost areas. The Emerald Basin 250 m record reflects the influence of slope water on the Scotian Shelf; it had the largest temperature decline, 2.2°C. Lurcher Shoals temperature anomalies (50 m) decreased by 2°C nearly matching the Emerald Basin value. Temperature changes of -1.1°C in Georges Basin and -1.3°C on eastern Georges Bank from 2006 observations were recorded.

Temperatures during the Summer Groundfish Surveys

The broadest spatial CTD coverage of the Scotian Shelf is obtained during the annual DFO groundfish survey, usually in July. A total of 169 CTD stations were taken during the 2007 survey and an additional 175 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 observations are plotted without taking the time of sampling into account. Thus, Sydney Bight, sampled at the end of the survey, has had about a month longer solar heating than the area to the west of Halifax sampled at the start of the survey. This is not accounted for directly in the analysis. Consequently, Sydney Bight often has the highest sea surface temperatures. On the other hand, the 1971-2000 July temperature climatology is dominated by data from 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 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 using Vemco Minilogs© attached to the trawl.

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 2007 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 2007 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 (9-10°C) were found near the mouth of the Bay of Fundy, and represent a decrease of about 2°C from 2006 (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 2007 were dominated by warmer than normal (by 0-4°C) values east of 64°W, and cooler than normal (by 0-2°C) readings over the remaining survey area (Fig. 11a).

The temperatures at 50 m ranged from about 2°C to 8°C with the coldest waters in the northeast and the warmest waters in the Bay of Fundy (Fig. 10a). The lower temperatures occupy most of the Shelf from Cape Breton to SW Nova Scotia and mark the CIL, which was considerably more extensive than in 2006. The higher temperatures towards the outer edge of the Shelf in the central region reflect the influence of Slope Waters but are about 3°C cooler than in 2006. The warmer waters in the Gulf of Maine compared to the Scotian Shelf are, in part, due to the increased importance of tidal mixing which transfer heat from the surface to deeper waters from spring to fall, and from deeper to shallower waters during the winter. In contrast to the near-surface temperatures, the 50 m anomalies were predominantly negative, ranging from 0°C to ~1°C below normal (Fig. 11a).

The temperatures at 100 m ranged from <2°C on the northeastern Scotian Shelf to 8°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 is similar to but ~2°C cooler than the one observed in 2006. The 2007 anomaly pattern at 100 m, like the one seen at 50 m, was dominated by below normal temperatures in the range of 0-2°C (Fig. 11b).

Near-bottom temperatures ranged from <2°C on Misaine Bank in the northeastern Scotian Shelf to ~8°C in Emerald Basin and 9°C in the upper Bay of Fundy, generally 1 to 2°C cooler than in 2006 (Fig. 10b). In Emerald Basin, the higher 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, caused by the intense vertical mixing by the tides which transfer heat efficiently from the warmer surface layer. 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 cooler than normal by ~1°C over the Scotian Shelf (Fig. 11b).

We also estimated the area of the bottom covered by waters in 1°C increments (i. e., 1-2°C, 2-3°C, 3-4°C, etc.) within NAFO Subareas 4Vn, 4Vs, 4W and 4X (Fig. 1). The areas were obtained from the optimally estimated temperature distributions from the July groundfish and ITQ surveys. The time series for each NAFO Subarea are shown in Fig. 12a, b. There were generally lower bottom temperatures in the 4 NAFO divisions in 2007 compared to 2006. This is seen in the diagrams as an upward slope of the lines defining the areas in each temperature range. An upward slope means that the areas corresponding to lower temperatures are increasing. In 4Vn, most of the bottom is covered by waters <6°C and about 49% is <5°C, an increase from 39% in 2006. For 4Vs, 72% is <5°C, again slightly up from 65% in 2006 (Fig. 12a). In 4W, 58% and in 4X, 32% of the bottom is covered by temperatures <6°C, up substantially from 28% and 8% in 2006 (Fig. 12b). In all 4 regions, bottom waters were cooler in 2007 than in 2006.

The interannual variability can be summarized by determining the average bottom temperatures in each region (Fig. 13a). All areas in 2007 featured average bottom temperatures that were below the 1971-2000 norms. Areas 4Vn and 4Vs had the least anomalous bottom temperatures, 0.1°C (0.2 SD) and 0.6°C (0.6 SD) below normal. Areas 4W and 4X were 0.9 (1.4 SD) and 1.1°C (1.6 SD) below normal, in both cases the 3rd coldest in 38 years. Combining the 4 NAFO areas (accounting for the different area sizes), we find an overall bottom temperature anomaly of -0.8°C (1.5 SD), the 5th coldest year. In 2004, the overall bottom temperature anomaly was -1.4°C (-2.5 SD), the coldest year from 1970 to present.

The volume of the Cold Intermediate Layer (CIL), defined as waters with temperatures <4°C, was estimated from the full depth CTD profiles for the region from Cabot Strait to Cape Sable (Fig. 13b). For the period 1970 to 1989, the number of CTD profiles per year was limited; therefore, 5 year blocks of data, e.g. 1970-1974, centre date 1972, were used as input for the procedure to map the irregularly spaced data onto a regular grid. The data were then incremented by 1 year and a new set of estimates made (i.e., 1970-74, 1971-75, …). This procedure is similar to filtering the data for the 1970-89 period, effectively reducing the variance. Thus the long-term mean and particularly the SD (based on the 1972-2000 data in Fig. 13b) could be affected. We expect that the true SD is higher than the one derived here.

There is considerable variation in the volume of the CIL since 1998. In 2007, the observed volume of 6800 km^3 was 1.9 SD greater than the long-term mean value of 5100 km^3.

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. 14a-d. The anomalies corresponding to these data were calculated for the date on which they were collected. In April, 0-150 m temperatures were 0-2°C across the entire Cabot Strait section, and from the coast to seaward of the shallowest slope station on the Louisbourg section. Cooler waters also dominated the Halifax section, with less than 2°C temperatures in a surface layer 50 to 100 m thick, and the Browns Bank section, where the <2°C layer extended from the surface to 50 m (Fig. 14a). Temperature anomalies were mostly negative on the Louisbourg, Halifax and Browns Bank sections, were largest near the shelf edge with values of up to -6°C in areas normally dominated by Warm Slope Water. The main feature of the Cabot Strait section was an area of warmer than normal temperatures stretching from the 100 m isobath off Cape Breton to the bottom waters of mid-strait. Fresher than normal waters, with salinities as much as 1.5 below normal, were associated with the large negative temperature anomalies at the shelf break on the Halifax and Browns Bank sections (Fig. 14b). This contrasts with the largely positive salinity anomalies observed on the Cabot Strait section, particularly on the western half of the Strait, the area where the flow is predominantly out of the Gulf of St. Lawrence onto the Scotian Shelf. The Louisbourg section had a mixture of slightly above and below normal salinity anomalies.

In October, the remnant of the CIL from the Gulf of St. Lawrence is evident between 50 and 100 m in the Cabot Strait section (Fig. 14c). Moreover, surface cooling is already well underway on this section. The Louisbourg section features a >12°C surface layer and a <2°C layer from ~50 m to the bottom. The Halifax section temperature decreases from about 16°C near the surface to <4°C at 50 m. A 20 to 50 m thick subsurface layer with T<4°C spans the entire shelf. The Browns Bank section is dominated by a thick T<6°C layer over the shelf from about 30 m to the bottom. These fall sections feature generally below normal temperature anomalies over the shelf and upper slope except for the very near surface layer. Anomalies were as large as -6°C but -2°C was more typical. The outer stations on the Louisbourg, Halifax and Browns Bank sections featured strong positive anomalies. The salinity distributions had above normal values over most of Cabot Strait and the shelf portion of the Louisbourg. This implies an outflow of higher than normal saline waters from the Gulf of St. Lawrence. Salinity anomalies show more spatial variability on the two westernmost sections. On all four sections, the anomalies were generally between ±0.5.

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 from 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 fluctuations with a range of about 2.5°C, 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 ~7 years. More recent work by Gilbert (2004) agrees qualitatively with that of Bugden (1991) but with a shorter propagation time of about 3-4 years along the Laurentian Channel. In 2007, the temperature was 0.2°C (0.4 SD) below the long-term mean, a decrease of 0.3°C from the 2006 value (Fig. 15).

Density Stratification

Stratification of the near surface layer influences physical and biological processes in the ocean such as the extent of vertical mixing, the ocean's response to wind forcing, the timing of the spring bloom, vertical nutrient fluxes and plankton speciation. 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 layers. 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 a combination of subareas 4-23 on the Scotian Shelf (Fig. 16, 17). 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. A value of 0.01 (kg m^{-3})/m represents a difference of 0.5 kg m^{-3} over 50 m.

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. 16a, b). In 2007, there was little spatial variability of the stratification index in the region as 15 of 19 (areas 4-23) Scotian Shelf areas had positive anomalies. The average stratification parameter for areas 4-23 was above normal in 2007 (Fig. 17) and slightly lower than in 2006.

Sea Level

Sea level is a primary variable in the Global Ocean Observing System. Relative sea level is measured with respect to a fixed reference point on land. Consequently, relative sea level consists of two major components: one due to true changes of sea level and a second caused by sinking or rising of the land. In Atlantic Canada, the area roughly south (north) of the north shore of the Gulf of St. Lawrence is sinking (rising) in response to glacial retreat; this results in an apparent rise (fall) of sea level. Relative sea level at Halifax (1990-2007) is plotted as monthly means and as a filtered series using a 12-month running-mean filter (Fig. 18). The linear trend of the monthly mean data (1990-2007) has a positive slope of 26.3 (±7.4) cm/century, lower than the value of 36.7 cm/century (1897-1980) given by Barnett (1984) but within the standard error (note Barnett does not give a standard error). Despite the long-term rising trend, relative sea level generally decreased at Halifax from 1998-2003. The trend is referenced to a benchmark fixed on the land and therefore is not an absolute value of the sea level rise. The green 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 1990-2006 by only ~3 cm/century. In 2007 relative sea level was about 4 cm lower than in 2006.

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 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 charts did not contain data east of 60°W but within a year were extended east to 55°W. Data for 2007 have been digitized, estimates of monthly mean positions determined, and anomalies relative to 1973-2000 were calculated. Since May 2005, we have been downloading front positions from the U.S. Naval Oceanographic Office. During the past several years, the analysis only extends east to 56°W due to inconsistencies in the data at 55°W. In 2006, it was extended again to 50W.

The overall mean position of the Shelf/Slope front and the 2007 annual mean position are shown in Fig. 19. 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 100-200 km from the shelf edge off the Scotian Shelf and the southern Grand Bank. It is generally farthest offshore in winter and at its most northern position in late summer and early autumn. During 2007, the shelf/slope front was southward, by 30 km, of its long-term mean position. This was due to a nearly uniform southward displacement along the entire length of the front. In 2007, the front moved about 22 km offshore from its mean position in 2006.

Gulf Stream

The position of the northern boundary of the Gulf Stream was 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. The time series consists of the monthly position at each degree of longitude from 56°W to 75°W. The average position of the northern edge of the Gulf Stream and the 2007 annual mean are shown in Fig. 20. The Gulf Stream leaves the shelf break near Cape Hatteras (75°W) running towards the northeast. East of approximately 62°W, the average position is oriented approximately east-west. In 2007, the Gulf Stream showed only minor deviations from and was within 1 km of its long-term mean position.

Summary

A review of physical oceanographic conditions on the Scotian Shelf and in the Gulf of Maine and adjacent offshore areas during 2007 indicates that the annual average temperatures were generally lower than in 2006, one of the warmest years on record. This decline brought annual values to near normal at the mouth of the Bay of Fundy, Sydney Bight and eastern Scotian Shelf area. The central and western Shelf, the subsurface temperatures from the July groundfish survey and the spring and fall AZMP sections generally featured below normal temperatures by about 1°C, but with extreme anomalies as large as 6°C below normal over the upper continental slope.

The St. Andrews annual sea surface temperature was normal in 2007, a marked decline from 2006, the warmest year in the 87 year time series. At the 90 m deep AZMP fixed station site Prince 5, monthly anomalies varied from -1.3°C to +2.7°C. The annual temperatures at 0 and 90 m were normal. Annual salinity anomalies were +0.3 (0 m) and +0.1 (90 m). The annual Halifax sea surface temperature was 1°C below normal, making 2007 the 10th coolest in 82 years. At Halifax Station 2 from 0 to 140 m, temperature anomalies were generally 1°C below normal; salinity anomalies were near normal from the surface to 100m, and about +0.5 from 100 m to the bottom. Misaine Bank had weak, annual temperature anomalies varying from -0.5 to +0.3°C in the upper 100 m; Emerald Basin anomalies were negative at all depths ranging from -0.1 to -1.8°C from 0-250 m, with the larger anomalies occurring from 30 m to the bottom. Lurcher Shoals annual anomalies varied from +0.6°C near the surface to a minimum of -0.8°C from 50 to 75 m. Georges Basin annual anomalies were quite uniform and about -0.9°C from 0 to 300 m. The eastern Georges Bank annual anomalies ranged from +0.4°C at 0 m to -0.7°C from 30 to 100 m. The outstanding feature of the observations from standard sections in April and October on the Scotian Shelf was the widespread negative anomalies over the shelf, particularly at the shelf break on the spring sections. Cabot Strait deep-water (200-300 m) temperatures were near normal. The overall temperature anomaly for the combined NAFO areas of 4Vn, 4Vs, 4W and 4X from the July groundfish survey was -0.8°C, a decrease of 1.5°C from the 2006 value and the largest decrease in the 38 year record. The overall stratification was above normal for the Scotian Shelf region in 2007. The Shelf/Slope front was about 30 km south of its long-term mean position; the Gulf Stream front was within 1 km of its mean position. A composite index for the region indicates that 2007 was the 7th coldest overall of the past 38 years. This represents the largest single year decline of the composite index in the 38 year record.

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. 21, 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 2007, 9 variables had normalized anomalies <-0.5, 7 ranged from -0.5 to +0.5, and 2 were >+0.5.

The mosaic plot can be summarized as a combination bar and line-scatter plot (Fig. 21, lower panel). 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 evident. The overall index makes 2007 the 10th coldest in the 38 year record. Moreover the change that has occurred since 2006 is striking. The average value of this index and its standard deviation based on its components are shown in Fig. 22. Though the index tended to be positive from 1970 to 1986 and negative from 1987 to 1998, the standard deviation includes 0 in all but 2 years. With the beginning of the AZMP program in 1999, this index has shown considerably more variability.

This plot is an attempt to derive an overall climate index for the area. In the manifestation presented in Fig. 21, 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. It may be that some of the series should be consolidated or others added, e.g. a volumetric estimate of the amount of water with a temperature less than 4^{o}C from the July groundfish survey, before summing to get an overall climate index. We shall continue to experiment with the development of an index over the next year.

There were a number of notable events in 2007 including: 1) the overall cooling since 2006; 2) the increase in the environmental variability since 1998, to which 2007 contributes; 3) the massive spring bloom reported by Harrison et al. (2008) which may have been driven in part by physical oceanographic events; and, 4) the apparent influx of Labrador Slope Water.

The cooling relative to 2006 is captured by the composite index shown in Fig. 21 and 22. Of the 18 variables displayed and including the CIL volume from the July groundfish survey to get a total of 19 time series, 18 of the 19 show a large negative change from 2006 to 2007. In SD units, the negative values range from -1.2 to -3.9. The only positive change was for the Georges Bank 0 m temperature with a value of +0.16. The overall average value changed from 1.4 in 2006 to -0.7 in 2007, i.e. by more than 2 SD.

We noted above that there seemed to be greater variability in the composite index since 1999, the first year of the AZMP program. The index tended to be positive from 1970 to 1986, negative from 1987 to 1998, and highly variable from 1999-2007. Indeed, the variance of the index was 0.17 for 1970-1986, 0.09 for 1987-98, and 1.02 for 1999-2007. Thirteen of the 18 variables showed the greatest variance for the 1999-2007 period.

Harrison et al. (2008) reported a strong, widespread spring bloom on all 4 AZMP sections in 2007 (see Table 1). To determine if the winter inventory of nutrients could have supported this bloom, we have summarized the time series of chlorophyll and nitrogen observed at the AZMP fixed station, Halifax 2, in Table 2. If the nitrogen inventory alone could account for the bloom, then the decrease of nitrogen in successive profiles should match the increase of chlorophyll. The estimates agree reasonably well for March 4 to March 18 and April 4 to April 7; however, for the main part of the bloom from March 18 to April 4, the change in nitrogen can only account for 16% of the change. There must be another source of nitrogen. It cannot be advected horizontally because the bloom occurred everywhere on the shelf (Table 1). The nutrients must come from depths greater than ~100 m. To support the difference between the chlorophyll produced (534 mg m^{-3}) and the nitrogen remaining in the April 4 profile from 0 to 100 m (558 mmole m^{-2}) requires approximately 1100 mmole m^{-2}. Integrating the March 18 profile to 120 m can supply the necessary nitrogen. This means that there must be a physical mechanism to upwell water from 120 to 100 m. It cannot be wind driven upwelling as the bloom occurs across the entire shelf; wind driven upwelling would confine the enhanced production in a narrow coastal band and near the shelf break. Moreover, sea level at Halifax indicates mostly downwelling response during this period, with a transition to weak upwelling in early April. Wind at Sable Island indicates upwelling favourable conditions from March 27 to April 1. Calculating the total Ekman flux gives (Flux = Alongshore Stress*time/ρf = 190 000 m^3 over the duration of the event) an upwelling of 1 m spread over the 200 km wide shelf. We conclude that wind driven upwelling cannot supply sufficient nitrogen. However, a strong onshore movement of water from off the shelf is another potential mechanism to supply the required nutrients. This would require about $2*10^{12}$ m^3 of water (20 m*500 km shelf length*200 km shelf width). Using 100 m as the cut-off depth at the edge of the shelf, then we would require a northward movement of the shelf/slope front of 40 km (20 m*200 km shelf width/100 m cut-off) between March 18 and April 4. Between 57 and 67°W, the shelf/slope front moved northward an average of 45 km (SD = 38 km) from the 15th of March to the 15th of April. This agrees quite well with the required movement of 40 km. It appears then that a northward movement of the shelf/slope front is a plausible mechanism to account for the nutrient flux necessary to account for the chlorophyll bloom from March 18 to April 4 and maintain the nitrogen profile on April 4. Additional processes and dynamics must come into play though. For example, sea level on the shelf obviously does not rise by 20 m; the water must go somewhere. There must for example be increased transport downshelf or, alternatively, seaward off the shelf. Northward movement of water would also be subject to vorticity constraints as the bottom was encountered on the upper slope. Simple onshore movement could be transformed into a current moving along the shelf break.

Table 1. General characteristics of spring bloom, April 6-15, 2007

Section	Surface Chl (mg m^{-3})	Layer Thickness (m)	Spatial Extent
Cabot Strait	8	50	Stn 1-5, 100 km
Louisbourg	10	75	All Stn, 300 km
Halifax	10	100	All Stn, 275 km
Browns Bank	12	65	All Stn, 180 km

Table 2. Chlorophyll and nitrogen data from Halifax 2, 0-100 m integrated concentrations.

Date	Nitrogen (mmole m^{-2})	Chlorophyll (mg m^{-2})	N to Chl	ΔChl
Mar-04	667	31		
Mar-18	658	93	8	62
Apr-04	558	728	101	635
Apr-07	357	939	201	210

The final tale in this year's review involves the apparent influx of Labrador Slope Water (LSW) to the shelf region manifested by the large temperature anomaly on the spring and fall Scotian Shelf sections and moderate, less extensive salinity anomalies on those same transects. We examined the H2 fixed station data, other stations from Emerald Basin and the spring and fall AZMP surveys on the Scotian Shelf in relation to the water mass classifications of IIP (1965) and Gatien (1976) (Fig. 23). While the observations from H2 closely approached the T/S properties that define LSW, they did not quite fall within the boundaries shown in Fig. 23. On the other hand, other stations from Emerald Basin fell within the LSW classification and also showed characteristics classified as Warm Slope Water (WSW). Water mass properties from the spring and fall Louisbourg sections fall well within the LSW class with some WSW evident as well. This is also the case for the Halifax section; the Browns Bank section showed the largest amount of WSW but also featured LSW, particularly in the spring section. It is not surprising that the LSW is beginning to play a larger part in the Scotian Shelf water mass distributions since in the past this has occurred during extended periods of low or negative NAO anomalies.

Acknowledgements

We wish to thank the many individuals who provided data or helped in the preparation of this paper, including: Mathieu Ouellet of the Marine Environmental Data Service in Ottawa; R. Losier of the Biological Station in St. Andrews, for providing St. Andrews and Prince 5 data; and J. Jackson for maintaining of the BIO hydrographic database. We also thank Eugene Colbourne and Peter Galbraith for their comments which improved the document.

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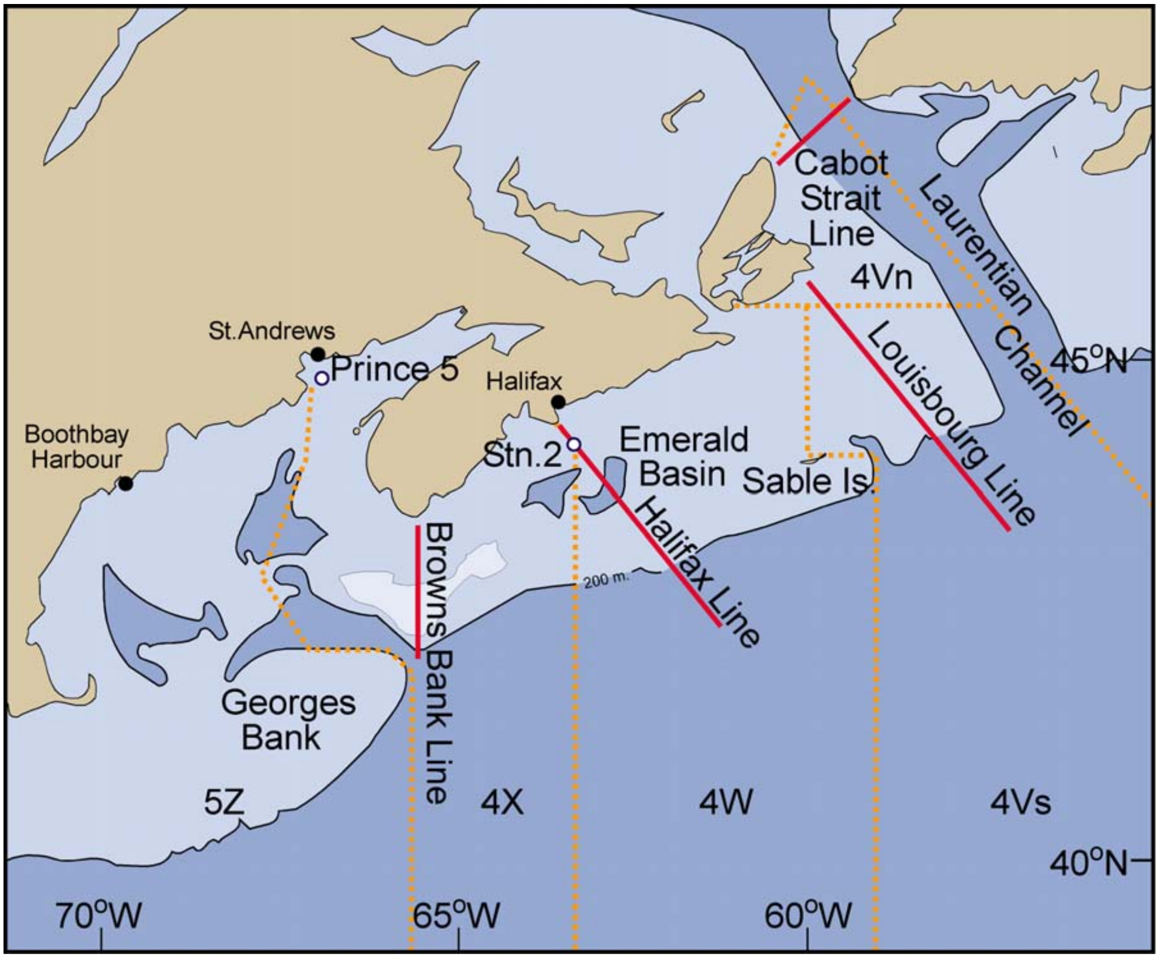


Fig. 1. The Scotian Shelf and the Gulf of Maine showing hydrographic stations, standard sections and topographic features. The dotted lines indicate the boundaries of the NAFO Subareas.

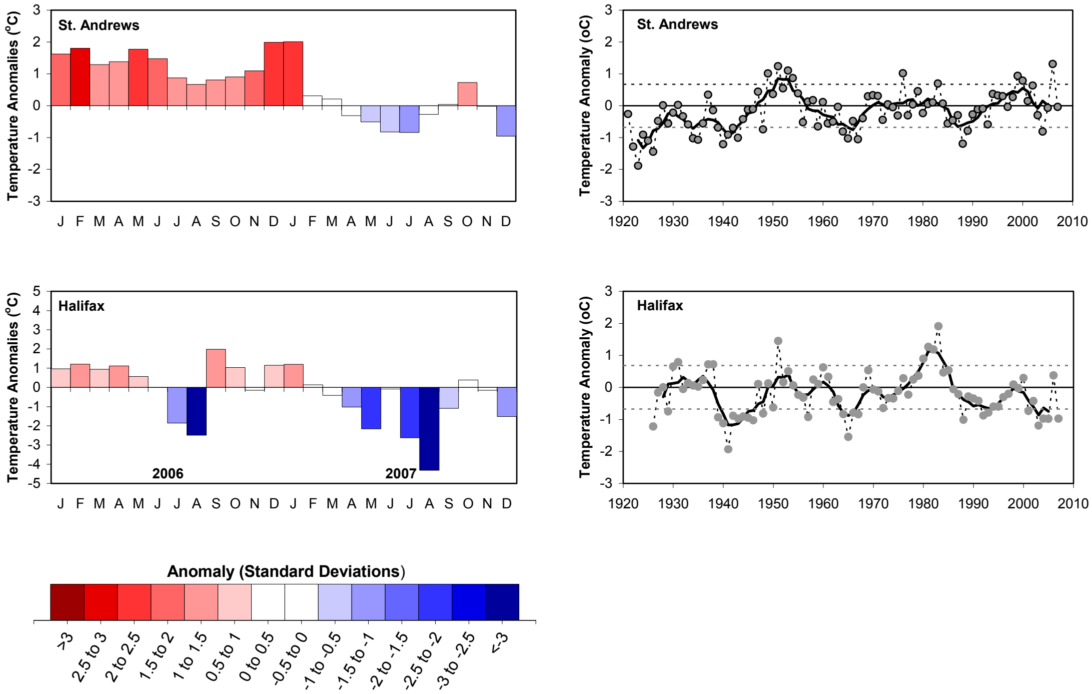


Fig. 2. The monthly sea surface temperature anomalies during 2006 and 2007 (left) and the annual temperature anomalies (dashed line with dots) and their 5-year running means (heavy black line, right) for St. Andrews and Halifax Harbour. Anomalies are relative to the 1971-2000 means. The anomalies in the bar charts are colour coded in terms of the number of standard deviations above or below normal values. The times series chart shows dashed horizontal lines at ±1 standard deviation.

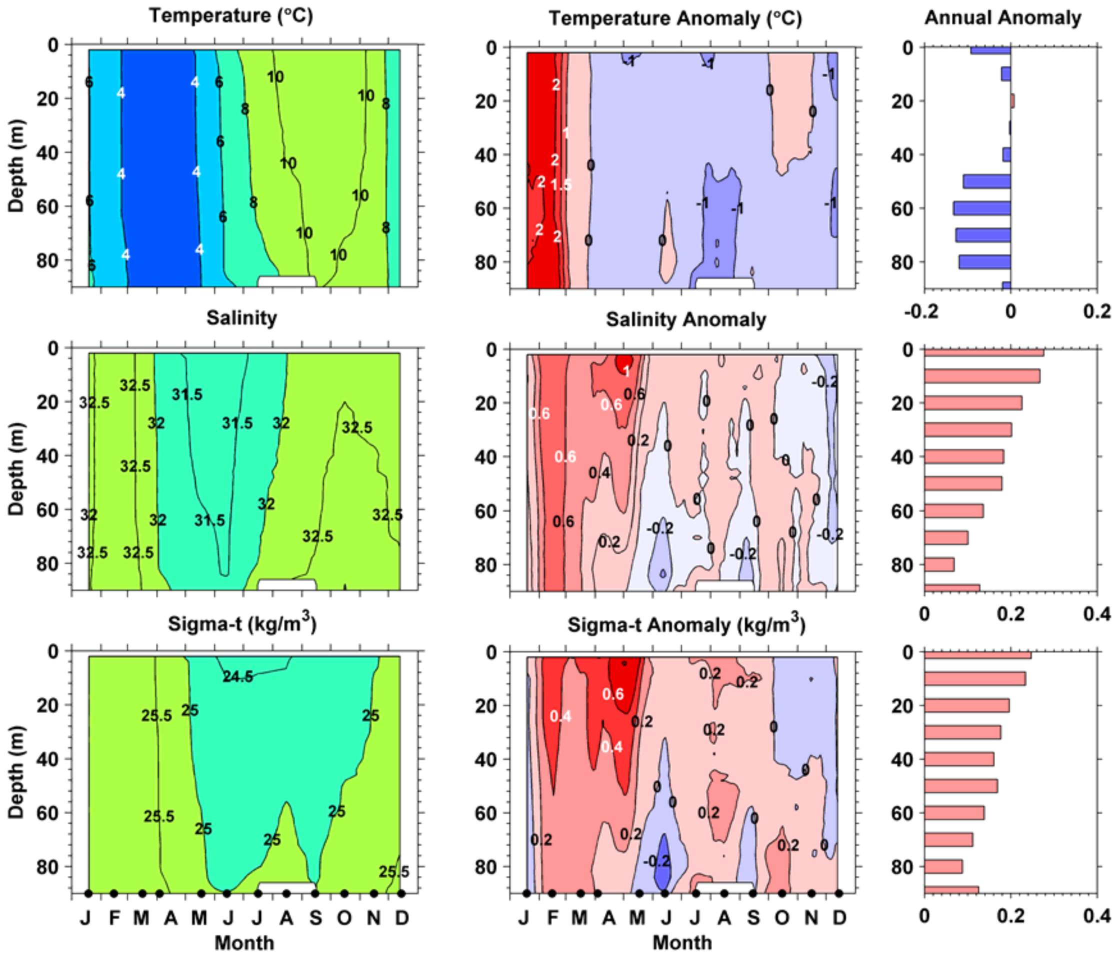


Fig. 3. Contours of temperature, salinity and sigma-t and their anomalies for the Prince 5 fixed station as a function of depth during 2007 relative to the 1971-2000 means. Blue (red) indicates below (above) normal anomalies. The bar chart shows the annual anomalies.

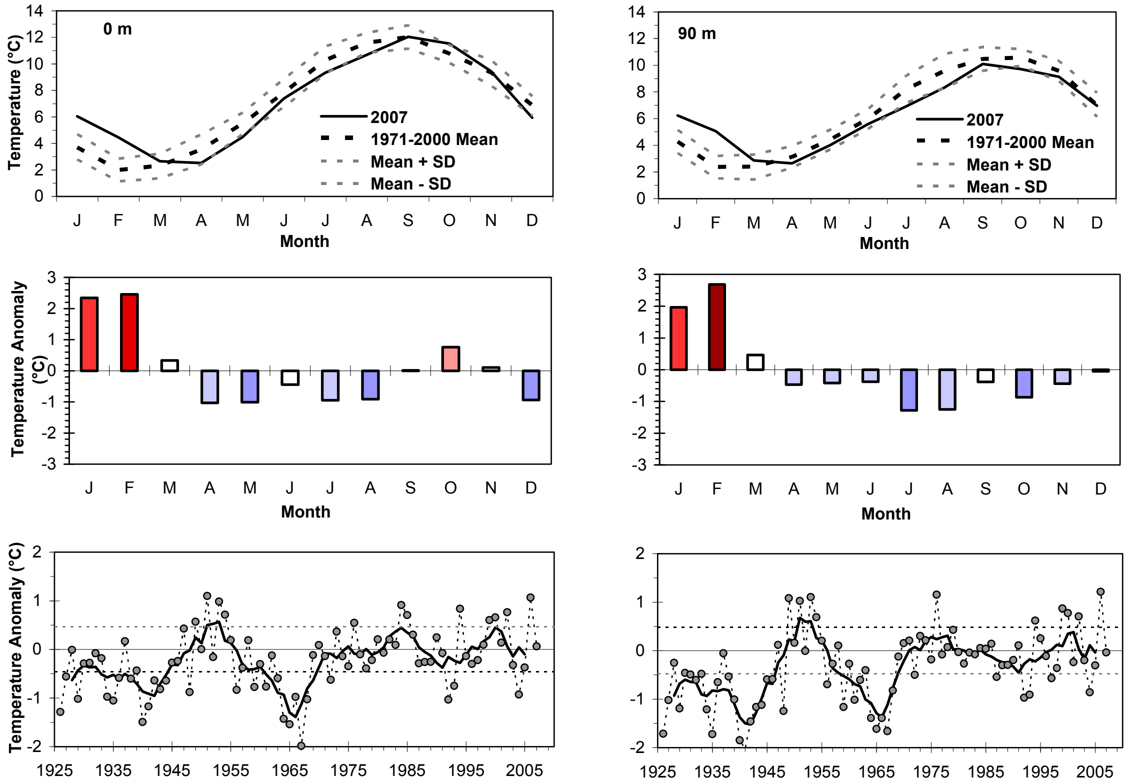


Fig. 4. The monthly mean temperatures for Prince 5 in 2007 (solid line; top panels) and their long-term means and ±1 standard deviation (black, grey dashed lines; top panels), the monthly anomalies relative to the long-term means for 1971-2000 (middle panels, colour coded as in Fig. 2). The bottom panels are the time series of the annual means (dashed lines with dots) and their 5-year running means (solid line), 0 m (left) and 90 m (right). The dashed horizontal lines indicate ±1 standard deviation.

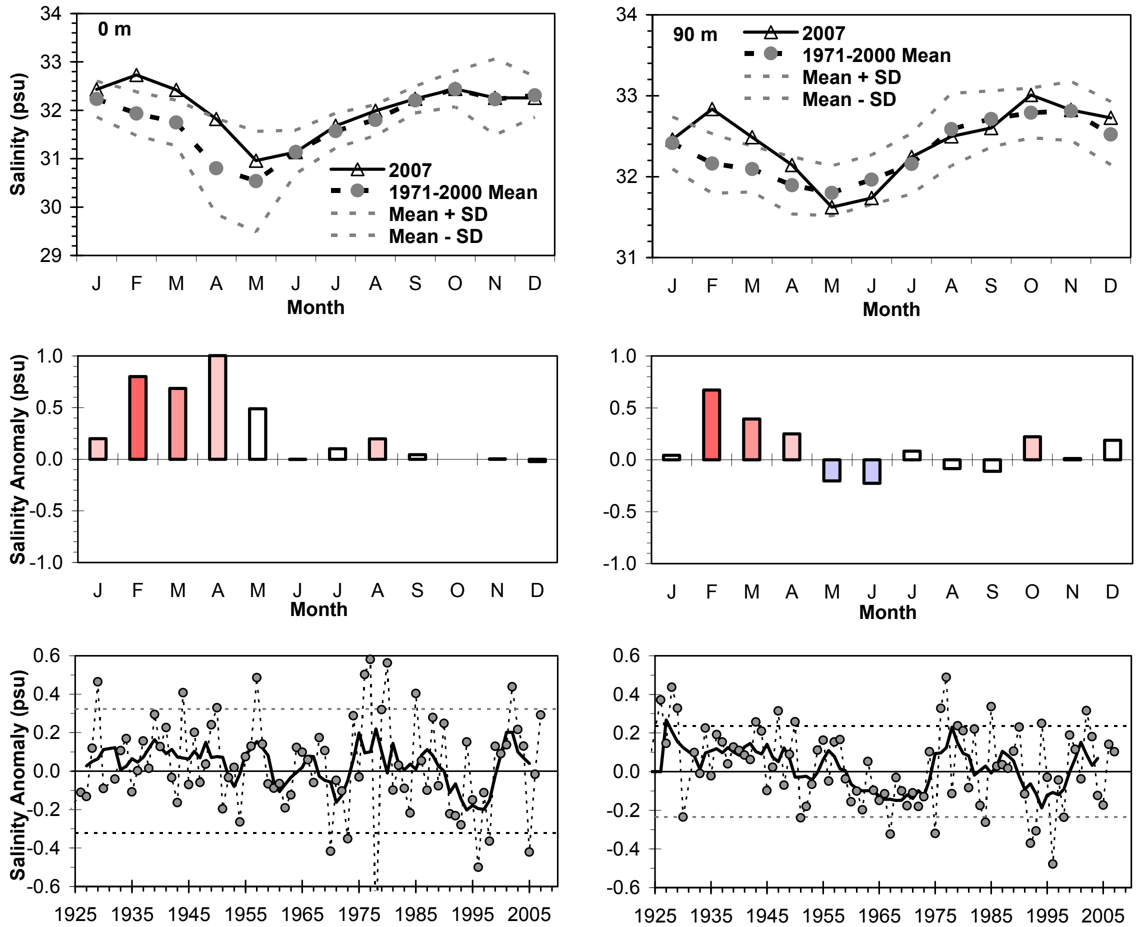


Fig. 5. The monthly mean salinities for Prince 5 in 2007 (solid line; top panels) and their long-term means and ±1 standard deviation (black, grey dashed lines; top panels), the monthly anomalies relative to the long-term means for 1971-2000 (middle panels, colour coded as in Fig. 2). The bottom panels are the time series of the annual means (dashed lines with dots) and their 5-year running means (solid line), 0 m (left) and 90 m (right). The dashed horizontal lines indicate ±1 standard deviation.

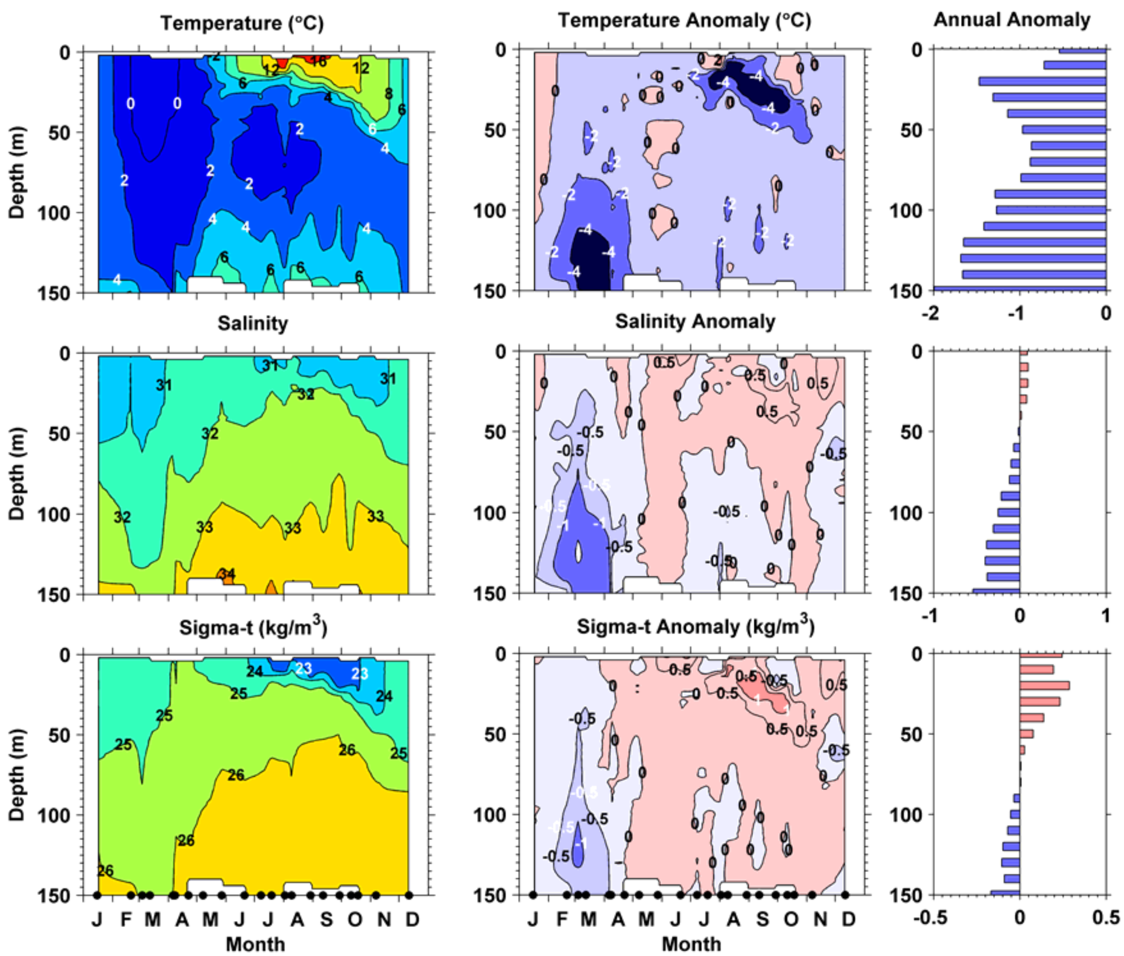
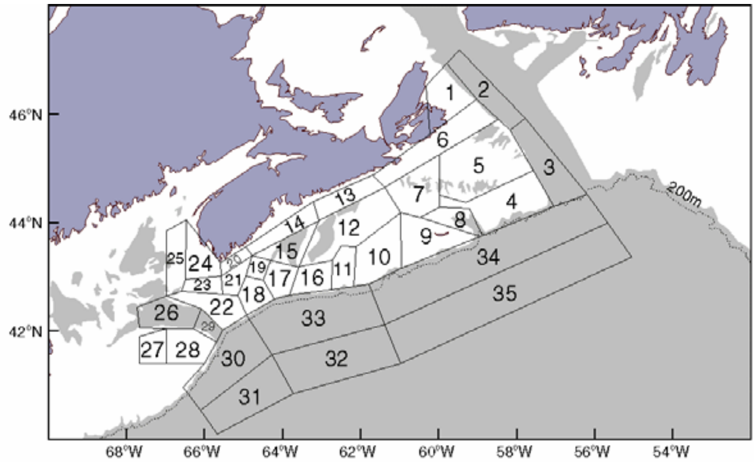


Fig. 6. Contours of the 2007 temperature, salinity and density (sigma-t) (left) and their anomalies (right) for the AZMP fixed station, Halifax Section Station 2. Blue (red) indicates below (above) normal anomalies. The bar chart shows the annual anomalies.



1. Sydney Bight
2. N. Laurentian Channel
3. S. Laurentian Channel
4. Banquereau
5. Misaine Bank
6. Canso
7. Middle Bank
8. The Gully
9. Sable Island
10. Western Bank
11. Emerald Bank
12. Emerald Basin
13. Eastern Shore
14. South Shore
15. Lahave Basin
16. Saddle
17. Lahave Bank
18. Baccaro Bank
19. Roseway Bank
20. Shelburne
21. Roseway Basin
22. Browns Bank
23. Roseway Channel
24. Lurcher Shoals
25. E. Gulf of Maine
26. Georges Basin
27. Georges Shoal
28. E. Georges Bank
29. N.E. Channel
30. Southern Slope
31. Southern Offshore
32. Central Offshore
33. Central Slope
34. Northern Slope
35. Northern Offshore

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

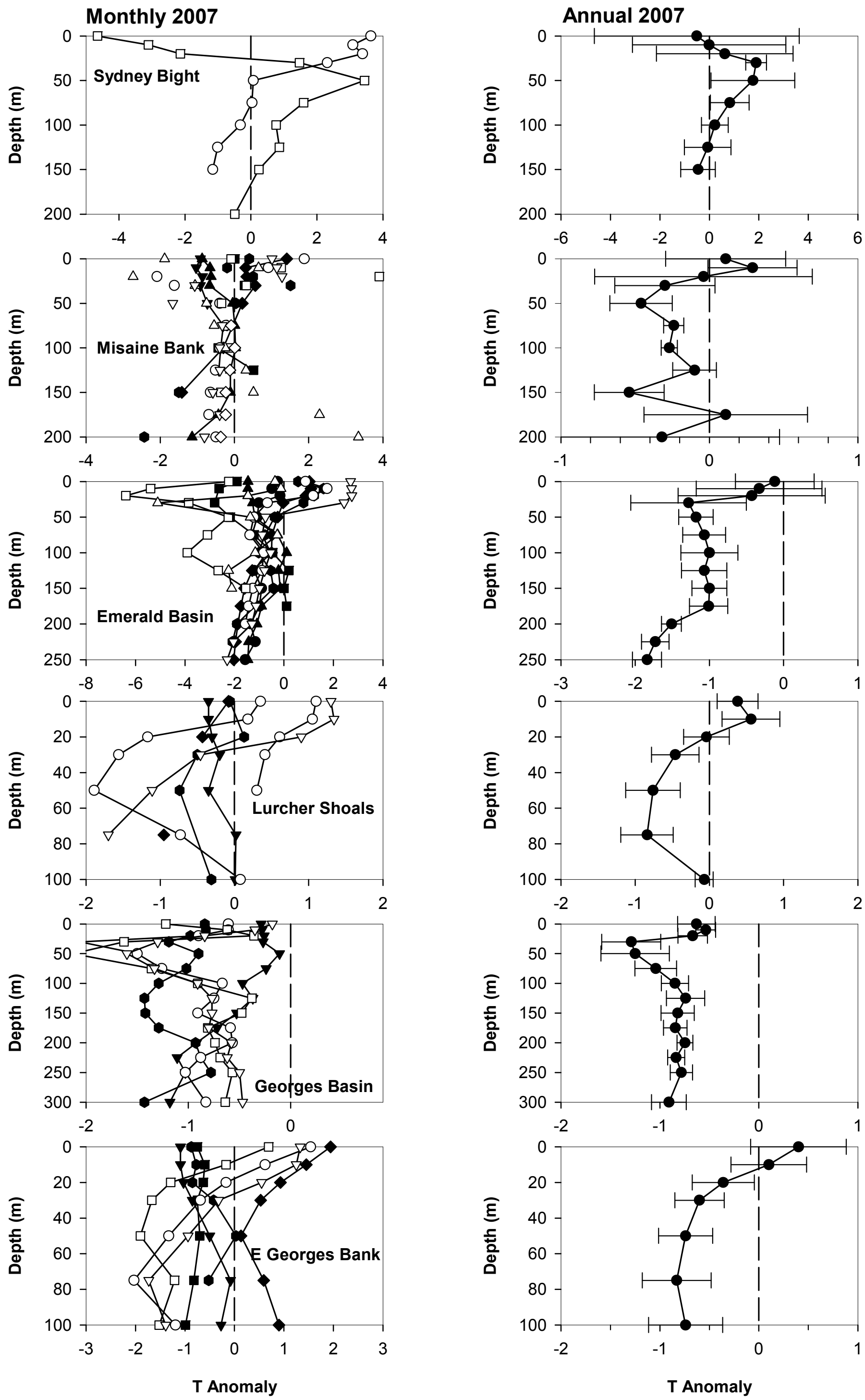


Fig. 8. Monthly (left) and annual (±std. error, right) 2007 temperature anomaly profiles for selected locations. Symbol order for monthly profiles is filled dot, square, up triangle, down triangle, diamond, hexagon for January-June,, then open symbols in the same order for July-December.

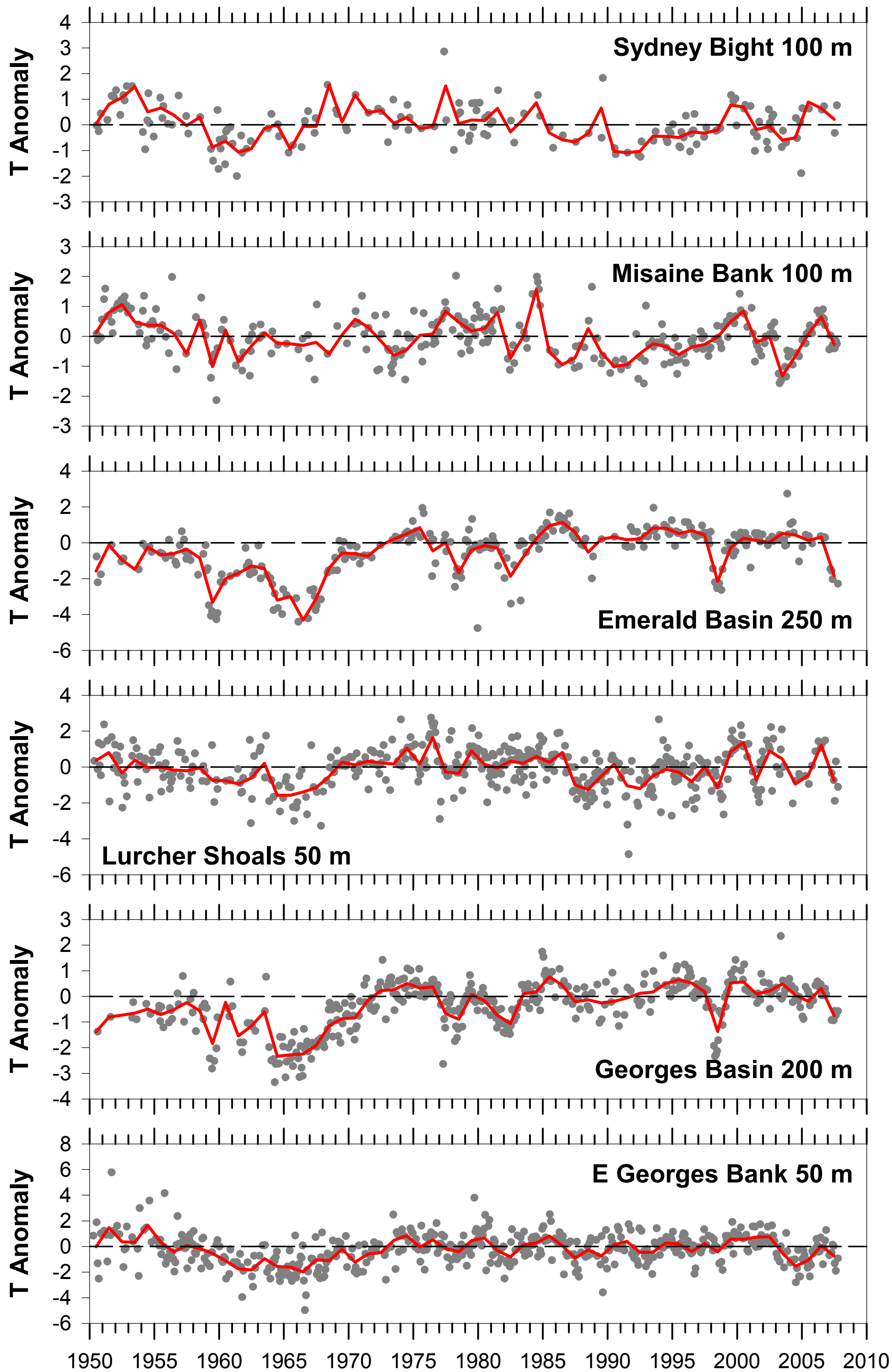


Fig. 9. The monthly mean temperature anomaly time series (grey dots) and the estimated annual anomalies (solid line) at 6 sites on the Scotian Shelf and in the Gulf of Maine (see Fig. 7).

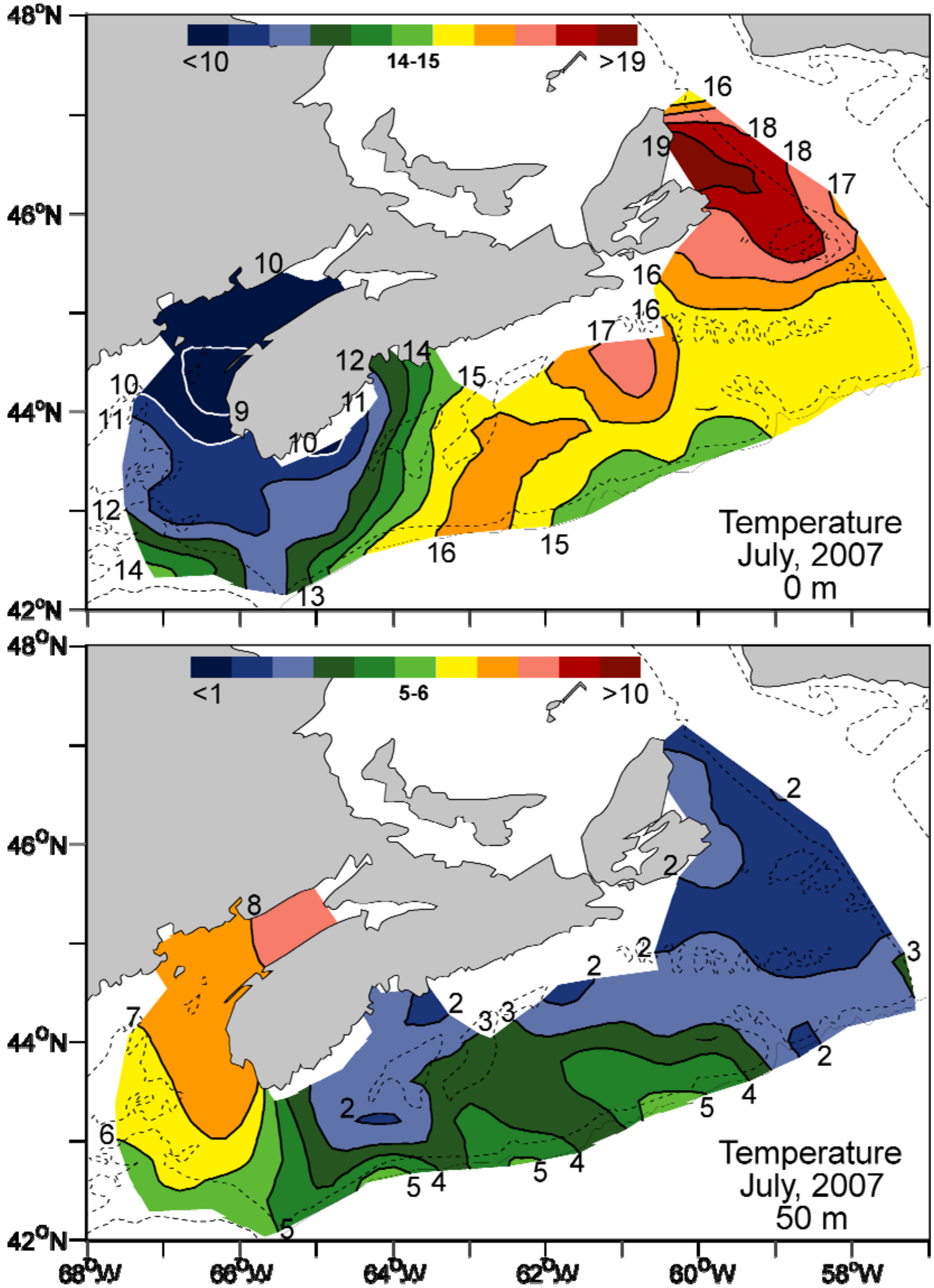


Fig.10a. Contours of temperatures at the surface (top panel) and 50 m (bottom panel) during the 2007 July groundfish and ITQ surveys.

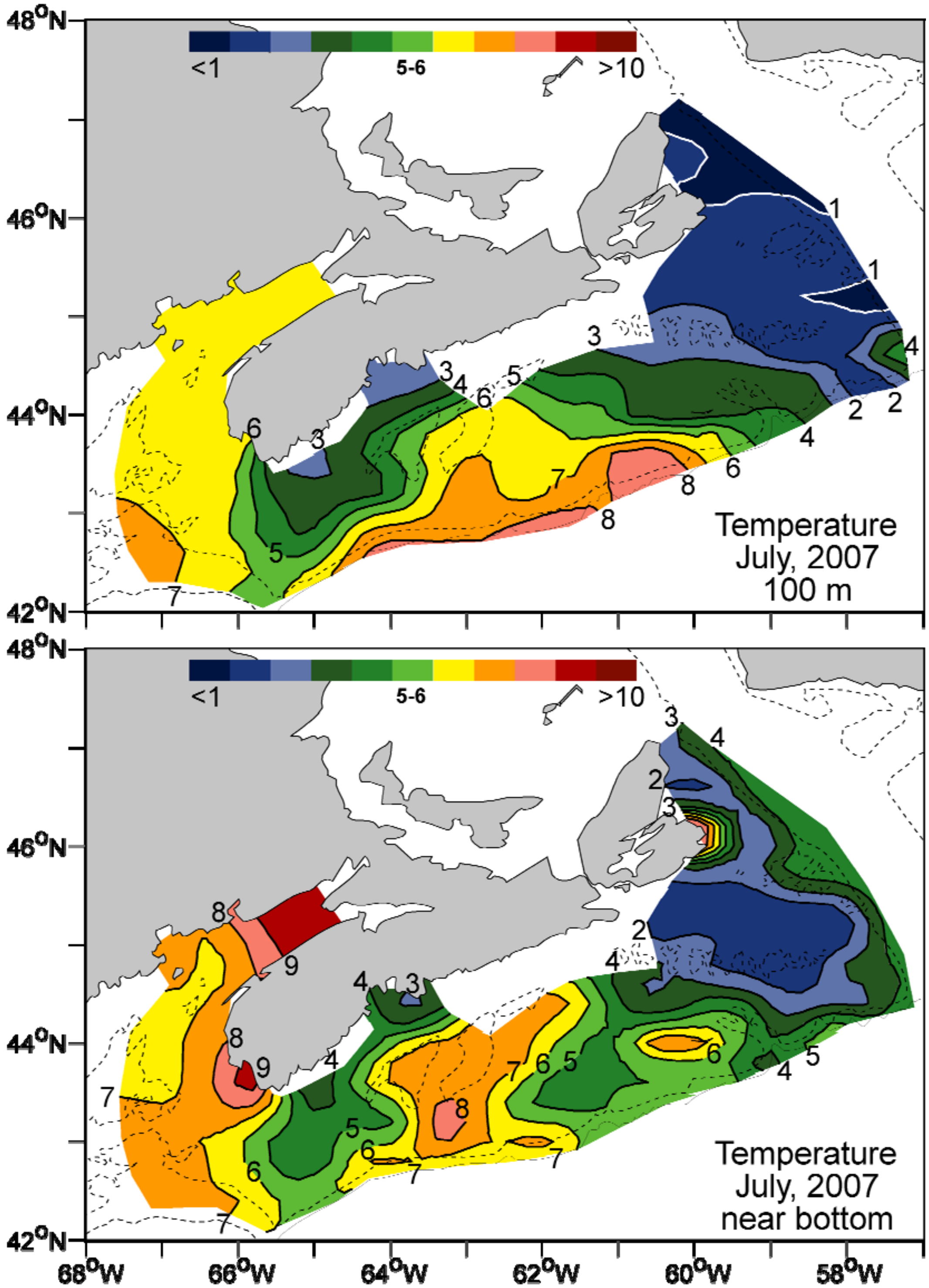


Fig. 10b. Contours of temperatures at 100 m (top panel) and near bottom (bottom panel) during the 2007 July groundfish and ITQ surveys.

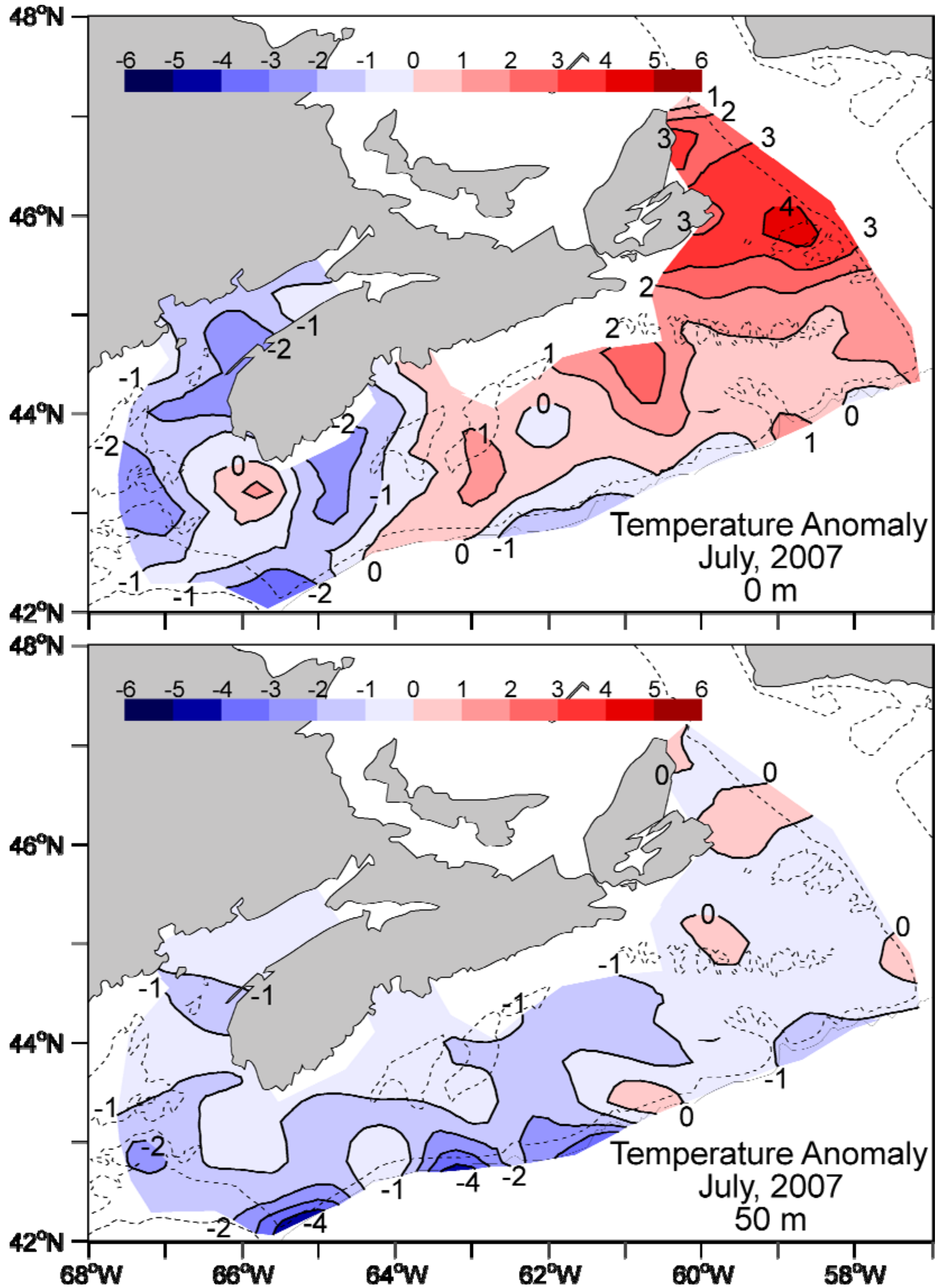


Fig. 11a. Contours of temperature anomalies at the surface (top panel) and 50 m (bottom panel) during the 2007 July groundfish and ITQ surveys.

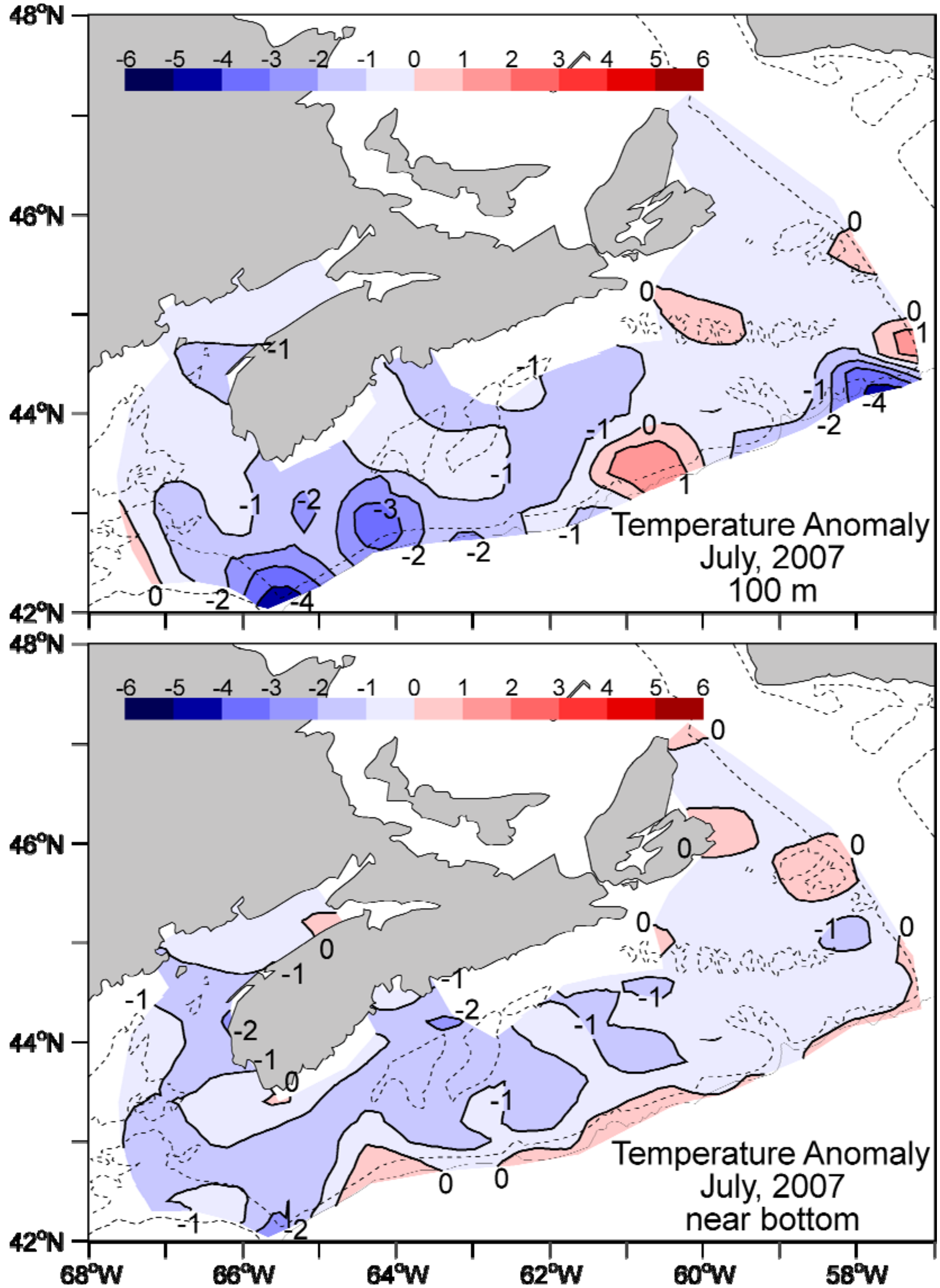
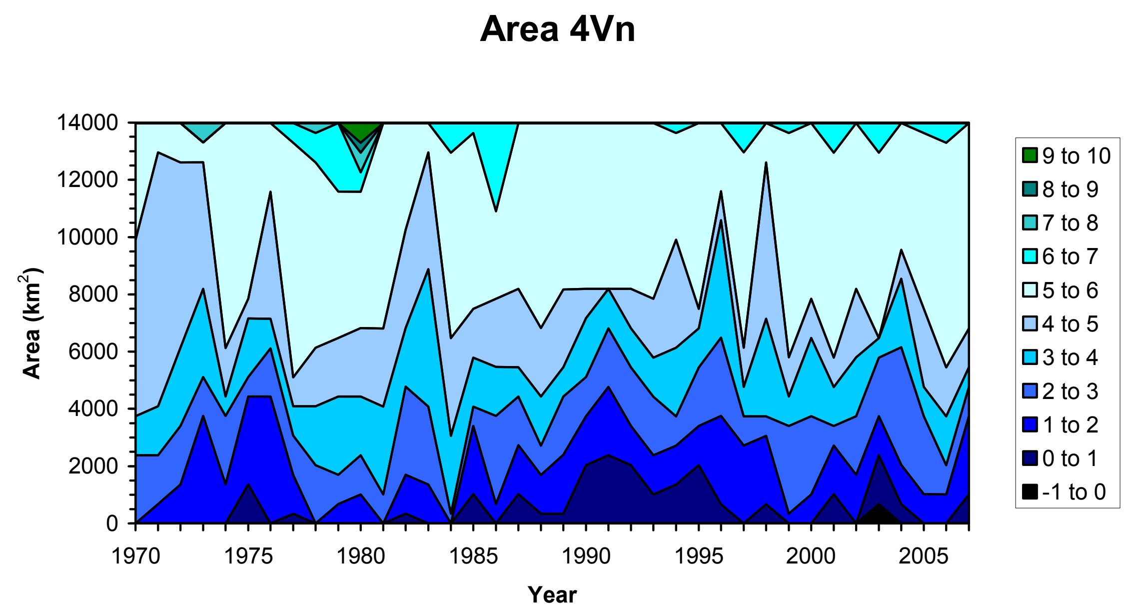


Fig. 11b. Contours of temperature anomalies at 100 m (top panel) and near bottom (bottom panel) during the 2007 July groundfish and ITQ surveys.



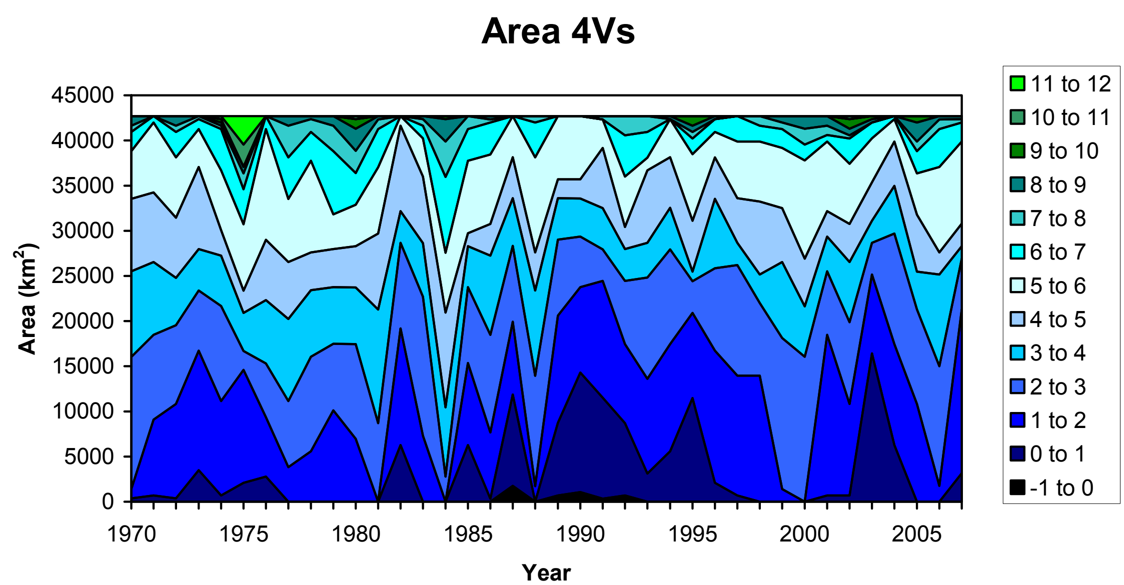


Fig. 12a. The time series of the area of the bottom for each 1°C temperature range for NAFO Subareas 4Vn (top panel) and 4Vs (bottom panel).

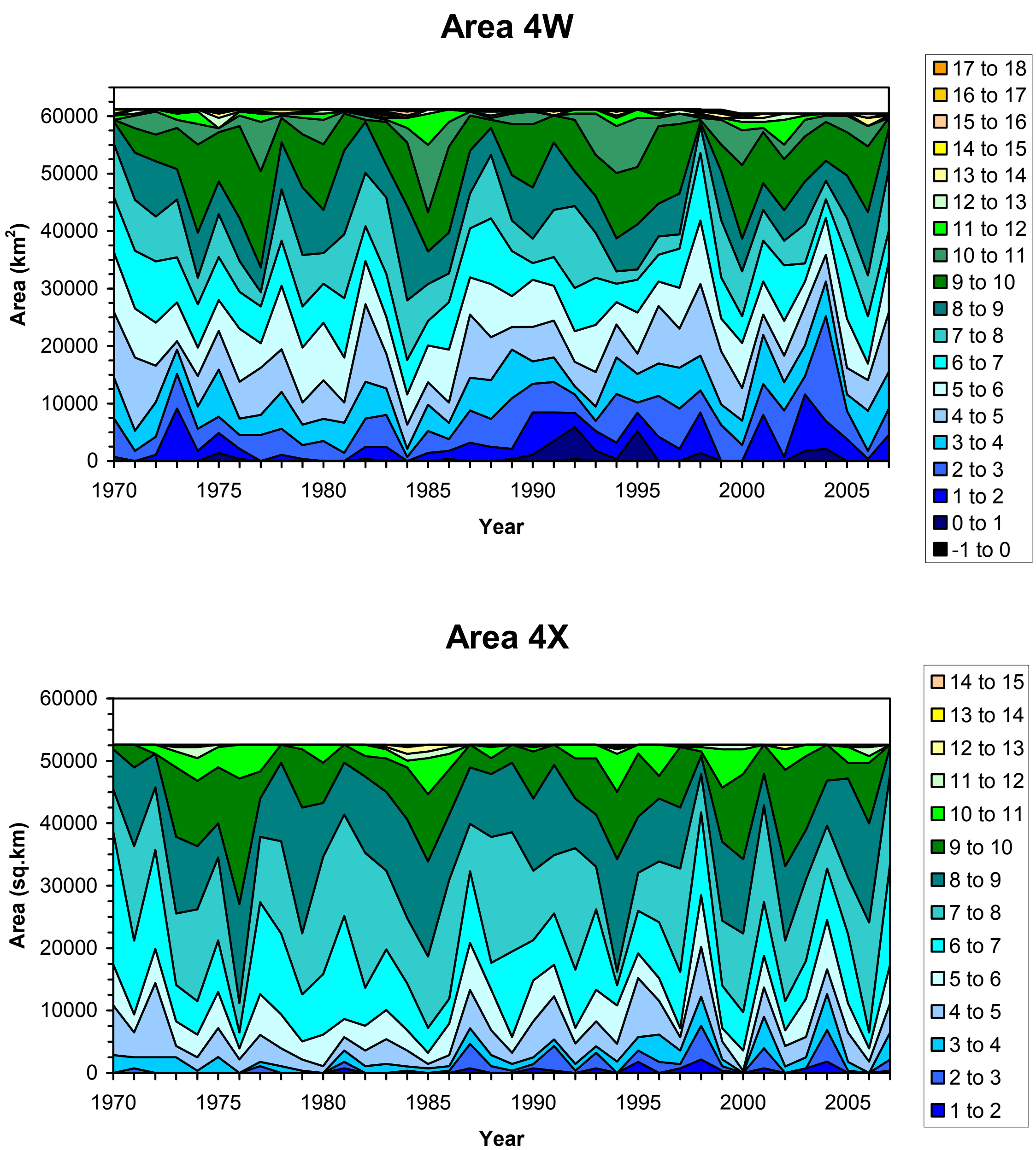


Fig. 12b. The time series of the area of the bottom for each 1°C temperature range for NAFO Subareas 4W (top panel) and 4X (bottom panel).

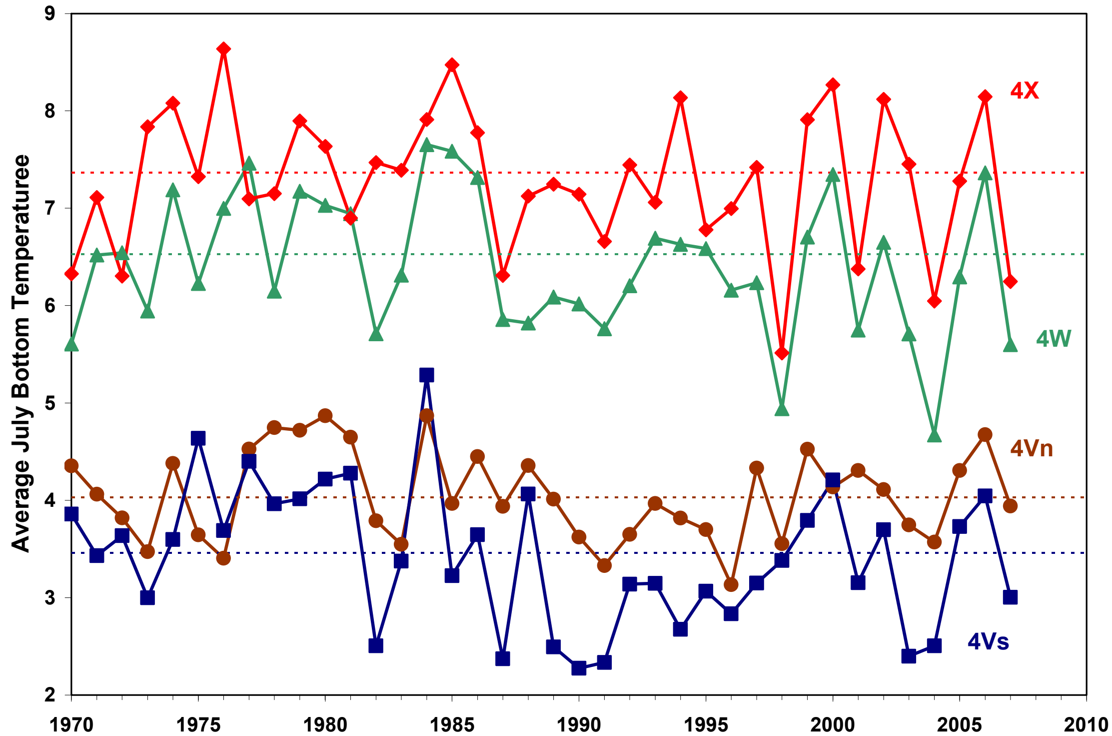


Fig. 13a. Time series of annual mean bottom temperatures from areas 4Vn, 4Vs, 4W and 4X. The horizontal lines are the 1971-2000 means.

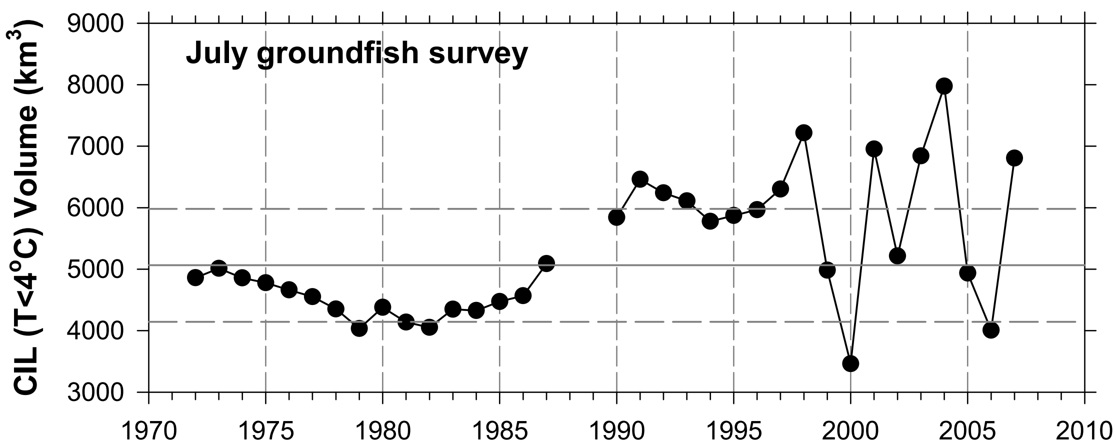


Fig. 13b. Time series of the Cold Intermediate Layer (CIL) volume on the Scotian Shelf based on the July groundfish survey. The solid horizontal line is the long-term mean, the dashed horizontal lines are the mean ± SD.

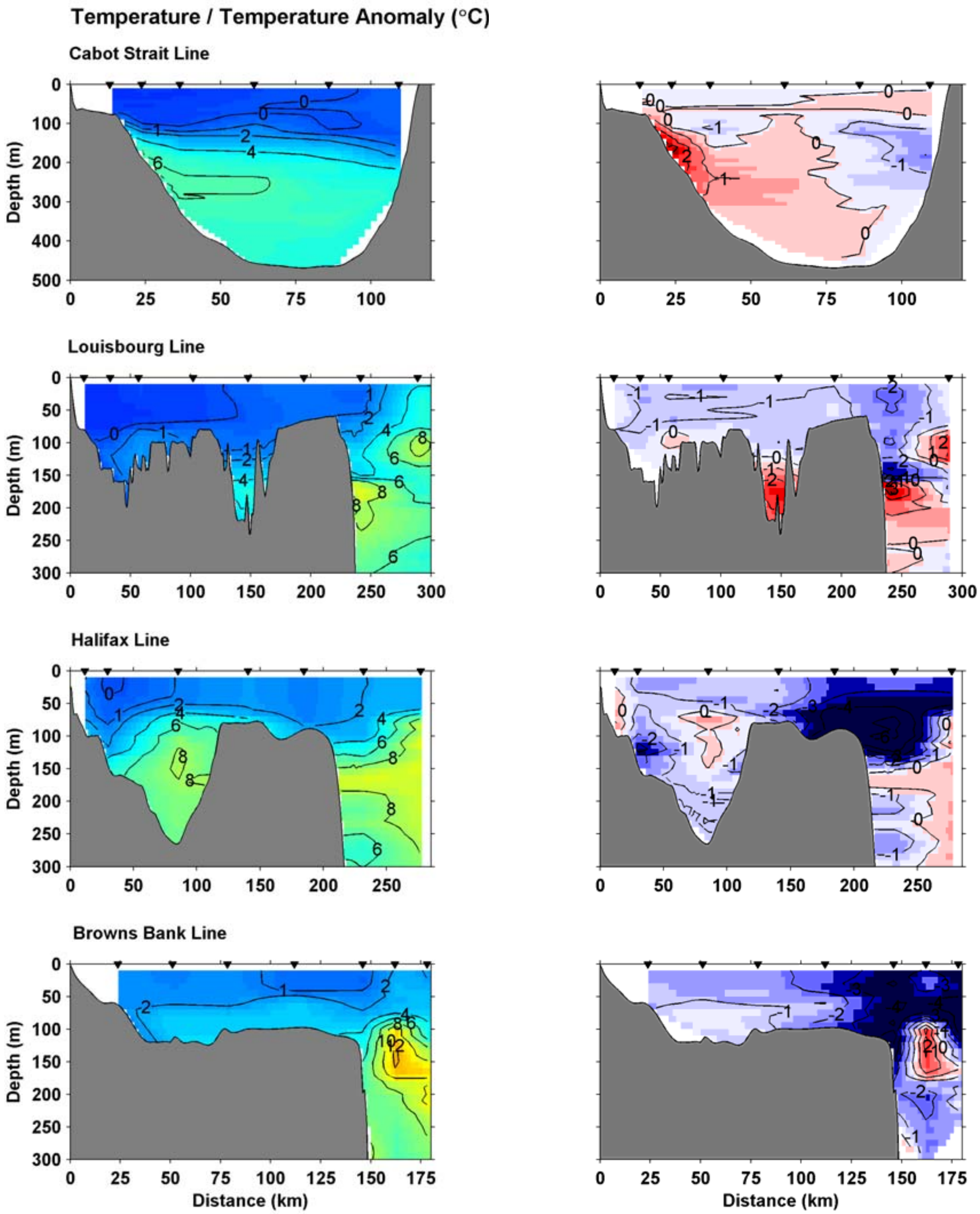


Fig. 14a. Temperature and temperature anomalies for standard Scotian Shelf sections, April 2007.

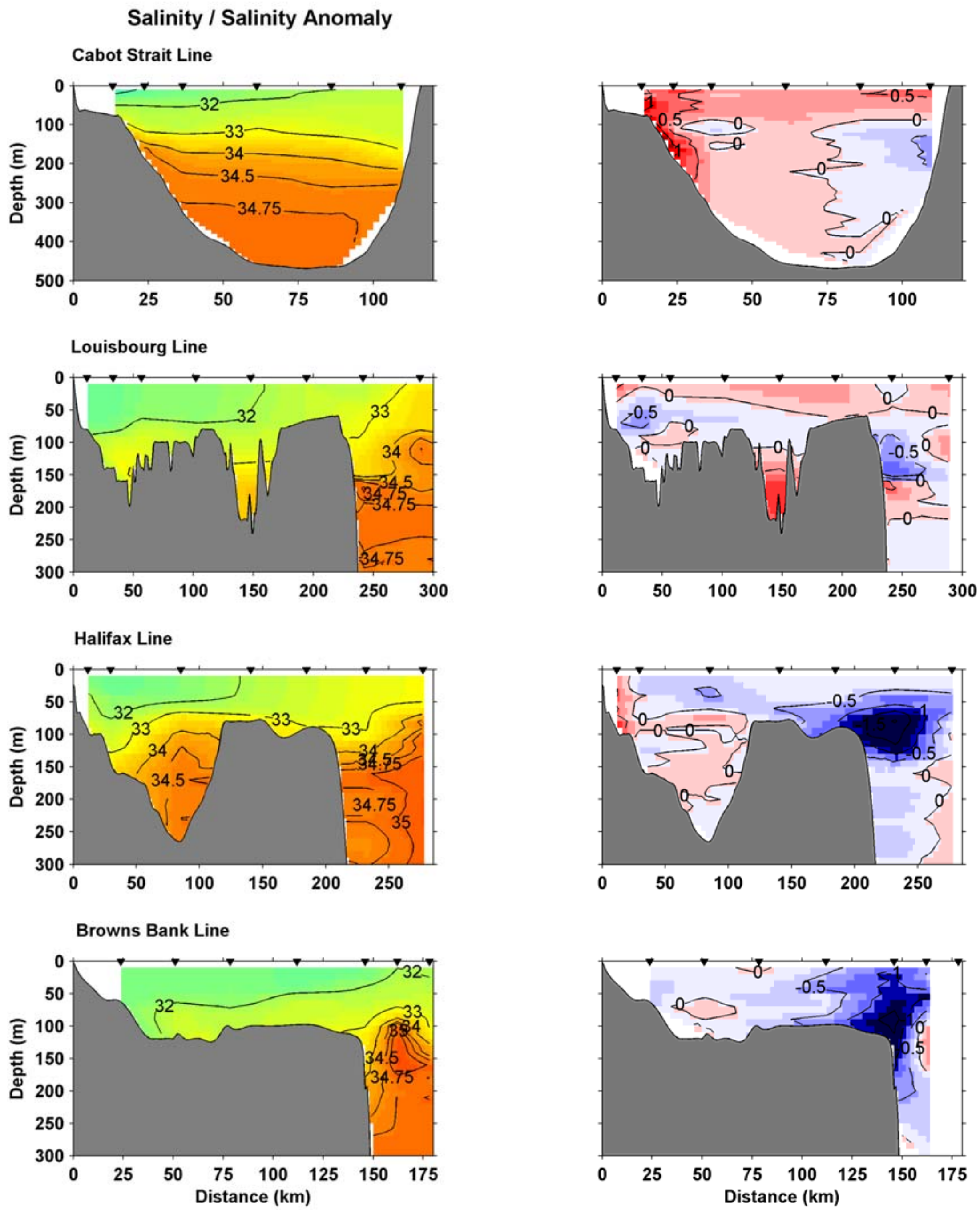


Fig. 14b. Salinity and salinity anomalies for standard Scotian Shelf sections, April 2007.

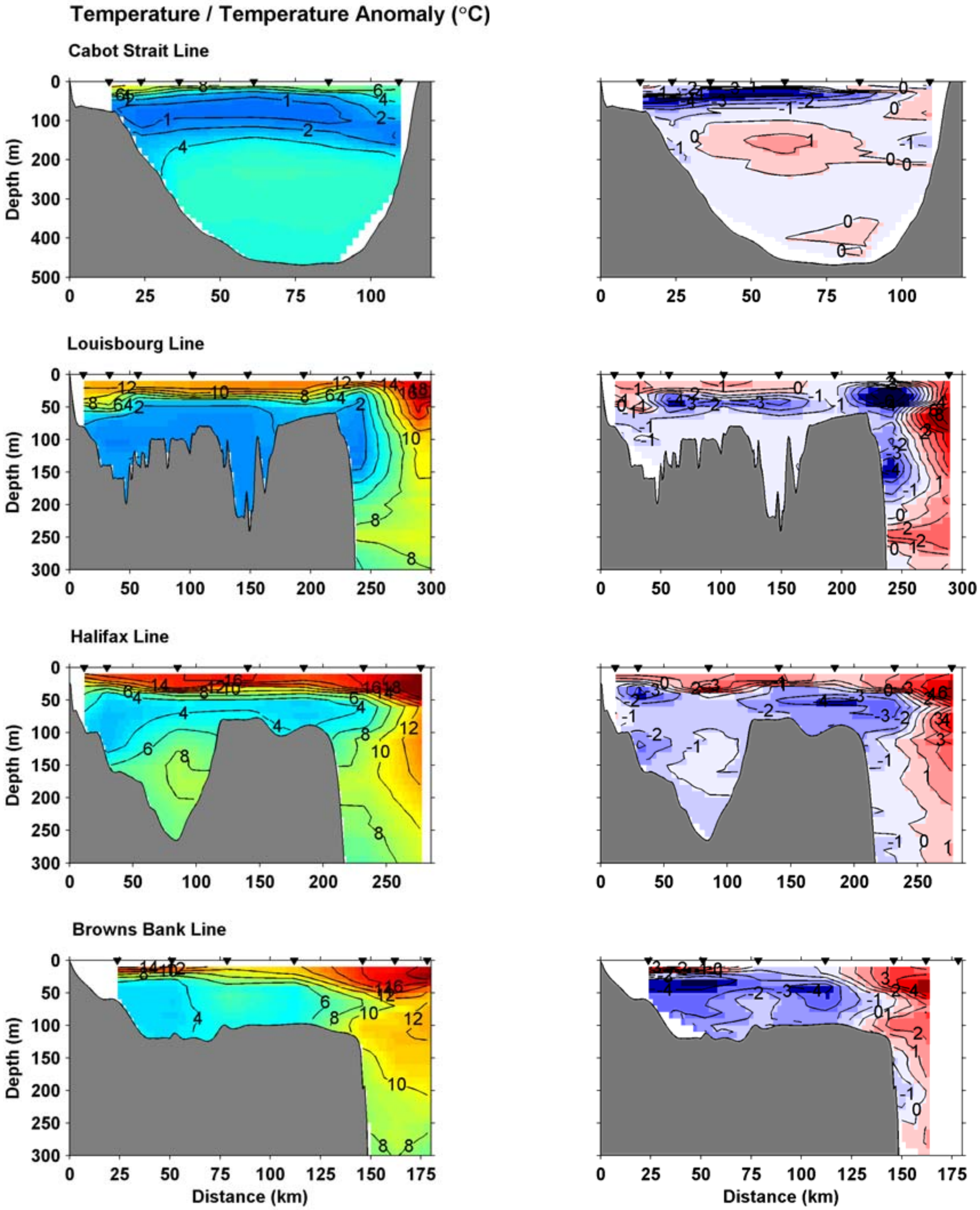


Fig. 14c. Temperature and temperature anomalies for standard Scotian Shelf sections, October 2007.

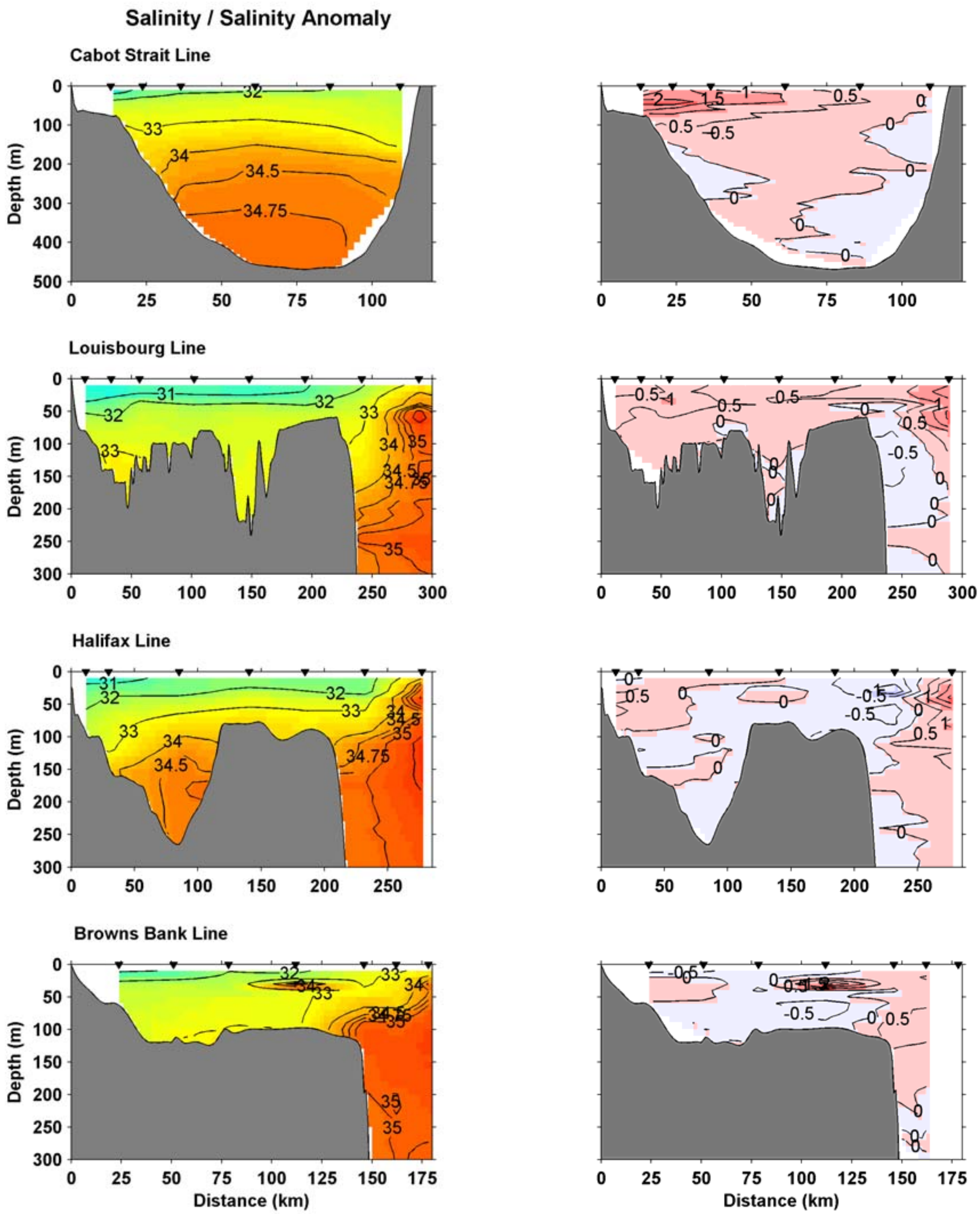


Fig. 14d. Salinity and salinity anomalies for standard Scotian Shelf sections, October 2007.

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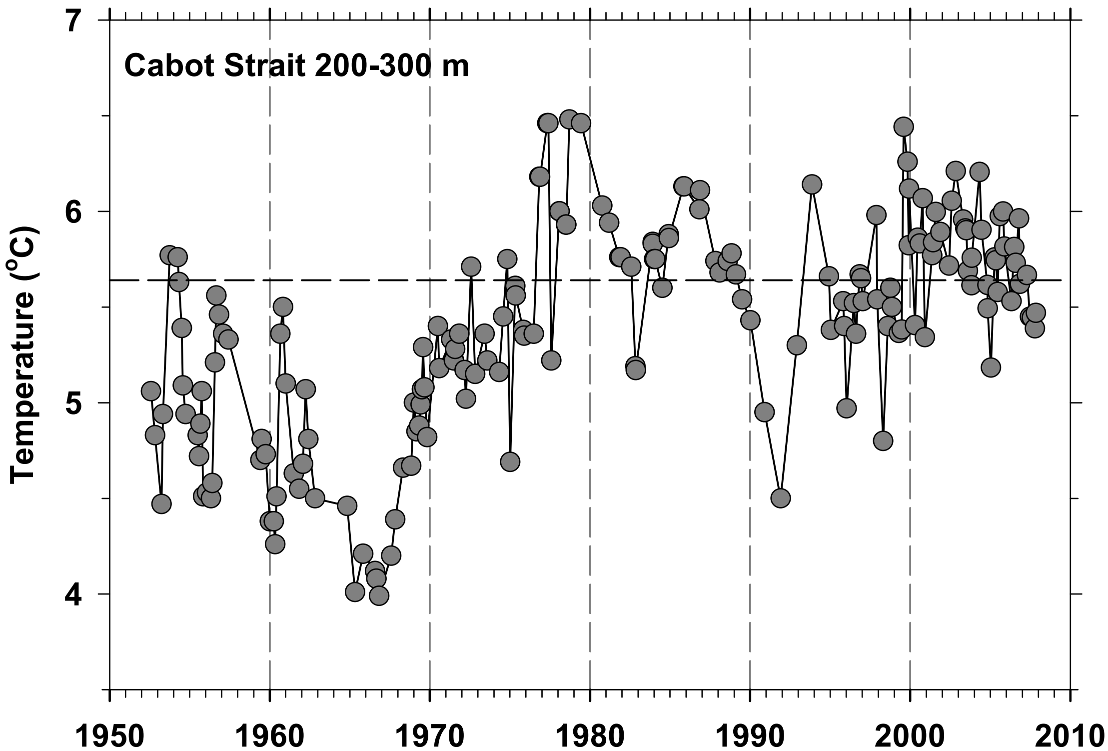


Fig. 15. Average temperature over the 200-300 m layer in Cabot Strait. Points are from individual sections in the Strait. The horizontal line indicates the 1971-2000 mean.

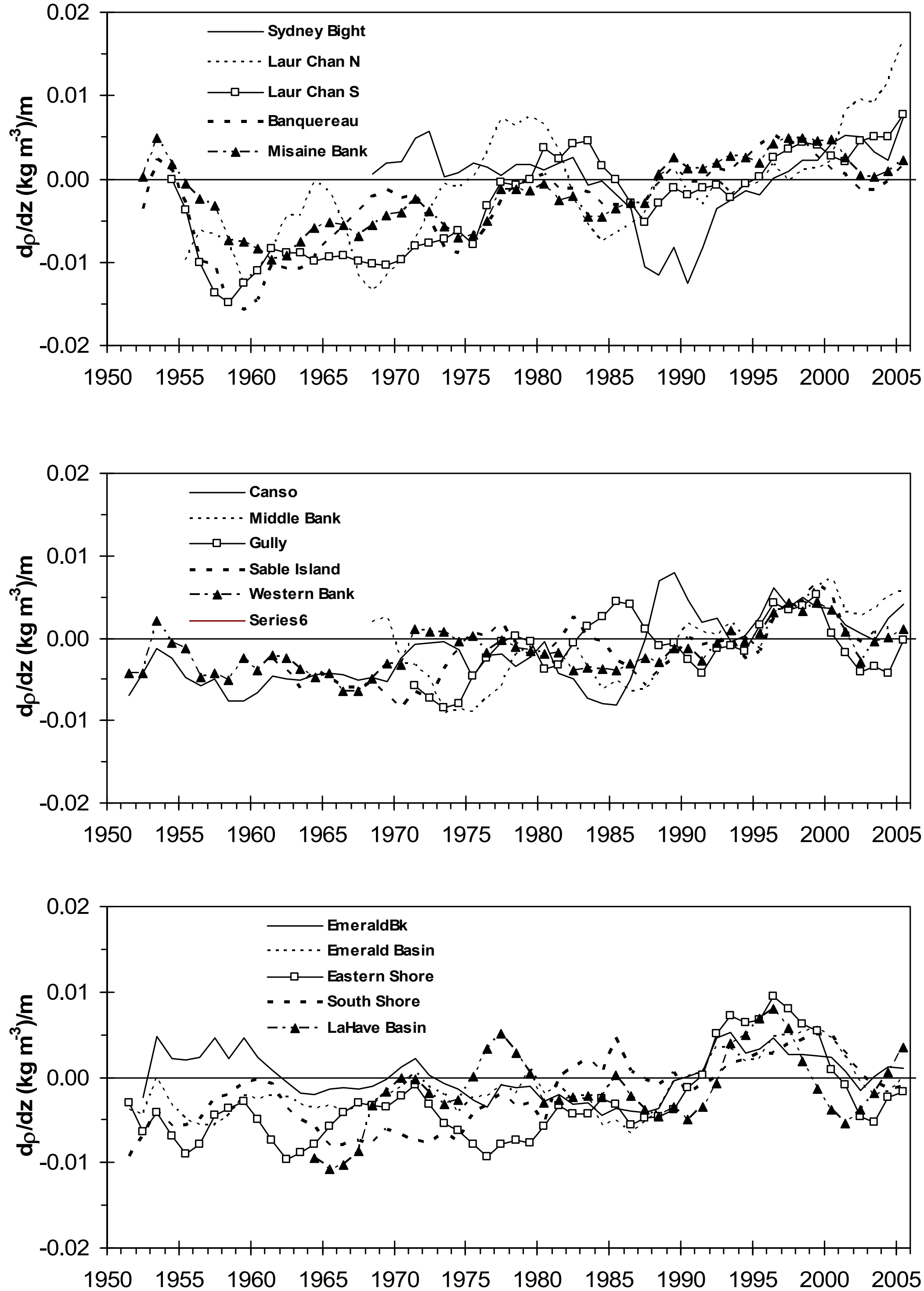


Fig. 16a. Five-year running means of the annual density gradient anomalies between the surface and 50 m calculated for the areas 1-15 in Fig. 7.

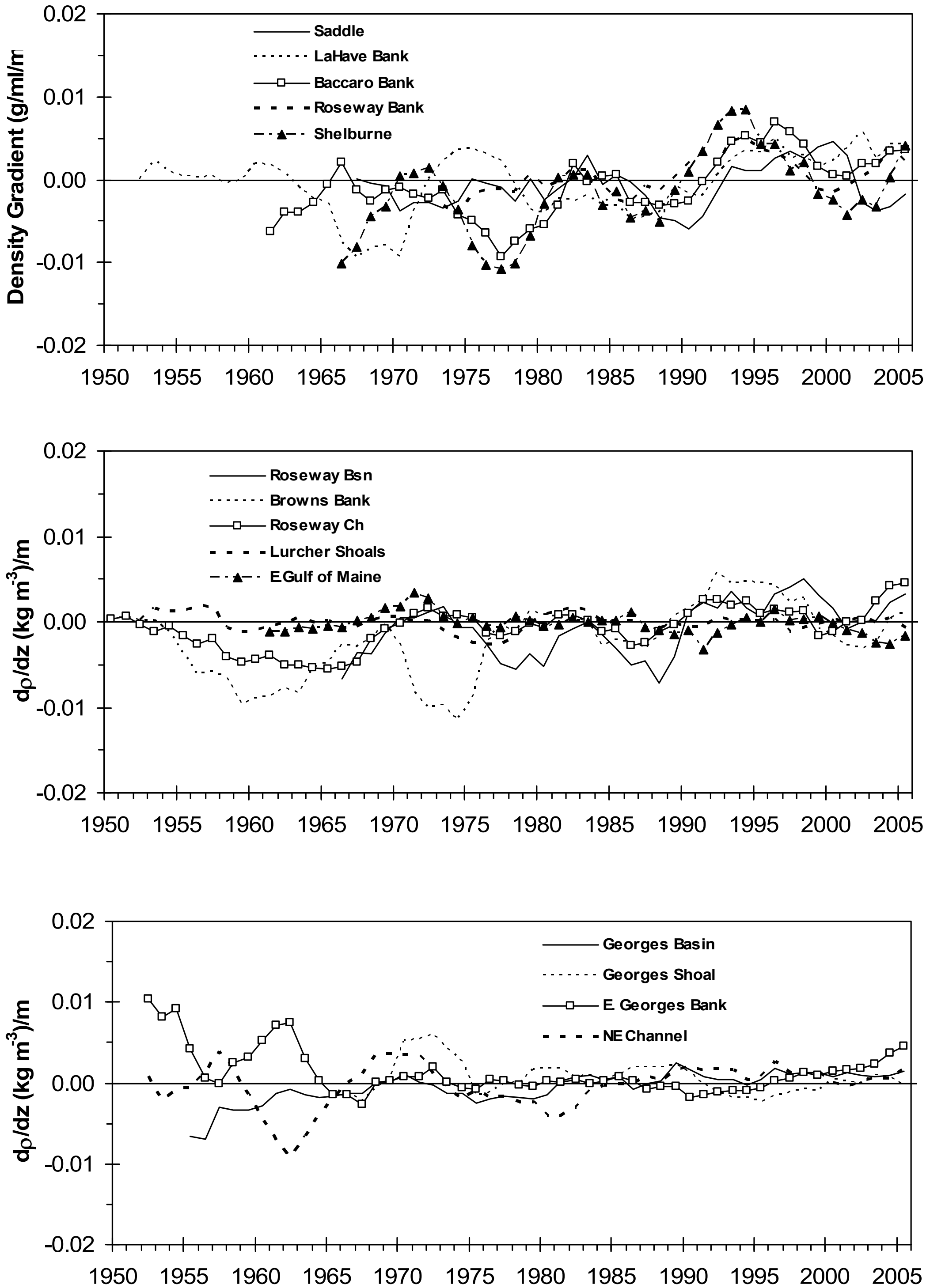


Fig. 16b. Five-year running means annual density gradient anomalies between the surface and 50 m calculated for the areas 16-29 in Fig. 7.

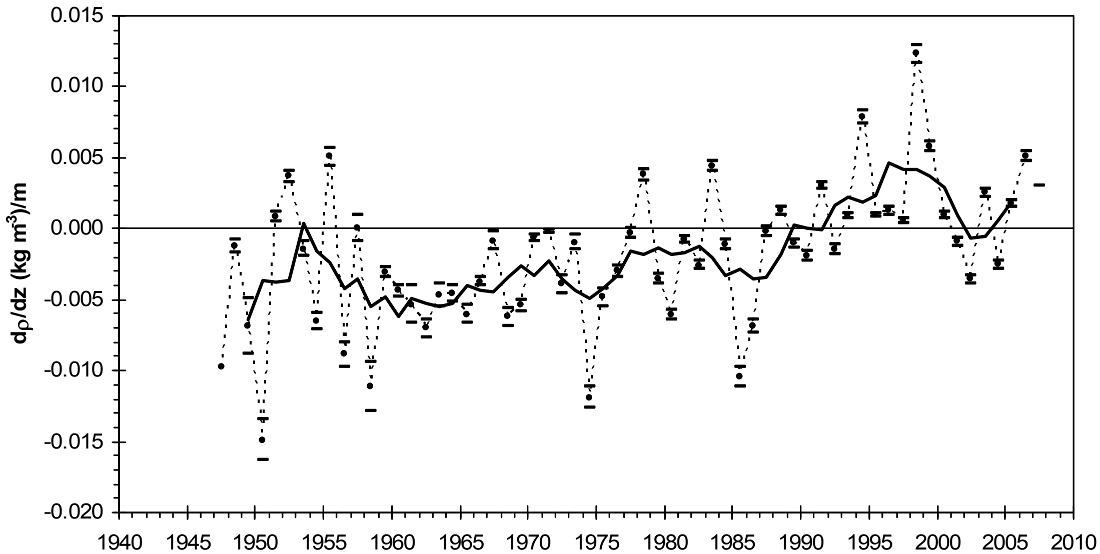


Fig. 17. The mean annual (dashed line) and 5-yr running mean (heavy solid line) of the stratification index (0-50 m density gradient) averaged over the Scotian Shelf (areas 4-23 inclusive). The short horizontal lines for each year represent the standard errors of the different areas.

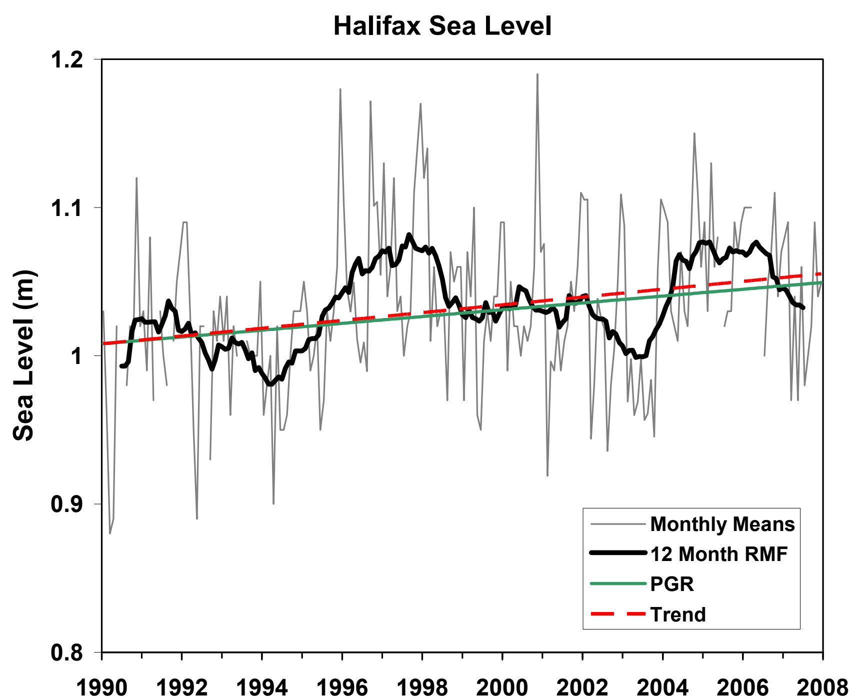
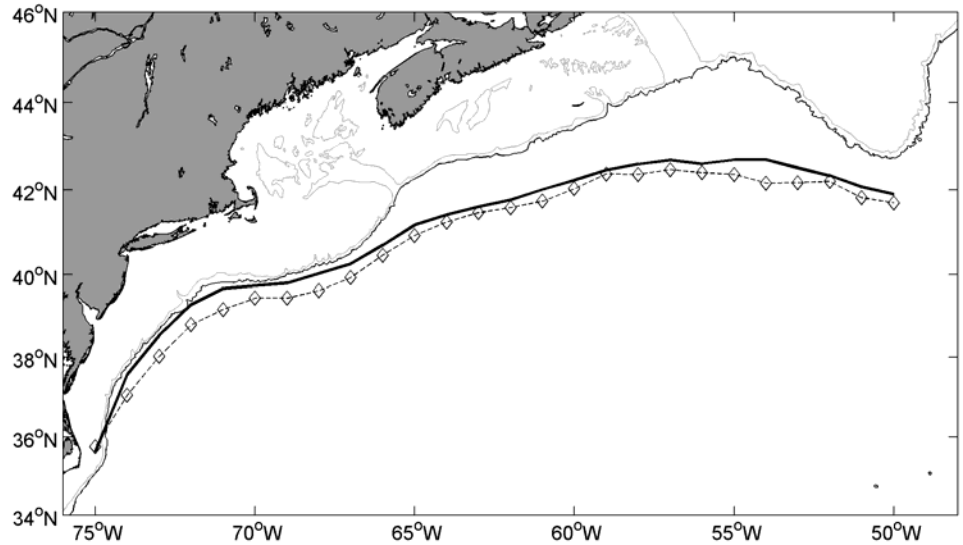


Fig. 18. The time series of the monthly means and a 12 month running mean of the sea level elevations at Halifax, along with the observed linear trend (1990-present) and that predicted by a model from post-glacial rebound (PGR).



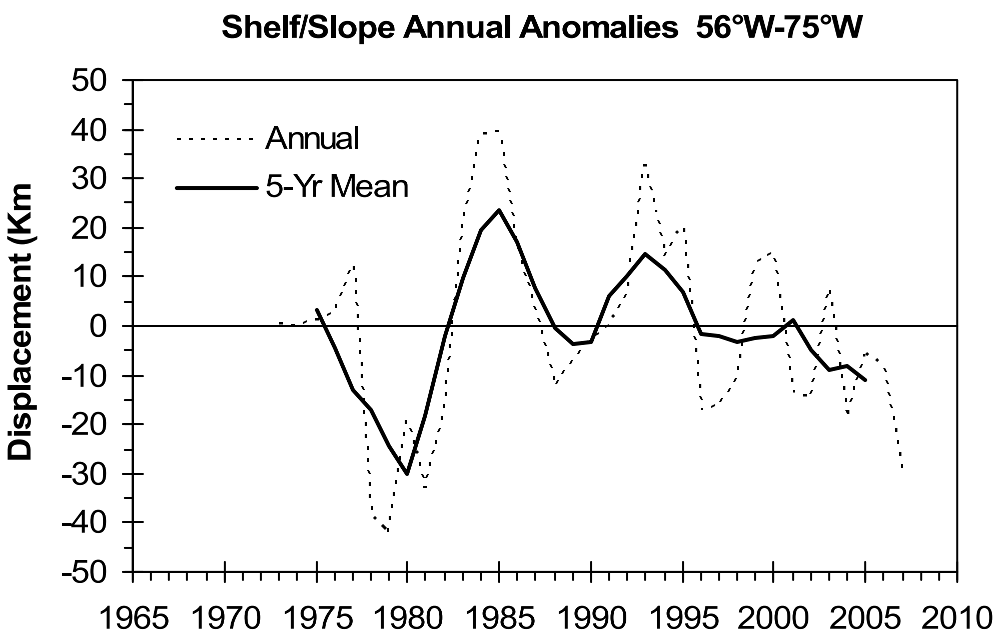


Fig. 19. The 2007 (dashed line) and long-term mean (1973-2000; solid line) positions of the shelf/slope front (top panel) and the time series of the annual anomaly of the mean (56°-75°W) position of the shelf/slope front (bottom panel).

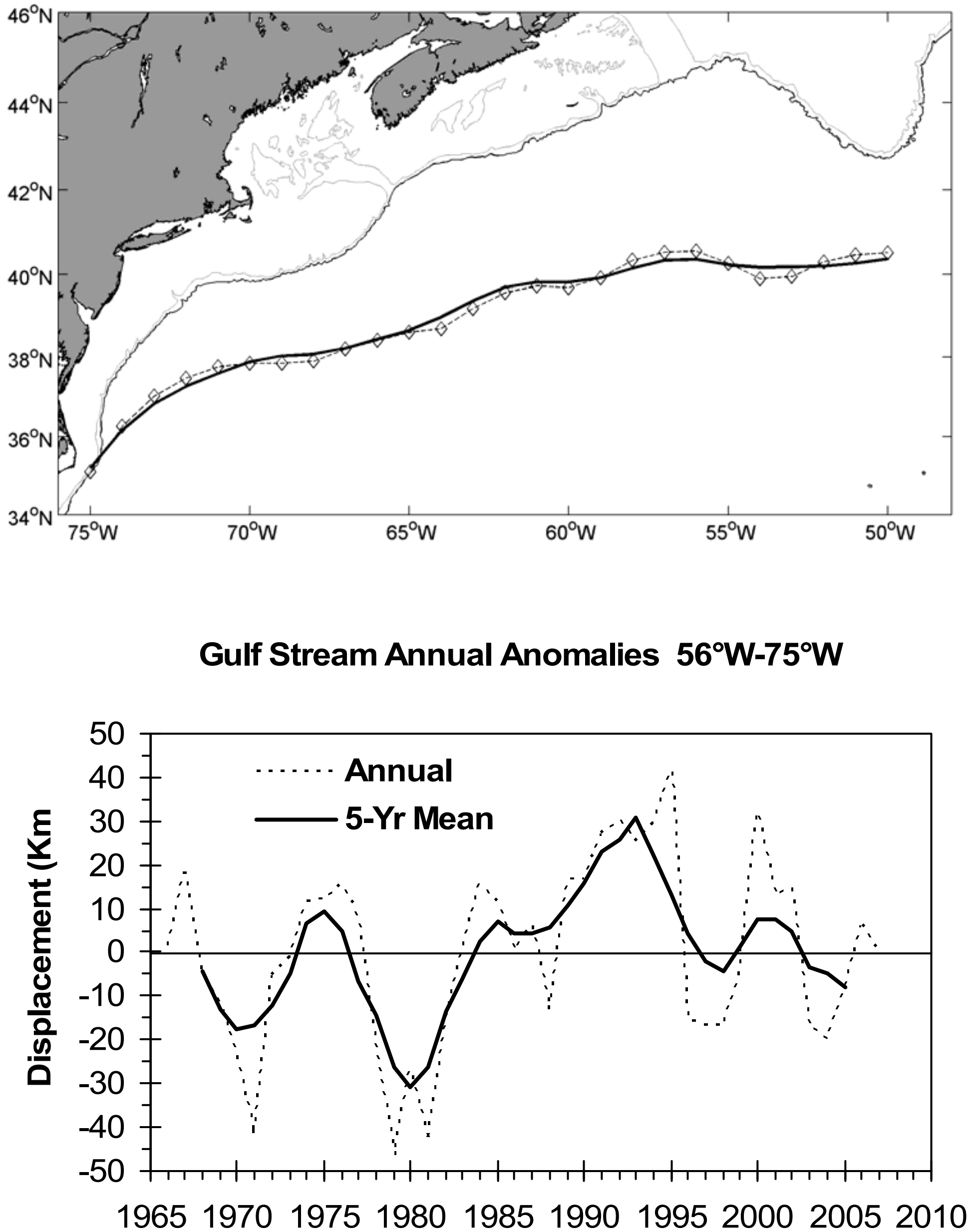


Fig. 20. The 2007 (dashed line) and long-term mean (1973-2000; solid line) positions of the northern edge of the Gulf Stream (top panel) and the time series of the annual anomaly of the mean (56°-75°W) position of the Gulf Stream front (bottom panel).

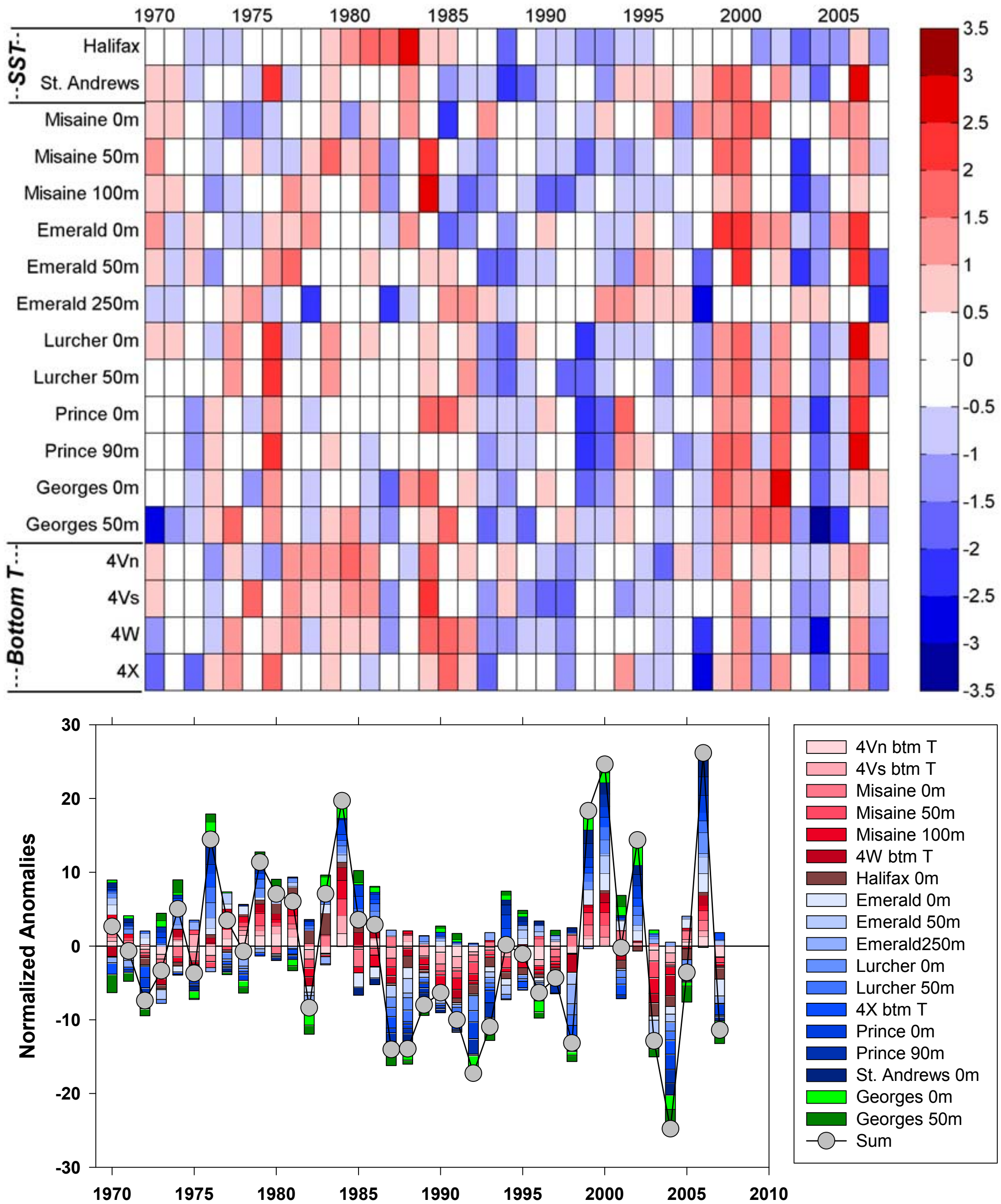


Fig. 21. Normalized annual anomalies of bottom temperatures and temperatures at discrete depths for the Scotian Shelf-Gulf of Maine region (upper panel). The normalized anomalies are the annual anomalies based on the 1971-2000 means, divided by the standard deviation. The scale represents the number 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).

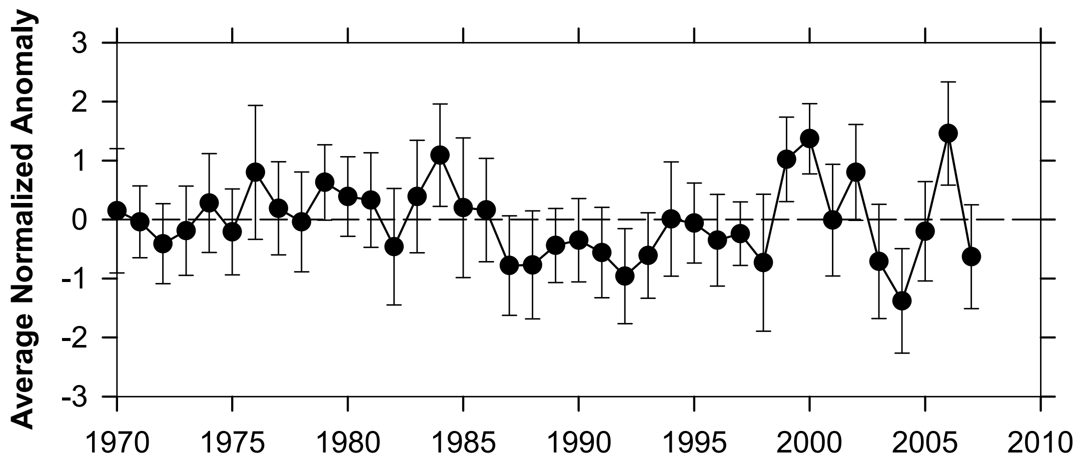


Fig. 22. Average normalized anomalies with standard deviations based on values shown in Fig. 21.

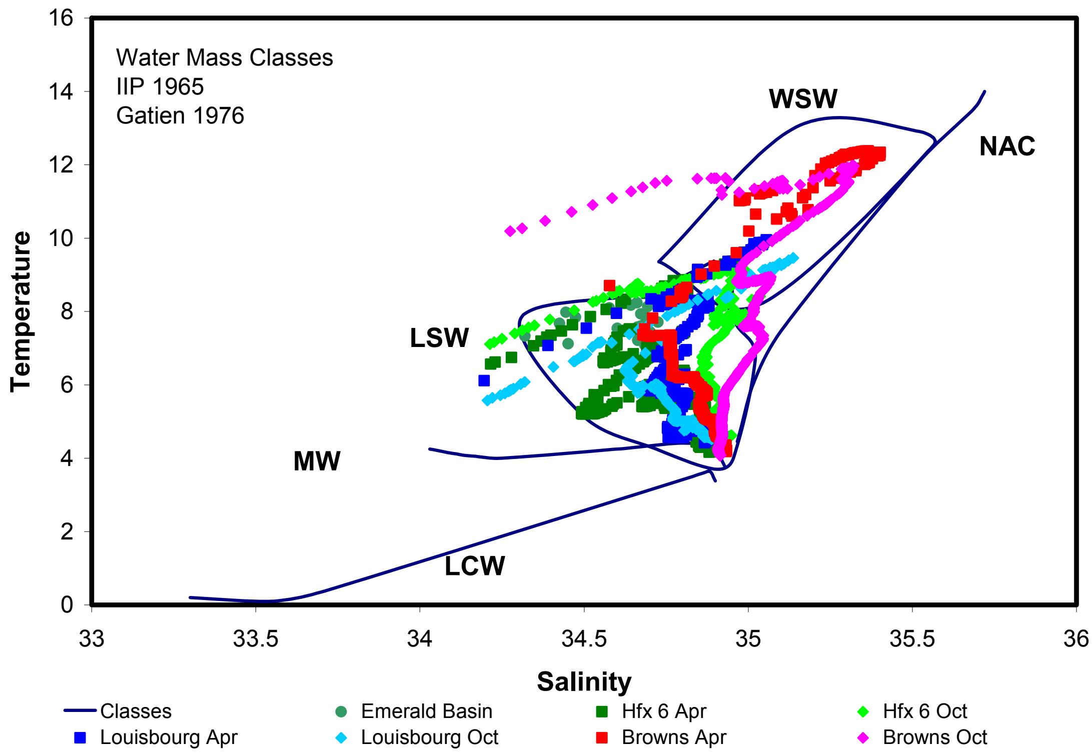


Fig. 23. Temperature-salinity plots from the AZMP standard sections and Emerald Basin in 2007.