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Physical Oceanographic Conditions on the Scotian Shelf and in the Gulf of Maine during 2008

Conditions océanographiques physiques sur le plateau néo-écossais et dans le golfe du Maine en 2008

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ABSTRACT

A review of the 2008 physical oceanographic conditions on the Scotian Shelf and in the eastern Gulf of Maine and adjacent offshore areas indicates that there was an overall balance between positive and negative anomalies in water mass properties. The climate index, a composite of 18 selected, normalized time series, had 12 variables within 0.5 standard deviations (SD) of their normal values and 3 each that were more than 0.5 SD above or below normal. The overall average of the 18 normalized anomalies was 0.06±0.97. However, there was systematic variability within the region: 7 of the 10 series from the eastern half (Halifax and eastward) were negative, with the 10 variables having an average value of -0.17 SD; whereas, 6 of the 8 from the western half were positive, with an average value of the 8 variables of +0.35 SD. Deep water temperatures in Emerald and Georges basins were 0.88 and 0.65 SD less than normal; Cabot Strait 200-300 m temperature was 0.45 SD below normal. This indicates colder than normal slope water conditions. These below normal temperatures were also reflected in the bottom temperatures in Northwest Atlantic Fisheries Organization (NAFO) areas 4W and 4X, which were 1.8 and 0.7 SD below normal.

RÉSUMÉ

Un examen des conditions océanographiques physiques en 2008 sur le plateau néo-écossais et dans les zones de l'est du golfe du Maine et extracôtières adjacentes indique qu'il y avait un équilibre global entre les anomalies positives et négatives des propriétés de la masse de l'eau. L'indice du climat, soit une combinaison de 18 séries chronologiques précises normalisées, comprenait 12 variables dont l'écart-type (SD) était inférieur à 0,5 de leur valeur normale et 3 dont l'écart-type était pour chacune supérieur à 0,5 au-delà ou en deçà de leur valeur normale. La moyenne globale des 18 anomalies normalisées était de 0,06 ±0,97. Toutefois, il y avait une variabilité systématique au sein de la région : 7 des 10 séries de la partie est (Halifax et à l'est) étaient négatives, les 10 variables ayant une valeur moyenne de -0,17 pour l'écart-type, tandis que 6 des 8 séries de la partie ouest étaient positives, avec une valeur moyenne pour les 8 variables de +0,35 pour l'écart-type. Pour la température en eau profonde dans les bassins d'Émeraude et du Banc-de-Georges, l'écart-type était de 0,88 et 0,65 en deçà de la normale; pour la température à 200-300 m dans le détroit de Cabot, l'écart-type était de 0,45 en deçà de la normale. Ceci indique des conditions d'eau du talus continental plus froides que la normale. Ces températures inférieures à la normale ont aussi été constatées pour la température au fond dans les régions 4W et 4X, où l'écart-type était de 1,8 et 0,7 en deçà de la normale.

INTRODUCTION

This research document briefly describes ocean temperature variability of Scotian Shelf and Gulf of Maine waters during 2008 (see Fig. 1 for the study area, Fig. 2 for area names of time series presented). The results are derived from data obtained at coastal and long-term monitoring stations, on annual ecosystem surveys and Atlantic Zone Monitoring Program (AZMP) missions, and from ships-of-opportunity and other research cruises. Most of the data are available in the Bedford Institute of Oceanography 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). The analyses use data archived prior to 14 January 2009. Additional hydrographic data were obtained directly from DFO fisheries surveys.

Many of the products which have been presented previously in the overview are now available on the ISDM website devoted to the AZMP program[2]. The products available include sections from the AZMP spring and fall surveys, time series of physical properties from fixed stations, climate indexes such as coastal temperature series, frontal boundary positions, and bottom temperatures from ecosystem surveys. In addition, the availability of quality controlled data from sources such as CLIMATE allow individuals to develop the product that most suits their needs. For these reasons, an abbreviated overview is presented to give a general idea of environmental variability in 2008.

In order to detect interannual variability and long-term trends of the time series presented, the potentially large seasonal cycle was removed by determining the monthly differences, i.e. the anomalies, from the long-term monthly means. In some cases, the standardized anomaly (anomaly divided by the standard deviation) is presented. When possible, long-term monthly and annual means, and standard deviations (SD) are based on data from 1971-2000. Meteorological, sea ice, and satellite-derived sea surface temperature (SST) data during 2008 are described in Petrie et al. (2009).

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. These offshore waters are generally of 2 types, Warm Slope Water, with temperatures in the range of 8-13^{o}C and salinities from 34.7-35.6, and Labrador Slope Water, with temperatures from 3.5^{o}C to 8^{o}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).

[1] http://www.mar.dfo-mpo.gc.ca/science/ocean/database/data_query.html
[2] http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/azmp-pmza/index-eng.html

COASTAL TEMPERATURES AND SALINITIES

Coastal sea surface temperatures have been collected at St. Andrews (New Brunswick) and Halifax (Nova Scotia) since the 1920s (Fig. 3). In 2008, the SST anomalies were +0.18^{o}C (+0.37 SD) for St. Andrews and -0.30^{o}C (-0.45 SD) for Halifax, increases of 0.22^{o}C and 0.68^{o}C from 2007 values.

Temperature and salinity measurements, for the most part sampled monthly, have been taken since 1924 at Prince 5, at the entrance to the Bay of Fundy (Fig. 1). It is the longest continuously operating hydrographic monitoring site in eastern Canada. Its waters are generally well-mixed from the surface to the bottom (90 m). The depth-averaged (0-90 m) temperature and salinity time series are shown in Fig. 3. In 2008, the annual temperature anomaly was +0.34^{o}C (+0.76 SD) and the salinity anomaly was -0.16 (-0.65 SD). These represent changes of +0.26^{o}C and -0.34 from the 2007 values.

SCOTIAN SHELF AND GULF OF MAINE TEMPERATURES

Drinkwater and Trites (1987) tabulated monthly mean temperatures and salinities from available bottle data for areas on the Scotian Shelf and in the eastern Gulf of Maine that generally corresponded to topographic features such as banks and basins (Fig. 2). Petrie et al. (1996) updated their report using these same areas and all available hydrographic data. Time series of annual mean and filtered (5-year running means) temperature anomalies at selected depths for 5 areas are presented (Fig. 4). The Cabot Strait (see Fig.1) temperatures represent the slope waters entering the Gulf of St. Lawrence along Laurentian Channel; the Misaine Bank (region 5, Fig. 2) series characterizes the near bottom temperatures on the eastern Scotian Shelf; the deep Emerald Basin (region 12) anomalies represent the slope water intrusions onto the Shelf; the Lurcher Shoals (region 24) observations define the ocean climate in southwest Nova Scotia and the shallow waters entering the Gulf of Maine via the Nova Scotia Current; finally, the Georges Basin (region 26) series represents the slope waters entering the Gulf of Maine through the Northeast Channel. Annual anomalies are based on the averages of monthly anomalies; however, observations are not available for each month in each area. For Cabot Strait, Misaine Bank, Emerald Basin, Lurcher Shoals. and Georges Basin, 2008 annual anomalies are based on observations from totals of 5, 8, 5, 4, and 6 months.

In 2008, the annual anomalies were -0.18^{o}C (-0.45 SD) for Cabot Strait 200-300 m, -0.20^{o}C (-0.32 SD) for Misaine Bank 100 m, -0.88^{o}C (-1.1 SD) for Emerald Basin 250 m, +0.09^{o}C (+0.13 SD) for Lurcher Shoals 50 m, and -0.65^{o}C (-1.2 SD) for Georges Basin 200 m. These values correspond to changes of -0.00^{o}C, +0.20^{o}C, +0.99^{o}C, +1.20^{o}C and +0.14^{o}C, respectively, over 2007 values.

TEMPERATURES DURING THE SUMMER GROUNDFISH SURVEYS

The broadest spatial CTD (Conductivity, Temperature, Depth) coverage of the Scotian Shelf is obtained during the annual July DFO ecosystem survey, which covers the Scotian Shelf from Cabot Strait to the Bay of Fundy. The deep water boundary of the survey is marked roughly by the 200 m isobath along the shelf break at the Laurentian Channel, the outer Scotian Shelf, and the Northeast Channel into the Gulf of Maine towards the Bay of Fundy. A total of 167 CTD stations were taken during the 2008 survey and an additional 59 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 last.

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.

Bottom temperatures ranged from 3.3°C in area 4Vs to 6.9°C in 4X, illustrating the substantial difference in the environmental conditions across the Shelf. The anomalies were least in the eastern areas 4Vn,s, greatest in 4W: +0.0°C (+0.01 SD) in 4Vn; -0.16°C (-0.22 SD) in 4Vs; -1.2°C (-1.8 SD) in 4W; and -0.49°C (-0.72 SD) in 4X (Fig. 5 (A)-(D)). Compared to 2007, bottom temperatures in areas 4Vn,s and 4X increased by 0.1, 0.3 and 0.6°C, whereas temperature decreased by 0.2°C in 4W.

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. 5(E)). 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. 5E) could be affected. It is expected that the true SD is higher than the one derived here.

There is considerable variation in the volume of the CIL since 1998 (Fig. 5(E)). In 2008, the observed volume of 6600 km^3 was 1.6 SD greater than the long-term mean value of 5100 km^3 but down slightly from 2007.

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. The variability in stratification was examined 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. 2. 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. These estimates could be biased 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 annual anomalies and their 5-year running means were then calculated for an area-weighted combination of subareas 4-23 on the Scotian Shelf (Fig. 6). A value of 0.01 (kg m^{-3})/m represents a difference of 0.5 kg m^{-3} over 50 m.

The dominant feature is the long-term trend of increasing stratification from the 1960s to present. Stratification on the Scotian Shelf (areas 4-23) in 2008 was above normal by 1 SD, the 4th strongest in 49 years, and increased from its 2007 value.

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 2 major components: one due to true changes of sea level and a second caused by sinking or rising of the land. In Atlantic Canada, post-glacial rebound (PGR) is causing the area roughly south (north) of the north shore of the Gulf of St. Lawrence to sink (rise) in response to glacial retreat; this results in an apparent rise (fall) of sea level. Tushingham and Peltier (1991) estimate a PGR component of the sea level trend of 23 cm/century at Halifax.

Relative sea level at Halifax (1920-2008) is plotted as monthly means and as a filtered series using a 12-month running-mean filter (Fig. 7(A)). The linear trend of the monthly mean data has a positive slope of 31.9 (±6.7) 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). In 2008, relative sea level at Halifax increased by 1.7 cm above the 2007 level. However, the interesting feature of the data is the long-term variation that has occurred since the 1920s. In Fig. 7(B) the differences of the annual sea level from the long-term trend is shown. It is apparent that from the 1920s to the early 1970s, the trend was greater than the trend calculated using all of the data. In fact, the trend from 1920-72 was 40.4 (±1.4) cm/century; for the period 1972-2008, the value was 20.3 (±2.4) cm/century, i.e. close to the PGR value predicted by the Tushingham-Peltier model.

SUMMARY

A graphical summary of many of the time series already shown indicates that the periods 1987-93 and 2003-2004 were predominantly colder than normal and 1999-2000 was warmer than normal (Fig. 8). The period 1976-86 also tends to be warmer than normal. 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. In 2008, 14 of the 22 series shown were within 0.5 SD of their normal values. Of the 8 remaining series, 4 were more than 0.5 SD greater than normal and 4 were more than 0.5 SD below normal. Most of the series associated with the eastern and central Shelf had negative anomalies; most associated with the western Shelf were positive.

Eighteen selected variables of the mosaic plot are summarized as a combination bar and line-scatter plot in Fig. 9. This plot is an attempt to derive an overall climate index for the area. 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 so that for any year the contribution of each variable can be determined and systematic spatial patterns 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 1987-93 and 2003-2004 and the warm period of 1999-2000 are apparent. Systematic differences from the overall tendency within a given year are also evident. The overall index in 2008 averaged +0.1 (±1) SD, i.e. essentially normal; 12 variables were within 0.5 standard deviations of their normal values and 3 each were more than 0.5 SD above or below normal. However, there was systematic variability within the region: 7 of the 10 series from the eastern half (Halifax and eastward) were negative, with the 10 variables having an average value of -0.17 SD; whereas, 6 of the 8 from the western half were positive, with an average value of the 8 variables of +0.35 SD. Deep temperatures in Emerald and Georges basins were 0.88 and 0.65 SD less than normal; Cabot Strait 200-300 m temperature was 0.45 SD below normal. This indicates colder than normal slope water conditions. These below normal temperatures were also reflected in the bottom temperatures in areas 4W and 4X, which were 1.8 and 0.72 SD below normal.

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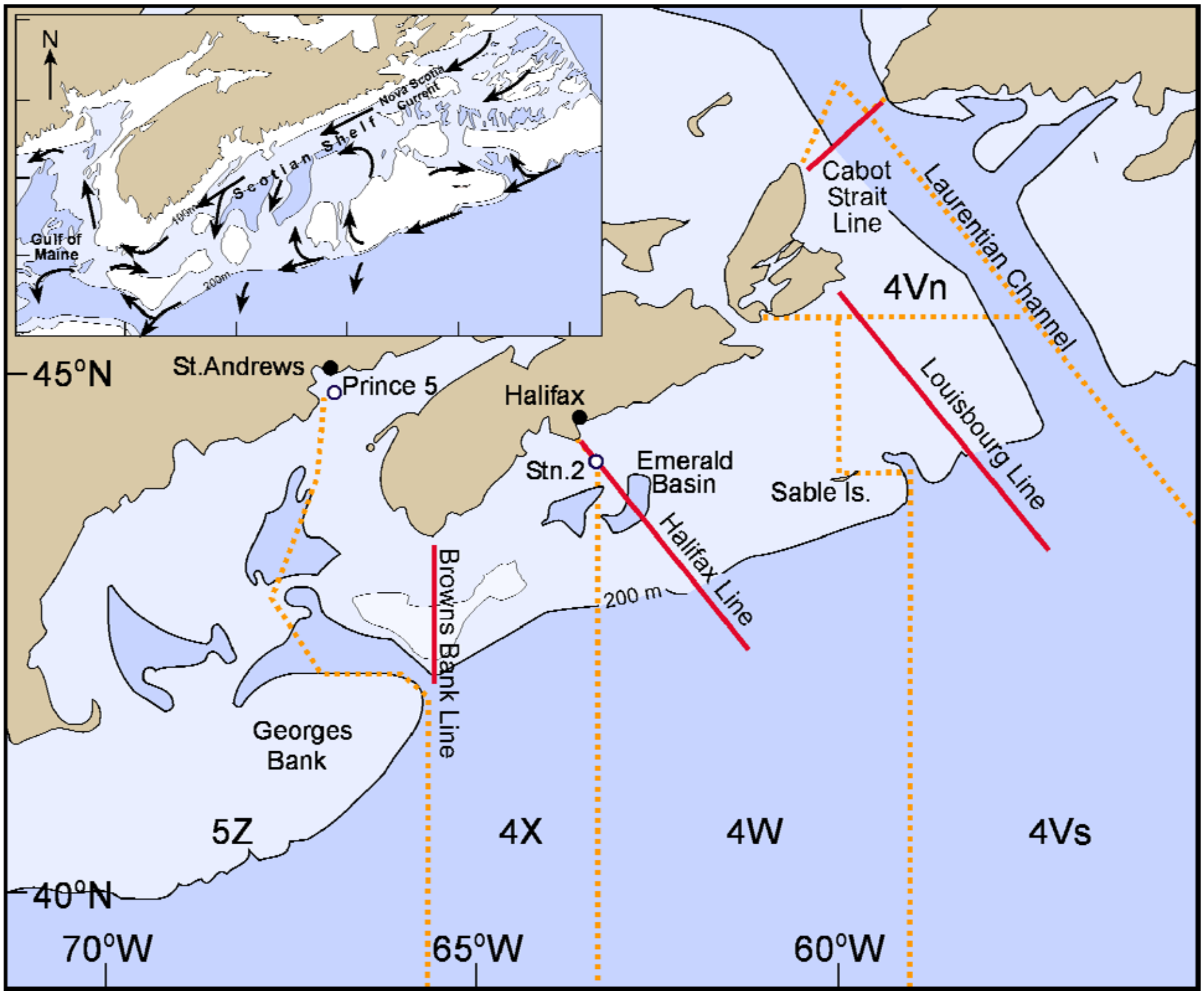
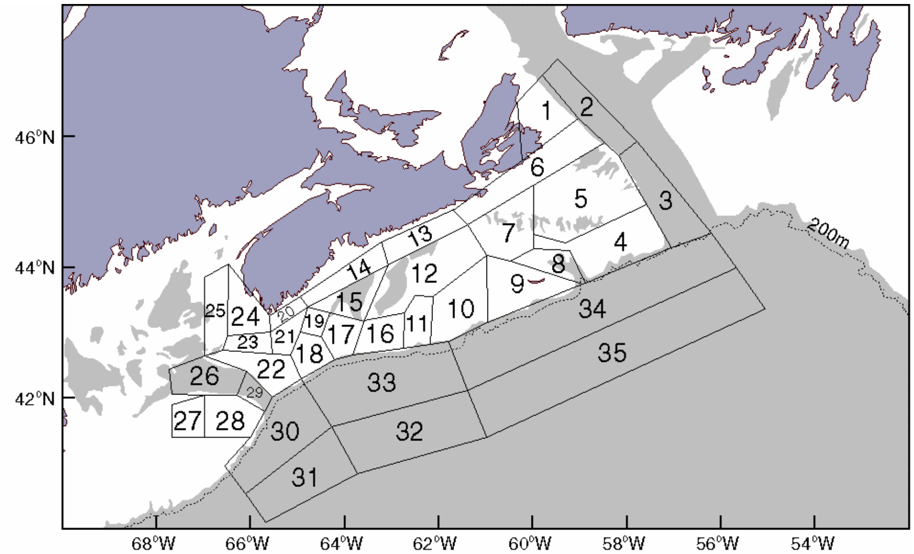


Figure 1. The Scotian Shelf and the Gulf of Maine showing hydrographic stations, standard sections and topographic features. The dotted lines indicate the boundaries of the Northwest Atlantic Fisheries Organization (NAFO) subareas. Inset depicts major circulation features.



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

Figure 2. Areas on the Scotian Shelf and eastern Gulf of Maine from Drinkwater and Trites (1987).

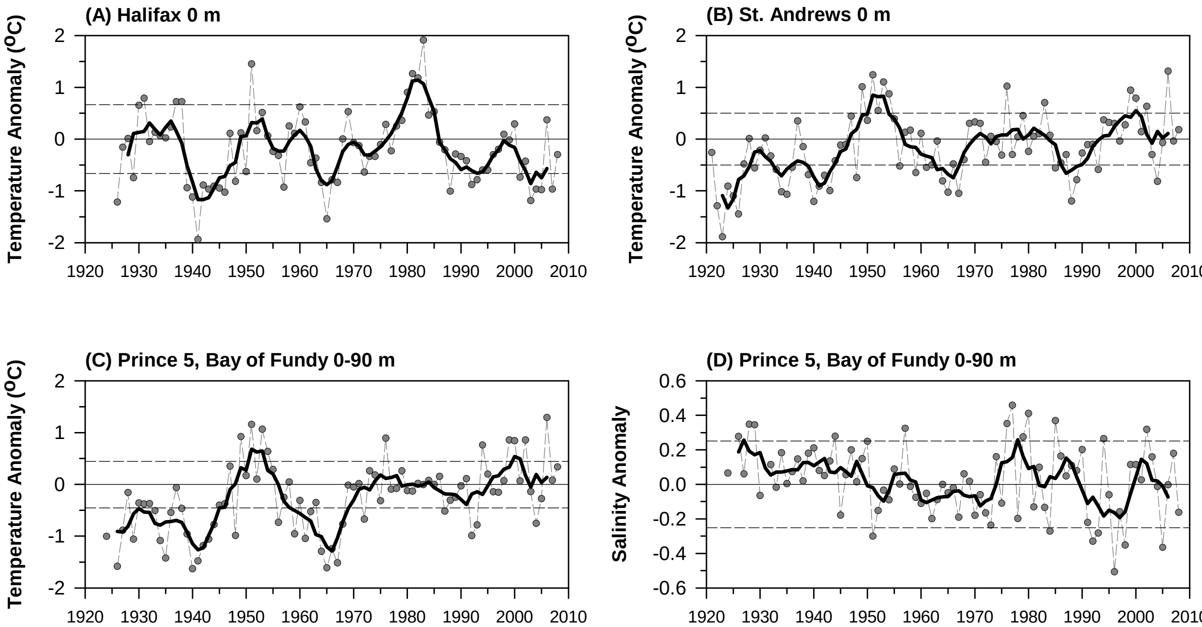


Figure 3. The annual surface temperature anomalies (dashed line with circles) and their 5-year running means (heavy black line) for (A) Halifax Harbour and (B) St. Andrews; annual depth-averaged (0-90 m) (C) temperature, and (D) salinity anomalies for the Prince 5 monitoring station at the mouth of the Bay of Fundy. Horizontal dashed lines mark ±1 standard deviation based on 1971-2000 observations.

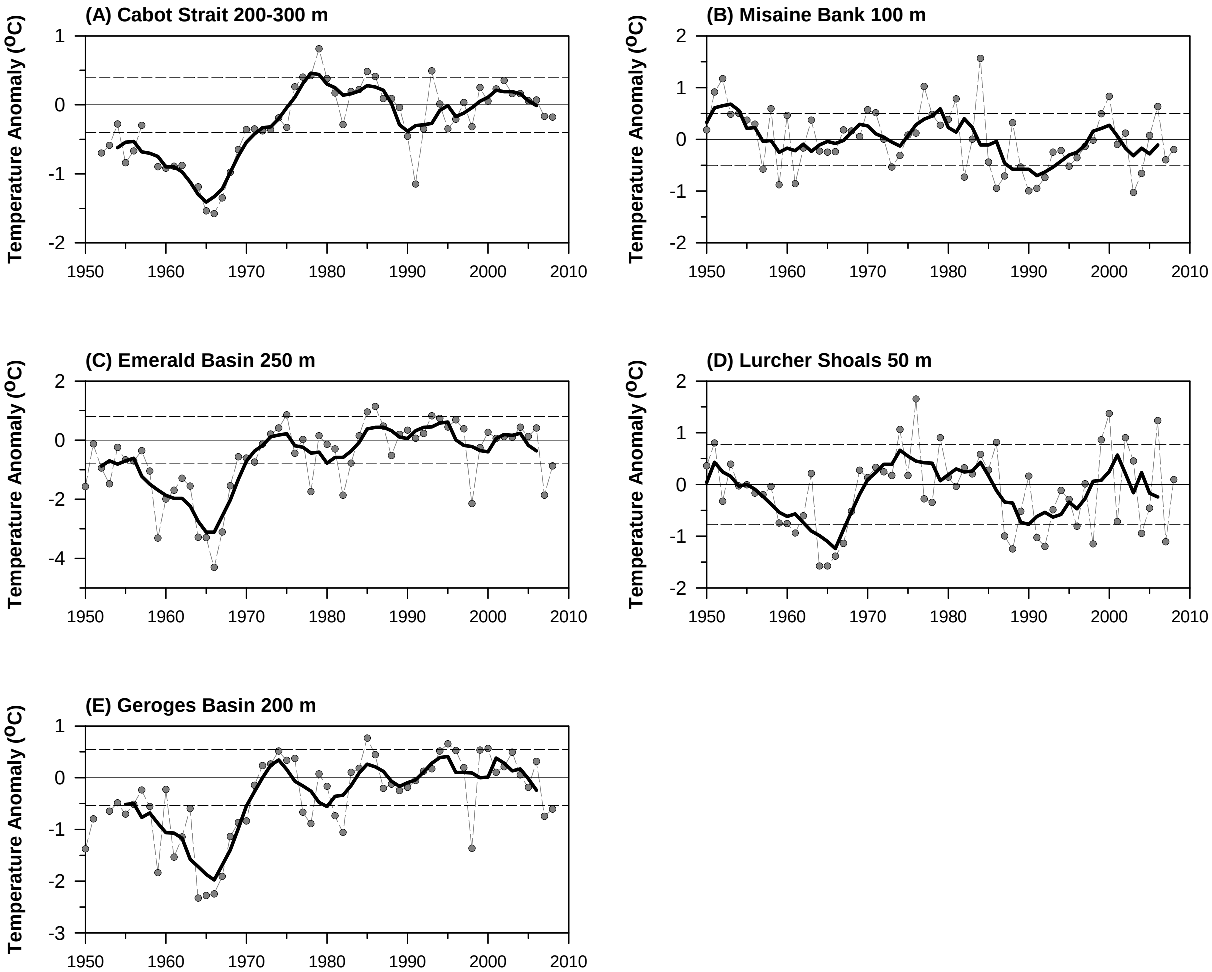


Figure 4. The annual mean temperature anomaly time series (dashed line with circles) and the 5-year running mean filtered anomalies (heavy solid line) on the Scotian Shelf and in the Gulf of Maine at (A) Cabot Strait 200-300 m; (B) Misaine Bank 100 m; (C) Emerald Basin 250 m; (D) Lurcher Shoals 50 m; and Georges Basin (200 m) (see figs. 1, 2). Horizontal dashed lines mark ±1 standard deviation based on 1971-2000 observations.

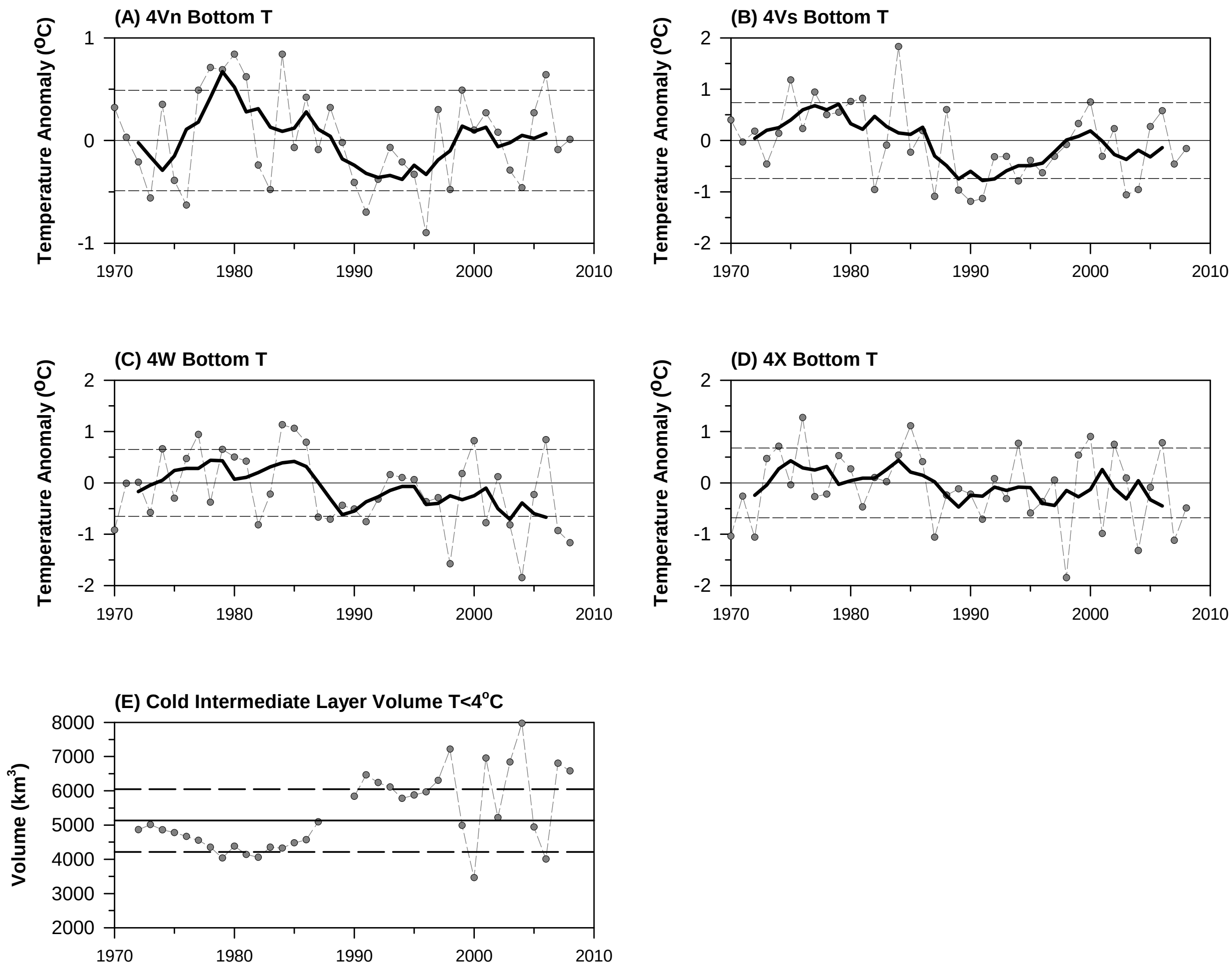


Figure 5. Time series of July bottom temperature anomalies (dashed lines with circles) and 5-year running mean filtered series (heavy line) for areas (A) 4Vn, (B) 4Vs, (C) 4W and (D) 4X. The horizontal dashed lines are ±1 SD. (E) Time series of the Cold Intermediate Layer (CIL, defined as waters with T<4°C) volume on the Scotian Shelf based on the July ecosystem survey. The solid horizontal line is the long-term mean, the dashed horizontal lines are the mean ±1 SD based on 1971-2000 observations.

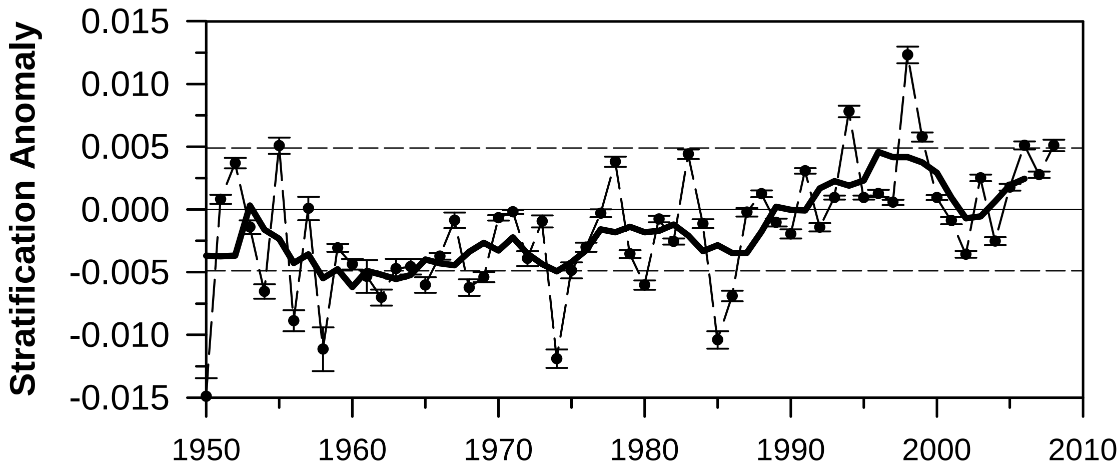


Figure 6. The mean annual (dashed line with circles) and 5-yearr running mean (heavy solid line) of the stratification index (0-50 m density gradient) averaged over the Scotian Shelf (areas 4-23 inclusive, see Fig. 2). The horizontal dashed lines are ±1 SD based on 1971-2000 observations. Standard error estimates for each annual value are also shown.

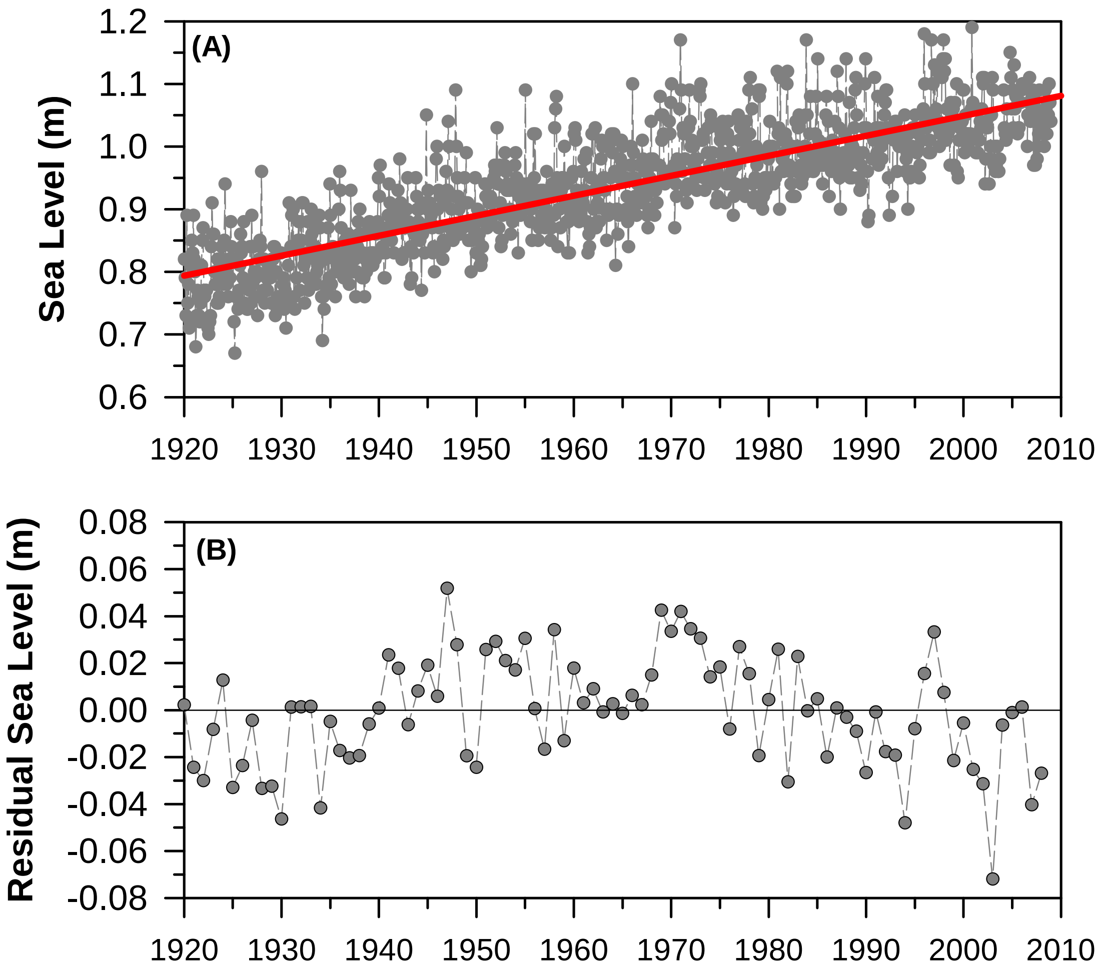


Figure 7. (A) The time series of the monthly means and a 12 month running mean of the relative sea level elevations at Halifax, along with the linear trend (1920-2008). (B) Residual relative sea level (monthly observed values – linear trend, averaged to annual estimates).

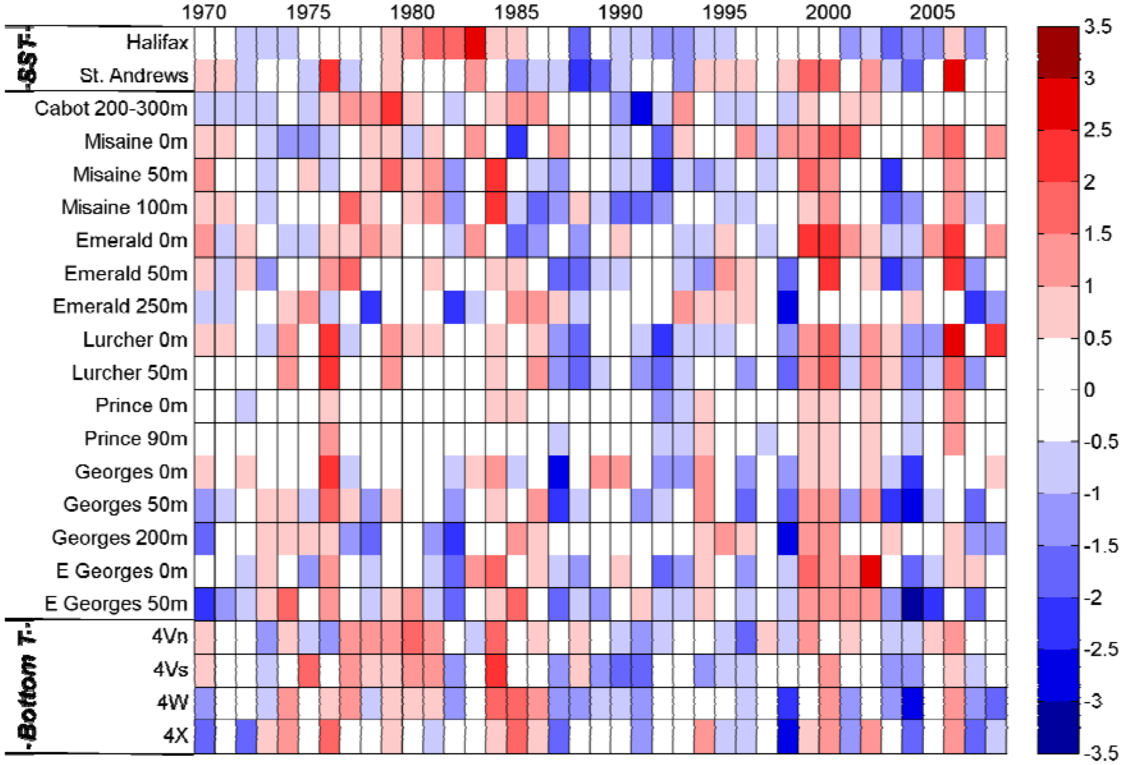


Figure 8. Normalized annual anomalies of temperatures at the bottom and discrete depths for the Scotian Shelf-Gulf of Maine region. These normalized, annual anomalies are based on the 1971-2000 means, divided by the standard deviation. The scale represents the number of standard deviations an anomaly is from normal; blue indicates below normal, red above normal.

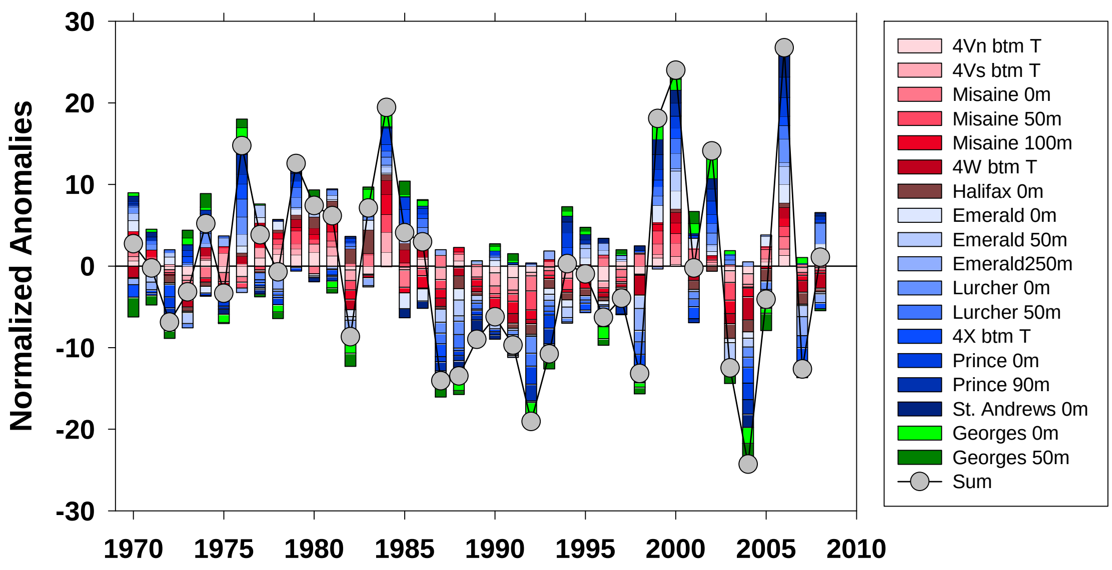


Figure 9. The contributions of each of the normalized anomalies are shown as a bar chart and their summation as a time series (grey circles, black line).